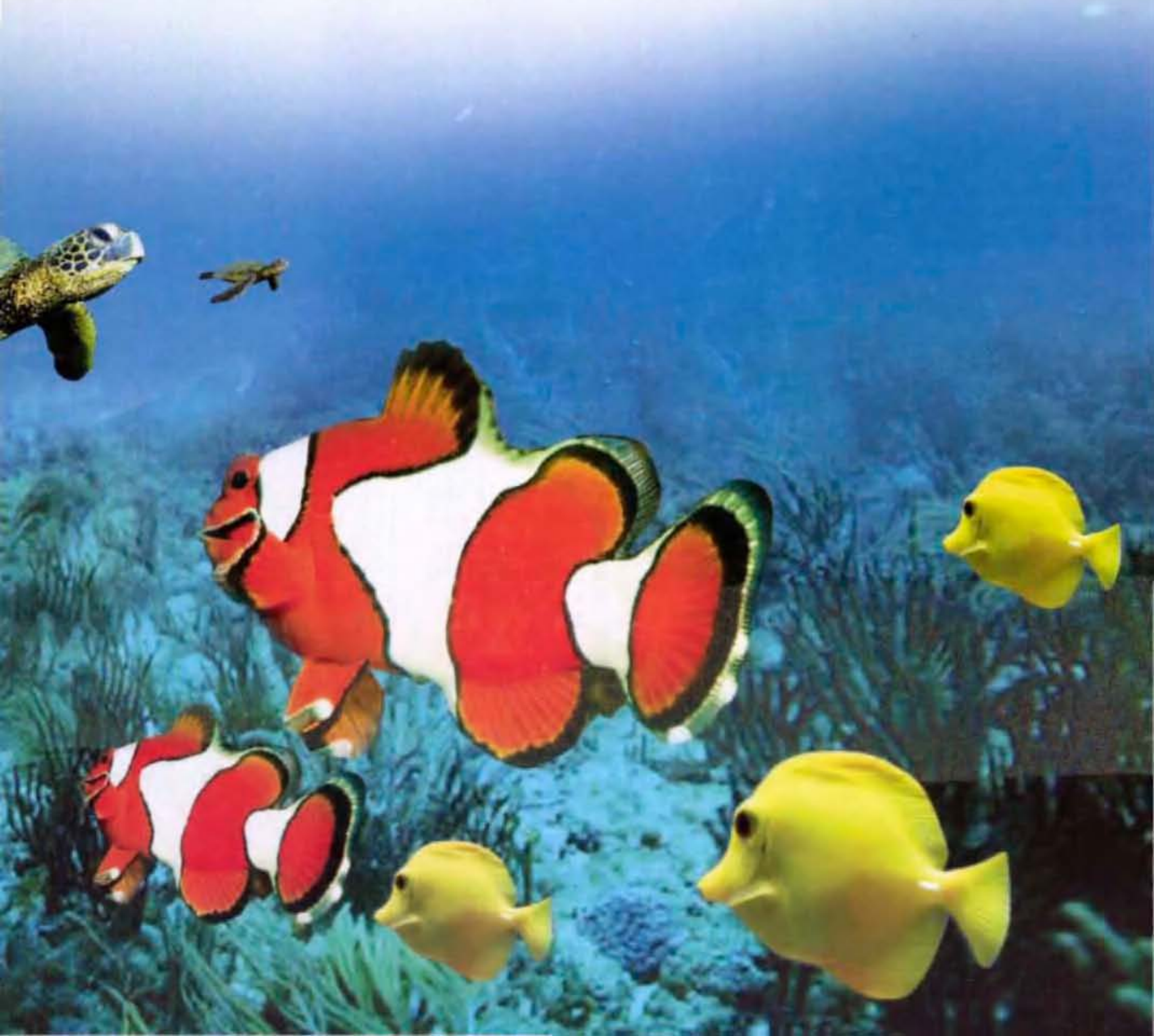
MODERN TEXT BOOK OF ZOOLOGY

VERTEBRATES

[ANIMAL DIVERSITY - II]



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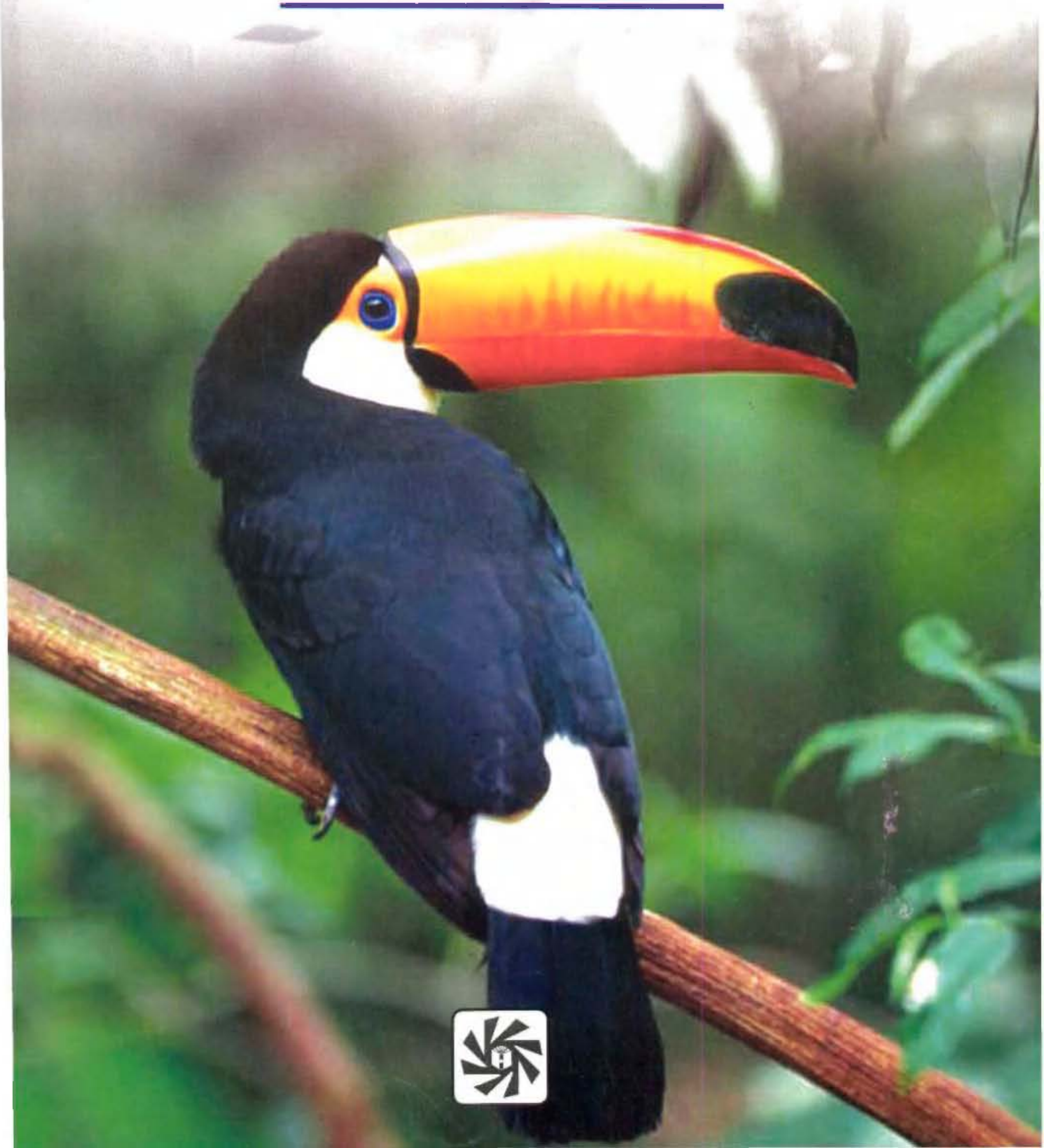

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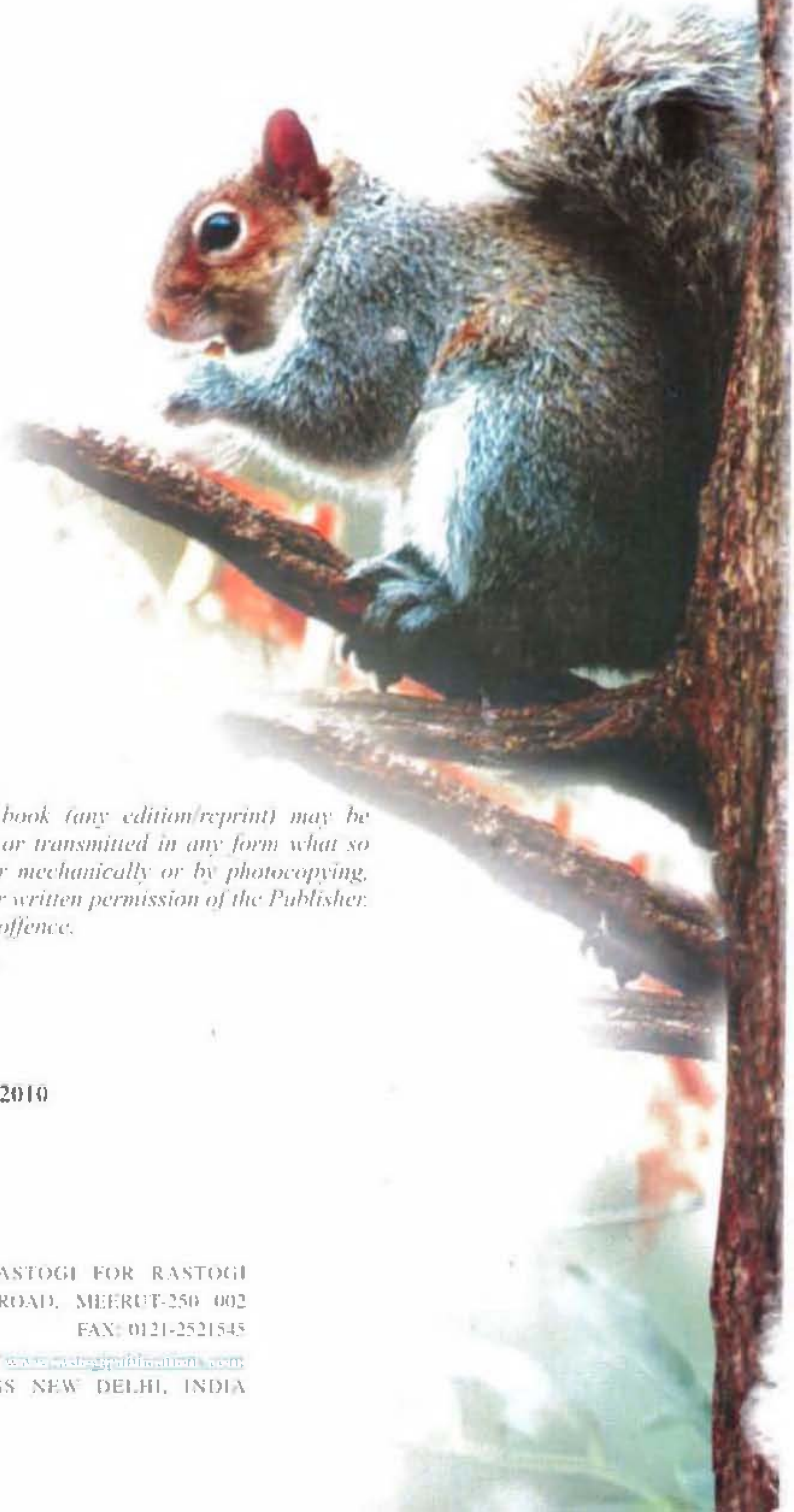

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VERTEBRATES

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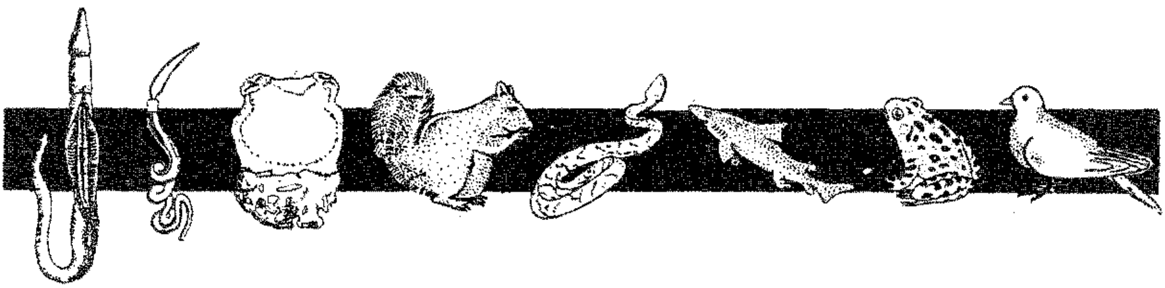

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1

Phylum Chordata : An Introduction

What is Chordata?

In the scheme of classification, the Animal Kingdom is divided first into several major animal groups called *phyla* (singular, *phylum*). There are approximately 30 animal phyla currently recognised. The last major group of the Animal Kingdom is known as phylum *Chordata*. It was created by Balfour in 1880. The name of this phylum is derived from two Greek words, the *chorde* meaning a string or cord, and *ata* meaning bearing. The reference is to a common characteristic feature in the form of a stiff, supporting rod-like structure along the back, the *notochord* (Gr., *noton*, back; L., *chorda*, cord), which is found in all the members of the phylum at some stage of their lives. Thus, chordates are animals having a cord, i.e., notochord. The animals belonging to all other phyla of the Animal Kingdom are often termed 'the non-chordates' or 'the invertebrates' since they have no notochord or backbone in their body structure.

Chordate Animals

Phylum Chordata is the largest of the deuterostome phyla. It is the highest and the most important phylum comprising a vast variety of living and extinct animals including man himself. Most of the living chordates are the well known familiar vertebrate animals such as the fishes, amphibians, reptiles, birds and mammals. Besides, they include a number of marine forms such as the tunicates and lancelets, that are less well known.

Diversity of Chordates

The chordates exhibit an astonishing diversity of form, physiology and habit.

Numerical strength. The number of chordate species is not unusually large. About 49,000 species are on record which are only half of the living species of molluscs, and less than one-tenth those of arthropods. The two subphyla Urochordata and Cephalochordata claim for nearly 2,500 species. The subphylum Vertebrata includes 46,500 species; of these, fishes are the most numerous with approximately 25,000 species. It is commonly assumed that amphibian species number about 2,500, reptiles 6,000, birds 9,000 and mammals 4,500.

Size. Despite their modest number of species, the chordates make a disproportionate contribution to the biomass of the earth. Nearly all of them are medium to large in size. The vertebrates, in particular, are considerably large and many of them are among the largest of living animals. The gigantic blue whale (*Balaenoptera musculus*), which grows to 35 meters long and 120 tons in weight, is the biggest known animal. The whale shark (*Rhineodon typus*) reaches a length of 15 meters and is the second biggest vertebrate after whales. The smallest fish is a Philippine goby (*Pandaka*) measuring only 10 mm long.

Ecology. The chordates are not only the largest animals in existence today, but ecologically they are among the most successful in the Animal Kingdom. They are able to occupy most kinds of habitats and they have adapted themselves to more modes of existence than any other group, including the arthropods. They are found in the sea, in freshwater, in the air, and on all parts of land from the poles to the equator. Birds and mammals have been able to penetrate cold climate because they have a constant body temperature, something no other animals have.

All lower chordates are marine, fishes are aquatic and higher chordates are predominantly terrestrial. Saltwater amphibians are unknown. No bird lives permanently in water, while some amphibians, reptiles and mammals occur as permanent residents of waters. While most tunicates are sessile, all chordates are free-living and none is strictly parasitic.

The chordates are probably the most conspicuous and the best-known group in the entire animal kingdom, partly because of their large size and partly because of the important role they perform in their ecosystems. They are of primary interest because man himself is a member of the group. From a purely biological viewpoint also the chordates are interesting because they illustrate so well the broad biological principles of evolution, development and relationship.

Three Fundamental Chordate Characters

All the chordates possess three outstanding unique characteristics at some stage in their life history. These three fundamental morphological features include :

(1) A dorsal hollow or tubular *nerve cord*

(2) A longitudinal supporting rod-like *notochord*

(3) A series of *pharyngeal gill slits*

These three distinctive features, which set chordates apart from all other phyla, are so important that each merits a short description of its own (Fig. 1).

1. Dorsal hollow nerve cord. The central nervous system of the chordates is present dorsally

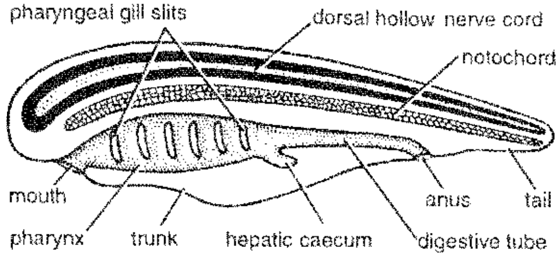

Fig. 1. Diagrammatic side view of a chordate showing the three fundamental chordate characters.

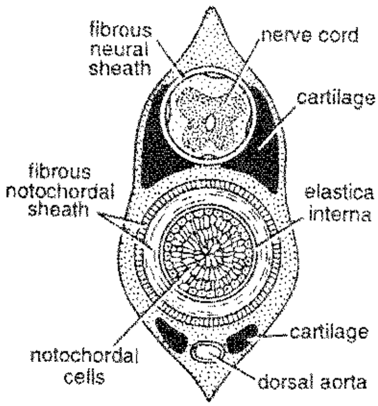

Fig. 2. T.S. Notochord of young dogfish.

in the body. It is in the form of a longitudinal, hollow or tubular nerve cord lying just above the notochord and extending lengthwise in the body. The nerve cord or *neural tube* is derived from the dorsal ectodermal *neural plate* of the embryo and encloses a cavity or canal called *neurocoel*. There are no distinct ganglionic enlargements. The nerve cord serves for the integration and coordination of the body activities.

In vertebrates, the anterior region of nerve cord is specialized to form a *cerebral vesicle* or *brain* which is enclosed by a protective bony or cartilaginous cranium. The posterior part of nerve cord becomes the *spinal cord* and protected within the vertebral column.

2. Notochord or chorda dorsalis. The notochord is an elongated rod-like flexible structure extending the length of the body. It is present immediately beneath the nerve cord and just above the digestive canal. It originates from the endodermal roof of the embryonic archenteron. Structurally, it is composed of large vacuolated *notochordal cells* containing a gelatinous matrix and surrounded by an outer fibrous and an inner elastic sheath (Fig. 2).

The notochord is the prime diagnostic feature of the phylum Chordata which derives its name from it. It serves as a support or internal skeleton and is not to be confused with the nerve cord. Protochordates have a typical notochord. In adult vertebrates, it is surrounded or replaced by the vertebral column.

3. Pharyngeal gill slits. In all the chordates, at some stage of their life history, a series of paired lateral *gill clefts* or *gill slits* perforate through the pharyngeal wall of the gut behind the mouth. These are variously termed as pharyngeal, branchial and visceral clefts or pouches. They serve primarily for the passage of water from the pharynx to outside, thus bathing the gills for respiration. The water current secondarily aids in filter feeding by retaining food particles in the pharynx.

In protochordates (e.g. *Branchiostoma*) and lower aquatic vertebrates, the gill slits are functional throughout life. But, in higher vertebrates, they disappear or become modified in the adult with the acquisition of pulmonary respiration.

The above three common features appear during early embryonic life of all the chordates. But all the three features rarely persist in the adult (e.g. *Branchiostoma*). Often they are modified or even lost in the adult stages of higher chordates. The notochord disappears during development in most vertebrates, while the nerve cord and the pharyngeal clefts or their derivatives remain in the adult.

The three common chordate characters were probably characteristic of the ancestral chordates. They distinguish chordates from all other animals and appear to reveal their common ancestry.

Characters Common to Chordates and Higher Nonchordates

There are a number of features in which the chordates resemble the higher nonchordates or invertebrates.

1. Axiation. The body in both has a distinct polar axis. The anterior end is differentiated into a cephalic region or *head* that usually precedes in locomotion. The opposite or posterior end forms a *tail* in most cases. This longitudinal axis of the body running from head to tail is known as the *antero-posterior axis.* However, this axiate body organization is not strictly homologous in the two groups. For instance, the head in the two groups is not homologous because the blastoporal end develops the mouth in most nonchordates (Protostomia), but forms the anus in chordates (Deuterostomia).

2. Bilateral symmetry. Due to existence of longitudinal *antero-posterior axis,* the body of all chordates and most higher nonchordates (Annelida, Arthropoda) exhibits *bilateral symmetry,* i.e., the right and left sides of the body are the exact mirror image of each other.

3. Triploblastic condition. Invertebrates above the level of coelenterates and all chordates are *triploblastic* animals. They have *three germ layers-ectoderm, endoderm* and *mesoderm.* In annelids, molluscs, arthropods and other related animals, the *embryonic mesoderm* arises as a solid cord-like outgrowth from the junction of ectoderm and endoderm in the gastrula stage. In contrast, in brachiopods, echinoderms, *Branchiostoma* and other enterocoelous forms, the mesoderm is formed as lateral outpushings of the archenteron of gastrula.

4. Coelom. A secondary body cavity or true coelom exists between the body wall and the digestive tube, and it is lined on all sides by mesoderm. However, it differs in its mode of origin in different groups of chordates and nonchordates. In annelids, molluscs, arthropods and higher chordates, it is *schizocoelous,* arising from the splitting of mesodermal bands which originate from the blastoporal region. In echinoderms, brachiopods and *Branchiostoma,* it is *enterocoelous,* formed by the fusion and expansion of a linear series of hollow outpushings or pouches of the archenteron.

5. Metamerism. Metamerism is a condition in which the body is composed of a linear series of similar body segments, called *metameres* or *somites*. It is found in three phyla : Annelida, Arthropoda and Chordata. In Annelida and Arthropoda, metameric segmentation is both internal as well as external, whereas in Chordata is it less clear externally. External segmentation is a necessity in Arthropoda so that joints between segments permit movement of the body. In fishes, metameric segmentation is visible in the arrangement of muscles. Metameric condition is well marked in embryonic chordates in the arrangement of muscles, and in the adult vertebrates in the arrangement of vertebrae.

6. Organ-systems. In an organ-system, several organs work together for the same function, such as digestion, circulation, respiration, etc. Organ-system plan or grade of organization is shown by all the chordates and all the non-chordates from nemertean worms onwards. However, the vertebrates show a greater stage of development and fundamental unity of this plan than even the highest invertebrates.

These structural similarities shared by the chordates and the nonchordates probably reflect upon their remote common ancestry. Although it is not possible to trace exact lineage, but all available evidences indicates that chordates have evolved from the invertebrates.

Advancements of Chordata over Other Phyla

Phylum Chordata has some advantages over other phyla due to certain characters.

1. Living endoskeleton. With the exception of echinoderms and a few others, only chordates possess a living endoskeleton. It grows in size with the rest of the body so that there is no compulsion to shed it periodically to allow for growth like the nonliving chitinous exoskeleton of the nonchordate phyla. Further, this living endoskeleton permits greater freedom of movement and indefinite growth so that many chordates are the largest creatures of animal world.

2. Efficient respiration. The gills in aquatic chordates and the lungs in terrestrial forms from efficient organs of respiration. The tracheal system of certain arthropods is also efficient but is suitable to animals of small size only.

3. Efficient circulation. The circulatory system of the chordates is well developed and the blood flows freely in the respiratory organs ensuring rapid exchange of gases. Moreover, the blood-vascular system forms an important medium for several other vital activities of the body.

4. Centralized nervous system. The invertebrate phyla show a growing tendency of centralization of nervous system, reaching its culmination in the higher chordates. The sensory system is also modified accordingly. The advancement in nervous and sensory systems explains the great power of the chordates for adapting themselves most successfully to a variety of environments.

Comparison (Differences) of Chordates with Nonchordates

So far we have seen that the Animal Kingdom is traditionally divided into two unequal groups : *Chordates* and *Nonchordates* (or *Invertebrates*). All the chordates belong to a single phylum, the *Chordata*, which are characterized by the presence of a dorsal hollow nerve cord, a series of pharyngeal gill clefts and a unique supporting axial rod, the *notochord* or vertebral column, running through the length of the body. The nonchordates or invertebrates belong to the remaining 30 or odd phyla of animals that do not possess a notochord or vertebral column. This division is purely artificial but this has a practical applicability in their taxonomic study.

We have also seen that chordates share many structural similarities with the nonchordates such as axiate body plan, bilateral symmetry, triploblastic coelomate condition, organ systems, metameric segmentation, etc. However, the two groups have several fundamental differences, the most striking of which have been shown in the Table 1.

The chordates can be pictured as 'upside-down' invertebrates owing to the position of their nervous and circulatory systems.

Table 1. **Comparison (Differences) of Chordata with Nonchordata.**

	Features	Chordata	Nonchordata
1.	Symmetry	Bilateral	Radial, biradial, bilateral or lacking
2.	Metamerism	True metamerism	True or pseudometamerism or lacking
3.	Post-anal tail	Usually present	Lacking
4.	Grade of organization	Organ-system	Protoplasmic to organ-system
5.	Germ layers	3, triploblastic	2 (diploblastic), 3 (triploblastic) or lacking
6.	Coelom	Truly coelomate	Acoelomate, pseudocoelomate or truly coelomate
7.	Limb derivation	From several segments	From same segment
8.	Notochord	Present at some stage or replaced by a backbone made of ring like vertebrae	Notochord or backbone lacking
9.	Gut position	Ventral to nerve cord	Dorsal to nerve cord
10.	Pharyngeal gill-slits	Present at some stage of life	Absent
11.	Anus	Differentiated and opens before the last segment	Opens on the last segment or absent
12.	Blood vascular system	Closed	Open, closed or absent
13.	Heart	Ventrally placed	Dorsal, lateral or absent
14.	Dorsal blood vessel	Blood flows posteriorly	Blood flows anteriorly
15.	Hepatic portal system	Present	Absent
16.	Haemoglobin	In red blood corpuscles	In plasma or absent
17.	Respiration	Through gills or lungs	Through body surface, gills or tracheae
18.	Nervous system	Hollow	Solid
19.	Brain	Dorsal to pharynx in head	Above pharynx or absent
20.	Nerve cord	Single, dorsal, without ganglia	Double, ventral, usually bearing ganglia
21.	Roots of segmental nerves	Dorsal and ventral separate	Dorsal and ventral roots not separate
22.	Reproduction	Sexual reproduction predominant	Asexual reproduction predominant
23.	Regeneration power	Usually poor	Usually good
24.	Body temperature	Cold or warm-blooded	Cold-blooded

Origin and Ancestry of Chordata

While a great deal is known about modern chordates, including the lower forms, their origin remains obscure. Scientists have not succeeded in determining which lower forms have given rise to them. Their early ancestors most likely were soft-bodied and left no definite fossil remains. They must have originated prior to Cambrian period as the oldest fossils of known vertebrates have been discovered in late Cambrian strata. Most scientists consider that the chordates have originated from invertebrates. Several theories attempt to explain the origin of chordates from nonchordate groups, but they have serious drawbacks and are far from being satisfactory. One theory advocates the descent of Chordata from the Echinodermata as such. The remarkable similarities between the echinoderm (bipinnaria) and hemichordate (tornaria) larvae is taken as good evidence for common ancestry. Garstang suggested that probably free-swimming auricularian larvae of some ancestral echinoderms evolved into chordates through paedogenesis, i.e., prolongation of larval life without undergoing metamorphosis and reproducing sexually.

Most zoologists (Romer, Berril, Barrington, etc.) now favour the deuterostome line of chordate evolution, according to which the phyla Echinodermata, Hemichordata and Chordata show common ancestry on embryological and biochemical evidences. The protochordates provide the connecting link between early chordate ancestors and verebrates. The differentiation probably occurred much earlier than Cambrian period. The earliest traces of vertebrates have been found in the rocks of late Cambrian and Ordovician. A number of fishes followed in Silurian and became abundant in the Devonian. The subsequent periods show the evolution of amphibians, reptiles, birds and mammals.

The topic of 'Origin of Chordata' has been treated in more details in Chapter 9 dealing with the subphylum Vertebrata.

Major Subdivisions of Phylum Chordata

Phylum Chordata is a rather heterogeneous assemblage of groups which differ widely from one another and show various degrees of relationships to each other. In a taxonomic outline or classification of the phylum, these groups are customarily arranged in larger functional divisions or subdivisions based on specific structures or features. These subdivisions or taxa have been accorded different ranks under different systems of classification. The following terminology includes major subdivisions of phylum Chordata.

1. Subphyla and classes. Phylum Chordata is first conveniently separated into 3 or 4 primary subdivisions, called *subphyla*, based on the character on notochord. These are :

Subphylum 1. Hemichordata (or Adelochordata)
Subphylum 2. Urochordata (or Tunicata)
Subphylum 3. Cephalochordata
Subphylum 4. Vertebrata

Subphylum *Hemichordata* (Gr., *hemi*, half; *chorde*, cord) have long been traditionally considered to be the lowest chordates. But recent workers consider the so-called notochord of the hemichordates not a true notochord but a *'stomochord'*. Hence the hemichordates are removed from the chordates and treated as an independent invertebrate phylum.

Subphylum *Urochordata* (Gr., *oura*, a tail; L., *chorda*, cord) includes 3 classes (Larvacea, Ascidiacea and Thaliacea), subphylum *Cephalochordata* (Gr., *kephale*, head; *chorde*, cord) includes a single class (Leptocardii), while the subphylum *Vertebrata* (L., *vertebratus*, backbone) is subdivided into 9 classes (Ostracodermi, Cyclostomata, Placodermi, Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia).

2. Protochordata and Euchordata. The first two subphyla under phylum Chordata (i.e., Urochordata and Cephalochordata) are all marine, relatively small and without a vertebral column or backbone. They are often collectively referred as

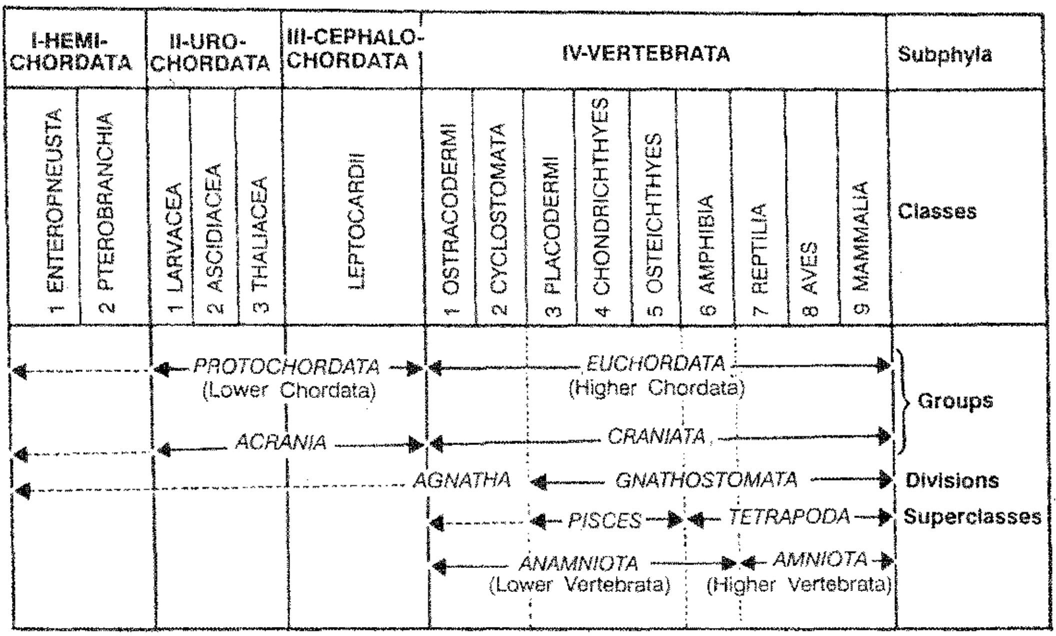

Fig. 3. Subdivisions of the phylum Chordata.

the *nonvertebrate* or *invertebrate chordates* or *protochordates*, (Gr., *protos*, first; *chorde*, cord), as they are regarded to be early, primitive, borderline or first chordates closely allied with the ancestral chordate stock. At one time, the *Protochordata* were treated as a distinct phylum with the Hemichordata included as a third subphylum. At present, the Hemichordata is placed as an independent invertebrate phylum while the Urochordata and Cephalochordata are considered to be true chordate subphyla. Therefore, the term 'Protochordata' no longer holds any official taxonomic position, but is merely descriptive. Its use does not reflect any close relationship between the two or three subphyla, but simply contrasts their general position with the greatly advanced vertebrates.

The third subphylum, i.e., *Vertebrata*, provided with a vertebral column, is regarded to be more advanced and belongs to the subdivision *Euchordata* of the phylum Chordata. Sometimes, the protochordates are known as the *lower chordates*, while the vertebrates or the euchordates as the *higher chordates.*

3. Acrania and Craniata. The protochordate subphyla lack a head and a cranium, so that they are known as *Acrania* (Gr., *a* absent; *kranion*, head). On the other hand, the subphylum Vertebrata (subdivision Euchordata) has a distinct head and a cranium and is also called *Craniata*. Some workers consider Acrania synonymous with the subphylum Cephalochordata alone.

4. Agnatha and Gnathostomata. The Vertebrata (or Craniata) are further subdivided in several ways. One possibility with universal agreement separates them into two unequal sections : Agnatha and Gnathostomata. *Agnatha* (Gr., *a*, not; *gnathos*, jaw) lack true jaws and paired appendages. Agnathans or agnathostomes include a small number of primitive but highly specialized fish-like forms, the extinct ostracoderms and the modern cyclostomes. Some workers include even the protochordates in Agnatha. All other vertebrates have true jaws and paired appendages, and are called *Gnathostomata* (Gr., *gnathos*, jaw: *stoma*, mouth). In the past, Agnatha and Gnathostomata were accorded the rank of subphyla in phylum Chordata. In recent years, they are considered as branches or groups or superclasses of the subphylum Vertebrata.

5. Pisces and Tetrapoda. A basic division of Gnathostomata recognises two superclasses : Pisces and Tetrapoda. The superclass *Pisces* (L., *piscis*, fish) includes all the fishes which are strictly aquatic forms with paired fins. Sometimes, the fish-like agnathans are also embraced here. The superclass *Tetrapoda* (Gr., *tetra*, four; *podos*, foot) is formed by four-legged land vertebrates including amphibians, reptiles, birds and mammals.

6. Anamnia and Amniota. Another method of grouping the vertebrates elicits an extremely important advance in the pattern of embryological development. It is based on the presence of a special membrane, the *amnion*, that holds the developing embryo in a reservoir of fluid, and permits the laying of eggs on land. The animals that possess it belong to *Amniota* which includes the classes Reptilia, Aves and Mammalia. The animals without this membrane are *Anamniota* including cyclostomes, fishes and amphibians. Sometimes, the anamniotes are referred to as the *lower vertebrates*, and the amniotes as *higher vertebrates.*

General Characters of Phylum Chordata

(1) Aquatic, aerial or terrestrial. All free-living with no fully parasitic forms.
(2) Body small to large, bilaterally symmetrical and metamerically segmented.
(3) A *postanal tail* usually projects beyond the anus at some stage and may or may not persist in the adult.
(4) Exoskeleton often present; well developed in most vertebrates.
(5) Bodywall *triploblastic* with 3 germinal layers : ectoderm, mesoderm and endoderm.
(6) *Coelomate* animals having a true coelom, enterocoelic or schizocoelic in origin.
(7) A skeletal rod, the notochord, present at some stage in life cycle.

***Table* 2. Outline Classification of Phylum Chordata.**

					Classes	
Phylum Chordata	*Group* Acrania or Protochordata (Lower Chordata)	Subphylum *Hemichordata			1. Enteropneusta	
					2. Pterobranchia	
		Subphylum Urochordata			1. Ascidiacea	
					2. Thaliacea	
					3. Larvacea	
		Subphylum Cephalochordata			1. Leptocardii	
	Group Craniata or Euchordata (Higher Chordata)	*Subphylum* Vertebrata	*Division* Agnatha		1. Ostracodermi	**Anamniota** (Lower Vertebrata)
					2. Cyclostomata	
			Division Gnathostomata	*Superclass* Pisces	3. Placodermi	
					4. Chondrichthyes	
					5. Osteichthyes	
				Superclass Tetrapoda	6. Amphibia	
					7. Reptilia	**Amniota** (Higher Vertebrata)
					8. Aves	
					9. Mammalia	

*Subphylum Hemichordata is now considered to be an invertebrate group.

(8) A cartilaginous or bony, living and jointed *endoskeleton* present in the majority of members (vertebrates).

(9) *Pharyngeal gill slits* present at some stage; may or may not be functional.

(10) *Digestive system* complete with digestive glands.

(11) *Blood vascular system* closed. Heart ventral with dorsal and ventral blood vessels. Hepatic portal system well developed.

(12) *Excretory system* comprising proto-or meso-or meta-nephric kidneys.

(13) *Nerve cord* dorsal and tubular. Anterior end usually enlarged to form brain.

(14) Sexes separate with rare exceptions.

Brief Classification of Chordata with Characters

The chordates form a large heterogeneous grouping of members differing widely from one another in many respects. This creates problems in their systematic classification. Different schemes have been proposed by a number of taxonomists from time to time. The one followed in this text is a synthesis of the most recent ones adopted here for the sake of simplicity and proper understanding. Table 2 provides an outline classiction of the phylum Chordata.

PHYLUM CHORDATA

(L. *chordatus,* having a cord, i.e., the notochord). Widely diversified in size, habits and habitat. Bilaterally symmetrical, metamerically segmented, triploblastic, coelomate deuterostomes. All possess, at some stage in their life-history, supporting skeletal rod or notochord, a hollow dorsal nerve cord and paired gills or gill-slits, which may persist, change or disappear in the adults. Cambrian to Recent. Chordates. About 50,000 species.

Phylum Chordata can be divided into two groups; *Acrania* (Protochordata) and *Craniata* (Euchordata) having contrasting characters (Table 3).

Group A. Acrania (Protochordata)

(Gr. *a,* absent; *kranion,* head, or, Gr. *protos,* first; *chorde,* cord). All marine, small, primitive or lower chordates. Lacking a head, a skull or cranium, a vertebral column, jaws and brain. About 2,000 species.

The Acrania is divided into three subphyla: *Hemichordata, Urochordata* and *Cephalochordata*, chiefly on the position of notochord.

Subphylum I. Hemichordata

(Gr. *hemi*, half; *chorde*, cord). Body divided into 3 regions : proboscis, collar and trunk. Notochord doubtful, short, confined to proboscis and non-homologous with that of chordates.

Class 1. Enteropneusta. (Gr. *enteron*, gut; *pneustos*, breathed). Body large and worm-like. Gill-slits numerous. Intestine straight. Acorn or tongue worms. 3 families, 15 genera and 70 species. *Balanoglossus, Saccoglossus.*

Class 2. Pterobranchia. (Gr. *pteron*, feather; *branchion*, gill). Body small and compact. Gill-slits one pair or none, Intestine U-shaped. Pterobranchs includes 2 orders, 3 genera and 20 species. *Cephalodiscus, Rhabdopleura.*

Class 3. Planctosphaeroidea. Transparent, round and specialized tornaria larva, having extensively branched ciliary bands and L-shaped alimentary canal, represents this class. *Planctosphaera pelagica.* This form is regarded as the larval form of some unknown hemichordates.

Class 4. Graptolita. The fossil graptolites (e.g. *Dendrograptus*) were abundant in Ordovician and Silurian periods and often placed as an extinct class under Hemichordata. Their tubular chitinous skeleton and colonial habits shoe an affinity with *Rhabdopleura.*

Subphylum II. Urochordata or Tunicata

(Gr. *oura*, a tail; L. *chorda*, cord). Notochord and nerve cord only in tadpole-like larva. Adult sac-like, often sessile and encased in a protective tunic. Tunicates.

Table 3. **Contrasting characters of Protochordata and Euchordata.**

	Group A. Acrania (Protochordata) or Lower Chordata		Group B. Craniata (Euchordata) or Higher Chordata
1.	Exclusively marine, small-sized chordates.	1.	Aquatic or terrestrial, mostly large sized vertebrates
2.	No appendages, cephalization and exoskeleton.	2.	Usually 2 pairs of appendages, well-developed head and exoskeleton present.
3.	Coelom enterocoelic, budding off from embryonic archenteron.	3.	Coelom schizocoelic, arising by splitting of mesoderm.
4.	Notochord persistent. No skull, cranium and vertebral column.	4.	Notochord covered or replaced by a vertebral column. Skull and cranium well developed.
5.	Pharynx with permanent gill-clefts. Endostyle present.	5.	Pharyngeal gill-clefts persist or disappear. Endostyle absent.
6.	Heart chamberless when present. No red blood corpuscles in blood.	6.	Heart made of 2,3 or 4 chambers. Blood contains R.B.C.
7.	Kidneys protonephridia.	7.	Kidneys meso-or metanephridia.
8.	Sexes separate or united. Reproduction asexual as well as sexual. Gonoducts usually absent.	8.	Sexes separate. Only sexual reproduction, Gonoducts always present.
9.	Development indirect with a free-swimming larval stage.	9.	Development indirect or direct, with or without a larval stage.

Class 1. Ascidiacea. Sessile tunicates with scattered muscles in tunic. Solitary, colonial or compound. Gill-clefts numerous. Ascidians or sea squirts. 2 subclass, 3 orders, 12 families, 37 genera and 1,200 species. *Herdmania, Ciona, Molgula.*

Class 2. Thaliacea. Free-swimming or pelagic tunicates with circular muscles in tunic. Sometimes colonial. Salps or chain tunicates. 3 orders, 5 families, 9 genera and 30 species. *Salpa, Doliolum, Pyrosoma.*

Class 3. Larvacea or Appendicularia. Tiny, transparent, free-floating. Adults retain many larval features including tail. Only two gill-slits. 2 orders, 2 families, 5 genera and 30 species. *Oikopleura.*

Subphylum III. Cephalochordata

(Gr. *kephale*, head; L. *chorda*, cord). Notochord and nerve cord present throughout life along entire length of body.

Class Leptocardii. Body fish-like, segmented with distinct myotomes and numerous gill-slits. Free-swimming and burrowing. Lancelets. One class, one family, 2 genera and 30 species. *Branchiostoma* (=*Amphioxus*), *Asymmetron.* About eight species have been recognized under the genus *Branchiostoma* and six species have been recognized from the genus *Asymmetron.*

Group B. Craniata (Euchordata)

Aquatic or terrestrial, usually large-sized, higher chordates or vertebrates with distinct head, a vertebral column, jaws and brain protected by a skull or cranium. The Craniata includes a single subphylum, the *Vertebrata.*

Subphylum IV. Vertebrata

(L. *vertebratus*, backbone). Notochord supplemented or replaced by a vertebral column or backbone composed of overlapping vertebrae. Body divisible into head, neck, trunk and tail. Usually dioecious. Vertebrates. Largest chordate subphylum including about 46,500 species.

The subphylum Vertebrata is divided into two divisions : *Agnatha* and *Gnathostomata*, with contrasting characters as follows :

Division I. Agnatha	Division II. Gnathostomata
1. Without true jaws.	1. True jaws present.
2. Paired appendages absent.	2. Appendages paired (pectoral & pelvic).
3. Inner ear with 2 semi-circular canals.	3. Inner ear with 3 semi-circular canals.
4. Notochord persistent in adults.	4. Notochord persists or replaced by vertebrae.

Division I. Agnatha

(Gr. *a*, not; *gnathos*, jaw). Jawless primitive fish-like vertebrates without true jaws and paired limbs.

Class 1. Ostracodermi. (Gr. *ostrakon*, shell; *derma*, skin). Several extinct orders of ancient primitive heavily armoured, Palaeozoic, world's first vertebrates, collectively called the ostracoderms. *Cephalaspis, Drepanaspis.*

Class 2. Cyclostomata. (Gr. *cyklos*, circular; *stoma*, mouth). Body eel-shaped, without scales, jaws and lateral fins. Mouth rounded and suctorial. Gills 5-16 pairs. Parasites and scavengers. 45 species. Lampreys (*Petromyzon*) and hagfishes (*Myxine*).

Division II. Gnathostomata

(Gr. *gnathos*, jaw; *stoma*, mouth). Jawed vertebrates having true jaws and paired limbs.

For convenience, some taxonomists further divide Gnathostomata into two superclasses. All the fishes and fish-like aquatic gnathostomes are placed in the superclass *Pisces*, whereas all the four-footed terrestrial gnathostomes in the superclass *Tetrapoda*. Their contrasting features are as follows :

Superclass 1. Pisces	Superclass 2. Tetrapoda
1. Exclusively aquatic gnathostome vertebrates.	1. Aquatic or terrestrial. Some arboreal and aerial.
2. Paired limbs, if present, as fins.	2. Paired pentadatyle limbs present.
3. Median fins present.	3. Median fins absent.
4. Skin usually moist and scaly.	4. Skin usually dry and cornified.
5. Respiration aquatic, by gills.	5. Respiration aerial, by lungs.
6. Sense organs functional in water.	6. Sense organs functional in air.

Superclass 1. Pisces

(L. *piscis,* fish). Fishes or fish-like aquatic forms with paired as well as median fins, gills and scaly skin.

Class 1. Placodermi. Several extinct orders of primitive earliest jawed fishes of Palaeozoic with bony head shield movably articulated with trunk shield. Placoderms. *Climatius, Dinichthys.*

Class 2. Chondrichthyes. (Gr. *chondros,* cartilage; *ichthys,* fish). Mostly marine. Cartilaginous endoskeleton. Skin with placoid scales. Gill-slits not covered by operculum. Pelvic claspers in male. Cartilaginous fishes. Approximately 600 species. *Scoliodon* (dogfish), *Chimaera* (ratfish).

Class 3. Osteichthyes. (Gr. *osteon,* bone; *ichthys,* fish). Freshwater and marine. Endoskeleton mostly bony. Skin having various types of scales (cycloid, ctenoid) other than placoid. Gill-slits covered by operculum. Males without claspers. Bony fishes. 20,000 species. *Labeo* (rohu), *Protopterus* (lungfish), *Hippocampus* (sea horse).

Superclass 2. Tetrapoda

(Gr. *tetra,* four; *podos,* foot). Land vertebrates with two pairs of pentadactyle limbs, cornified skin and lungs.

Class 1. Amphibia. (Gr. *amphi,* both; *bios,* life). Larval stage usually aquatic and breathes by gills. Adult typically terrestrial and respires by lungs. Skin moist, glandular and with no external scales. Heart 3-chambered. Amphibians. Approximately 2,500 species. *Rana* (frog), *Bufo* (toad), *Ambystoma* (salamander).

Class 2. Reptilia. (L. *reptilis,* creeping). Terrestrial tetrapods. Skin dry, covered by ectodermal horny scales or bony plates. Heart incompletely 4-chambered. Cold-blooded. Respiration by lungs. 7,000 species. *Hemidactylus* (wall lizard), *Uromastix* (spiny-tailed lizard), *Naja* (cobra), *Sphenodon, Crocodilus* (crocodile).

Class 3. Aves. (L. *avis,* bird). Typically flying vertebrates covered with feathers. Forelimbs modified into wings. No teeth in beak. Heart 4-chambered. Warm blooded. Birds. About 9,000 species. *Struthio* (African ostrich), *Columba* (pigeon), *Gallus* (fowl).

Class 4. Mammalia. (L. *mamma,* breast). Body covered by hair. Skin glandular. Female with mammary glands which secrete milk for suckling the young. Heart 4-chambered. Warm blooded, air breathing vertebrates. 4,500 species. *Echidna* (spiny anteater), *Macropus* (Kangaroo), *Rattus* (rat), *Homo* (man).

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Discuss the features in which Chordates show an advancement over Non chordates.
2. Discuss the similarities and differences between Chordates and higher chordates in detail.
3. Classify Phylum Chordata upto classes giving the important characters and examples of each group.

» *Short Answer Type Questions*

1. Give the main characteristics of phylum Chordata.
2. Draw a comparison between chordates and non-chordates.
3. Distinguish between— (i) Protochordata and Euchordata, (ii) Acrania and Craniata, (iii) Agnatha and Gnathostomata, (iv) Pisces and Tetrapoda.
4. Write short notes on— (i) Chorda dorsalis, (ii) Pharyngeal gill slits, (iii) Hemichordata, (iv) Urochordata, (v) Tetrapoda.

» *Multiple Choice Questions*

1. Which of this is not a chordate character?
   (a) A dorsal or hollow tubular nerve cord
   (b) A longitudinal supporting rod-like notochord
   (c) A series of pharyngeal gill slits
   (d) Diploblastic
2. Notochord is confined to proboscis in :
   (a) Urochordata (b) Hemichordata
   (c) Cephalochordata (d) Chordata
3. Placoid scales are present in
   (a) *Hippocampus* (b) *Scoliodon*
   (c) *Labeo* (d) *Protopterus*
4. First jawed vertebrates belong to class :
   (a) Cyclostomata (b) Placodermi
   (c) Ostracodermi (d) Chondrictheys
5. The endoskeleton of chordate animals is :
   (a) Living structure
   (b) Living structure without growth
   (c) Living structure with growth
   (d) Non-living structure
6. Which of the following is present in all chordates?
   (a) Umbilical cord
   (b) Ventral tubular nerve cord
   (c) Dorsal tubular nerve cord
   (e) Pseudocoelom
7. One of the following primitive class of chordates containing *Amphioxus* and a few related forms, which are all marine :
   (a) Cephalochordata (b) Urochordata
   (c) Hemichordata (d) Vertebrata
8. Which of the following is a chordate but not a vertebrate?
   (a) *Catla* (b) *Hippocampus*
   (c) *Hemidactylus* (d) *Amphioxus*
9. Name the primitive worm like animals having certain chordate features such as gill clefts and a small notochord in the anterior region of the head only :
   (a) Cephalochordata
   (b) Hemichordata
   (c) Urochordata
   (d) None of the above
10. Which of the following is not a characteristic of members of Urochordata or Tunicata :
    (a) Notochord and hollow central nervous system are present only in the larval stage
    (b) The body is externally covered by a thick cellulose cuticle or tunic
    (c) The coelom is absent
    (d) None of the above
11. Name the animal group whose members are considered doubtful chordates
    (a) Urochordata (b) Hemichordata
    (c) Cephalochordata (d) All of the above
12. Which of the following is a characteristic of members of the subphylum Urochordata?
    (a) Worm-like animals that live in burrows, in the muddy bottom of the shore
    (b) Cranium or brain box distinct
    (c) Both the notochord and the nerve cord are well developed
    (d) Notochord found in larva and is confined to the tail only
13. Chordates with a backbone are called :
    (a) Invertebrates (b) Protochordates
    (c) Vertebrates (d) Hemichordates
14. Which of the following animals is not a vertebrate?
    (a) Fish (b) Frog (c) Sea horse (d) Sea squirt
15. Scales in the sharks are :
    (a) Cycloid (b) Ctenoid (c) Placoid (d) Ganoid
16. Which of the following is anamniote animal?
    (a) *Labeo* (b) *Crocodilus* (c) *Columba* (d) *Rattus*

ANSWERS

1. (d) 2. (b) 3. (b) 4. (b) 5. (c) 6. (c) 7. (a) 8. (d) 9. (b) 10. (d) 11. (b) 12. (d) 13. (c) 14. (d) 15. (c) 16. (a)

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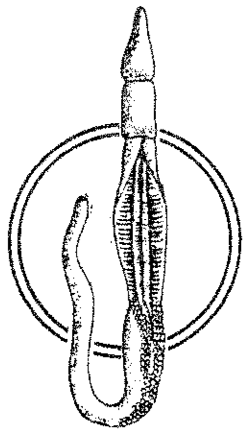


Type 1. *Balanoglossus* : A Tongue Worm

Hemichordata (Gr. *hemi,* half; *chorde,* cord), till recently treated as a subphylum of the phyium Chordata (or Protochordata), is now regarded to be an independent phylum of invertebrates close to Echinodermata. However, for convenience of the comparative study of the protochordates, the Hemichordata is being retained here as a chordate subphylum. It includes a small group of soft, vermiform, marine and primitive chordates, commonly called the 'acorn worms' or 'tongue worms'. The most familiar hemichordate genus is *Balanoglossus* which belongs to the class Enteropneusta. Other closely related genera are *Saccoglossus* (= *Dolichoglossus*), *Glossobalanus, Ptychodera, Spengelia,* etc.

Systematic Position

Phylum	Chordata
Subphylum	Hemichordata
Class	Enteropneusta
Family	Ptychoderidae
Type	*Balanoglossus* (tongue worm)

Derivation of Name

Balanoglossus clavigerous was recorded and named by Delle Chiaje in 1829. Its generic name was derived from two Greek words, *balanos* and *glossus*. The term *balanos* means an 'acorn' (fruit of oak) and refers to the proboscis projecting from collar looking like an acorn-nut, hence the common name 'acorn worm'. The term *glossus* means 'tongue' and refers to the shape of its proboscis, collar and genital wings bearing a close resemblance to an ox tongue, hence the common name 'tongue worm'. The local fishermen call *Balanoglossus* by the name 'ox tongue'.

Geographical Distribution

Balanoglossus, like all other hemichordates, is a marine animal having a world-wide distribution. About 20 species occur all over the world especially in the tropical and subtropical seas. Some species are *B. australiensis* (Australia), *B. carnosus* (Indo-Pacific), *B. misakiensis* (Japan), *B. jamaicensis* (West Indies), *B. gigas* (Brazil), *B. capensis* (South Africa) and *B. clavigerus* (Mediterranean and British isles).

Habits and Habitat

Habitat. *Balanoglossus* is a marine, tubicolous or burrowing hemichordate inhabiting shallow coastal waters of intertidal zone, but a few occur in deeper water.

Burrow. The animal may conceal under stones or sea weeds or excavate its own burrow in the bottom sand or mud. *B. clavigerus* lives inside a U-shaped tube or burrow with the two vertical limbs 50-75 cm deep and the two openings 10-30 cm apart. In some species (*Saccoglossus*), the body of the animal and tube are twisted, whereas the anterior and posterior extremities remain straight. The anterior opening of the burrow is funnel-shaped and exposed. The anterior vertical limb may give out side branches each having its independent funnel-like opening (Fig. 1). The posterior opening of the burrow is rounded and concealed below the spirally coiled faecal matter of the animal.

Protective device. The inner wall of the fragile tube is smoothly lined by sand particles cemented together into a tough cast with sticky mucus secreted by the skin mucous glands of the animal. This prevents the collapse of the burrow and protects the delicate animal from burial in loose sand. Another protective device is the secretion of a foul-smelling odour similar to iodoform. One species shows phosphorescence.

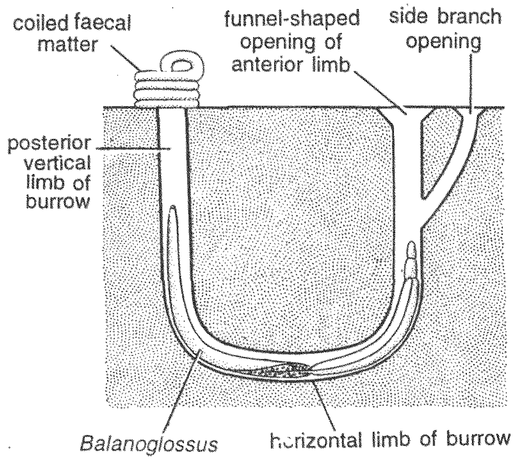


Fig. 1. *Balanoglossus clavigerous* in U-shaped burrow.

Movements. The worm is sluggish and little affected by external stimuli. It moves in its burrow by cilia covering its body surface. The most active part of the body is proboscis. It elongates and shortens by muscular activity and helps in burrowing. When the tide recedes, the tongue worm protrudes its anterior end out of the burrow to explore the surroundings, or its posterior end to cast out faecal matter.

Feeding and breeding. It swallows sand or mud to obtain diatoms, protozoans, other microorganisms and organic detritus on which it feeds. Sexes are separate. Males and females, living in separate tubes, shed their gametes in seawater where fertilization occurs. Life cycle includes a free-swimming planktonic ciliated larva, the *tornaria*. Tongue worm does not reproduce asexually, but its fragile body has considerable power of regeneration.

External Morphology

Shape, size and colouration. The body is soft, elongated, worm-like, cylindrical and bilaterally symmetrical. It measures 10 to 50 cm in length, according to species. *B. gigas* attains a length of 1.8m (Sawaya, 1951) or 2.5m (Spengel, 1893). Colour is bright or drab with reddish or orange tints. The body is uniformly ciliated and without any exoskeleton or external appendages.

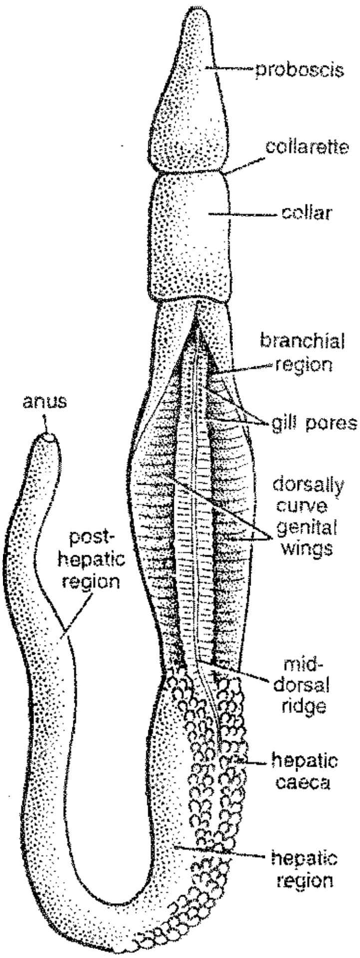


Fig. 2. *Balanoglossus*. External features in dorsal view.

Division of body. The body is unsegmented but divisible into three distinct regions or parts : *proboscis, collar* and *trunk* (Fig. 2).

1. Proboscis. The *proboscis* or *protosome* is the anteriormost part of the body. It is short, club-shaped or conical and circular in cross-section. It has thick muscular wall and is hollow within. Its cavity or proboscis coelom communicates with the outside through a minute *proboscis pore* situated mid-dorsally near its base. In some species the proboscis pore ends blindly or there are two pores. Posteriorly, the proboscis narrows into a slender *neck* or *proboscis stalk* which is attached to the collar. Below the stalk, the base of proboscis bears a U-shaped ciliated epidermal depression, called the *preoral ciliary organ,* which tests the quality of food and water entering the mouth.

2. Collar. The *collar* or *mesosome* is the middle, short and cylindrical part. Its flap-like or funnel-like anterior margin, termed *collarette,* completely surrounds and conceals the proboscis stalk and the posterior part of proboscis. Ventrally, below the proboscis stalk, the collarette or collar-rim encloses a permanently open wide aperture, the *mouth*. It opens into the buccal cavity inside the collar. The posterior end of collar is well demarcated from the trunk by a circular constriction. The wall of collar is thick, highly muscular and encloses a cavity, the *collar coelom.* It opens to outside through a pair of *collar pores* into the first pair of gill pouches.

3. Trunk. The *trunk* or *metasome* is the posterior and largest part of the body. It is rather flat and appears annulated due to circular constrictions on the surface. All along its length, the trunk bears a *mid-dorsal* and a *mid-ventral ridge*, each accommodating its corresponding nerve and blood vessel. The trunk is further differentiated into three regions : an anterior *branchiogenital*, a middle *hepatic* and a posterior *post-hepatic, abdominal* or *caudal* region.

(a) Branchiogenital region. The anterior or branchiogenital region of trunk is marked by a pair of lateral, thin, flat and longitudinal flaps, the *genital wings*, containing the *gonads*. The *gonopores* are microscopic and cannot be seen by the unaided eyes. The anterior half of branchiogenital region bears two longitudinal rows of small *branchial apertures* or *gill pores*. One row of gill pores is mounted on a prominent longitudinal ridge on each side of the mid-dorsal ridge. The number of gill pores increases with the age of the animal. The two genital wings can be curved to meet mid-dorsally so as to conceal the gill pores. In some species, a posterior prolongation of the collar, called the *operculum,* may cover the anteriormost gill pores.

(b) Hepatic region. The middle or hepatic region of trunk is somewhat smaller than the genital region. It is greenish in colour and its dorsal surface is marked by the presence of numerous irregular intestinal sacculations of *hepatic caeca.*

(c) ***Posthepatic region.*** It is the posterior most and the longest part of the trunk, also called the *abdomen* or the *caudal region.* It is more or less uniform in diameter but its posterior end tapers slightly, and bears a terminal *anus.*

Body Wall

The body wall is composed of epidermis, musculature and peritoneum.

1. Epidermis. The outermost layer or epidermis consists of a single layer of mostly tall, slender, columnar and ciliated cells. Three kinds of gland cells secreting mucus are present. *Goblet gland cells* are flask-shaped with fine granules. *Reticulate gland cells* have mesh-like vacuolated cytoplasm. *Mulberry* or *granular gland cells* contain coarse granules and also secrete amylase. The gland cells are more abundant in the collar region. Besides, *neurosensory cells,* which stain darker, are present in the epidermis of proboscis and anterior part of the collar. Dermis is absent. Below the epidermal cells is a thick *nervous layer* consisting of a network of nerve cells and nerve fibres. Below the nervous layer is a thick *basement membrane* which supports the epidermis and serves for attachment of the underlying musculature (Fig. 3).

2. Musculature. The muscles are smooth, weak and mostly longitudinal. Proboscis and the anterior end of collar (collarette) have an outer layer of circular muscle fibres and an inner layer of longitudinal muscle fibres. In the trunk region, only longitudinal muscle fibres are present.

3. Peritoneum. The coelom is lined by the parietal coelomic epithelium or peritoneum which covers the inner surface of the bodywall musculature.

Functions of body wall. (i) The body wall shields the soft internal organs from mechanical injuries. (ii) Mucus produced by epidermal gland cells adheres sand particles for lining the burrow in which the worm lives. (iii) Foul smell of mucus is protective. (iv) Neuro-sensory cells serve to receive the external stimuli. (v) Musculature helps in body movements.

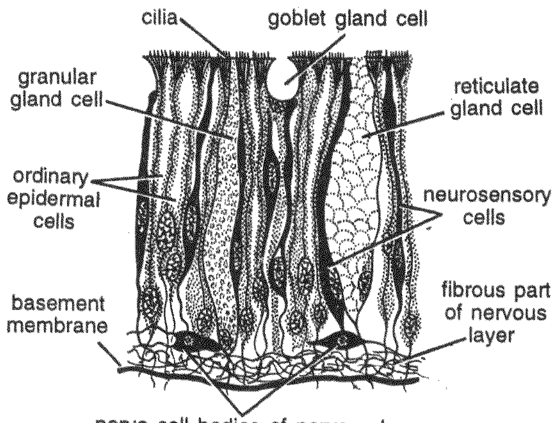


Fig. 3. *Balanoglossus.* V. S. of epidermis.

Coelom

Balanoglossus has a spacious coelom lined by coelomic epithelium and enterocoelous in origin. The coelomic cavities of proboscis, collar and trunk are completely separated from one another. However, in the adult, the original coelom is greatly obliterated by connective tissue and muscle fibres derived from coelomic epithelium which becomes inconspicuous and irregular. The adult coelom is represented by five separate cavities which originate as independent pouches from the archenteron of the embryo. These include one cavity in proboscis, two in collar and two in the trunk.

1. Proboscis coelom. The unpaired *proboscis coelom* or *protocoel* is greatly obliterated by connective tissue and muscle strands except for a small central space which is occupied by the *proboscis complex.* The latter includes the buccal diverticulum central sinus, heart vesicle and glomerulus. The proboscis coelom communicates with the outside through a *proboscis canal* and a *proboscis pore* situated mid-dorsally at the base of the proboscis stalk (Fig. 4).

2. Collar coelom. The *collar coelom* or *mesocoel* is represented by two narrow lateral cavities, one on each side between the collar wall and buccal tube. The two cavities are partitioned by incomplete mid-dorsal and mid-ventral mesenteries. The collar coelom does not

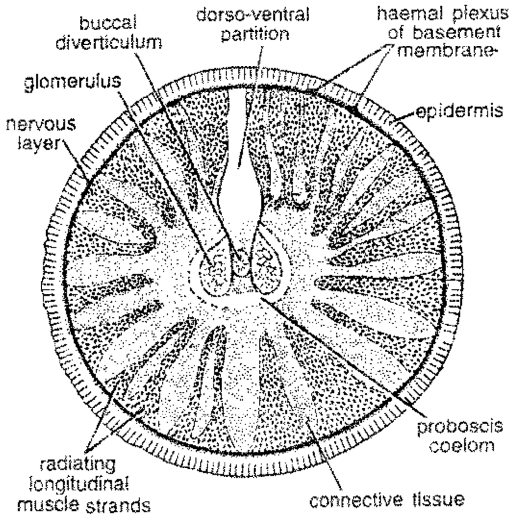


Fig. 4. *Balanoglossus*. T.S. through proboscis.

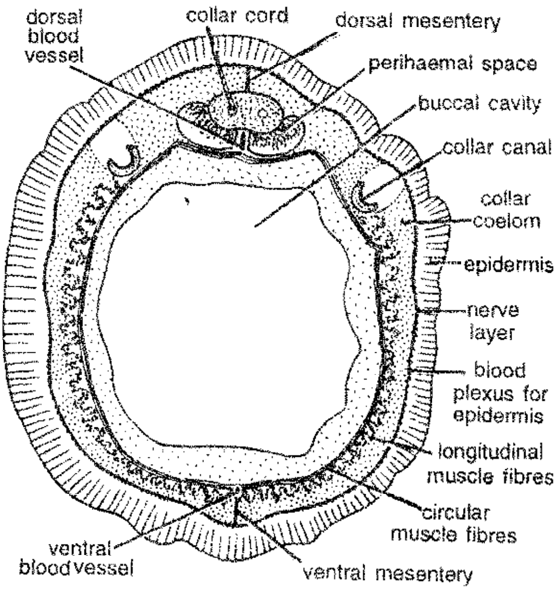


Fig. 5. *Balanoglossus*. T.S. through collar region.

communicate with the proboscis coelom, but, posteriorly, its each cavity opens into the first gill sac of its side by a *collar canal* and a *collar pore*. The collar coelom is greatly obliterated by the collar musculature and connective tissue (Fig. 5).

3. Trunk coelom. The *trunk coelom* or *metacoel* is represented by a pair of closed cavities between the body wall and gut wall. The two cavities are separated by an incomplete dorsal and a complete ventral mesentery. In the branchiogenital region each cavity is further divided by a *lateral septum* into a dorsal-lateral and ventro-lateral compartment. The trunk coelom is partitioned from the collar coelom by a *collar-trunk septum*. The trunk coelom is obliterated by the trunk musculature.

Coelomic fluid. The proboscis and collar coeloms communicate with the exterior and are largely filled with sea water which keeps them turgid. The trunk coelom is filled with a watery coelomic fluid containing amoeboid *coelomocytes*, each with a single large vacuole. The coelomocytes originate from the coelomic epithelium. According to Spengel, they behave like leucocytes by secreting a membrane around any foreign body that may invade the animal.

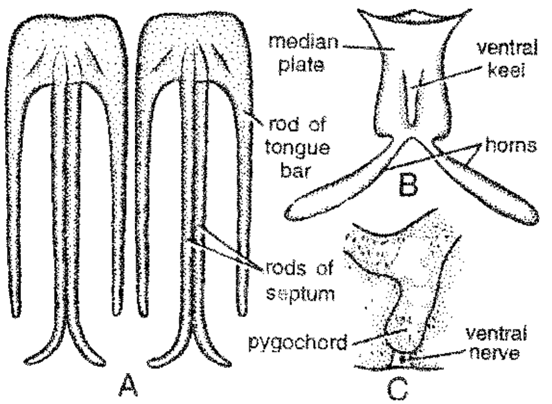


Fig. 6. *Balanoglossus*. Skeletal elements. A—Branchial skeleton. B—Proboscis skeleton. C—Pygochord.

Endoskeleton

Balanoglossus has no definite endoskeleton of bone or cartilage. However, the following four stiff structures are present : (i) *Buccal diverticulum*, (ii) *proboscis skeleton*, (iii) *branchial skeleton*, and (iv) *pygochord* (Fig. 6).

1. Buccal diverticulum. From the roof of buccal cavity (lying inside collar region), a short stiff, thick-walled, hollow projection extends forwards through the proboscis stalk into the proboscis coelom. Its wall is composed of a single layer of tall, slender, vacuolated endodermal cells. For a long time it was considered a *notochord* (Bateson, 1885), or *stomochord* (Willey, 1899 and Dawydoff, 1948). Histologically as well as developmentally, it is quite different from the true notochord of other chordates, but resembles the wall of the buccal cavity. To most modern workers it is only a preoral extension of buccal cavity, therefore, Hyman preferred to use the non-committal term *buccal diverticulum* for this tubular outgrowth of buccal cavity.

2. Proboscis skeleton. The *proboscis* or *nuchal skeleton* is a Y-shaped chitinous structure formed by the thickening of the basement membrane. It consists of a broad, flat, roughly rectangular *median plate* produced ventrally into a *keel* and posteriorly into two diverging *horns*. The median plate lies below the buccal diverticulum in the proboscis stalk while the two horns extend backwards into the roof of the buccal cavity. The median plate remains embedded in a reticulum of stiff *chondroid tissue* which resembles vertebrate cartilage.

3. Branchial skeleton. It is also formed by the thickening of the basement membrane. It consists of numerous M-shaped chitinous skeletal rods that lie in the wall of the pharynx and support the U-shaped gill-slits that perforate it. The middle arm of the skeletal rod is thicker than the others and bifurcated at the free end which indicates that is is formed by the fusion of two arms of two adjacent 'inverted U-shaped' rods that join to form the M-shaped rod.

4. Pygochord. In the post-hepatic region of the trunk, mid-ventrally between the intestine and body wall, develops a rod-like thickening called *pygochord*. Its cells are vacuolated. It supports the post-hepatic region of the body but probably also performs some other function not yet understood.

Digestive System

[I] Alimentary canal

The alimentary canal is a complete and straight tube running between the mouth and anus. It is supported throughout its length by the dorsal and ventral mesenteries. Its wall is made up of ciliated epithelium covered externally by a basement

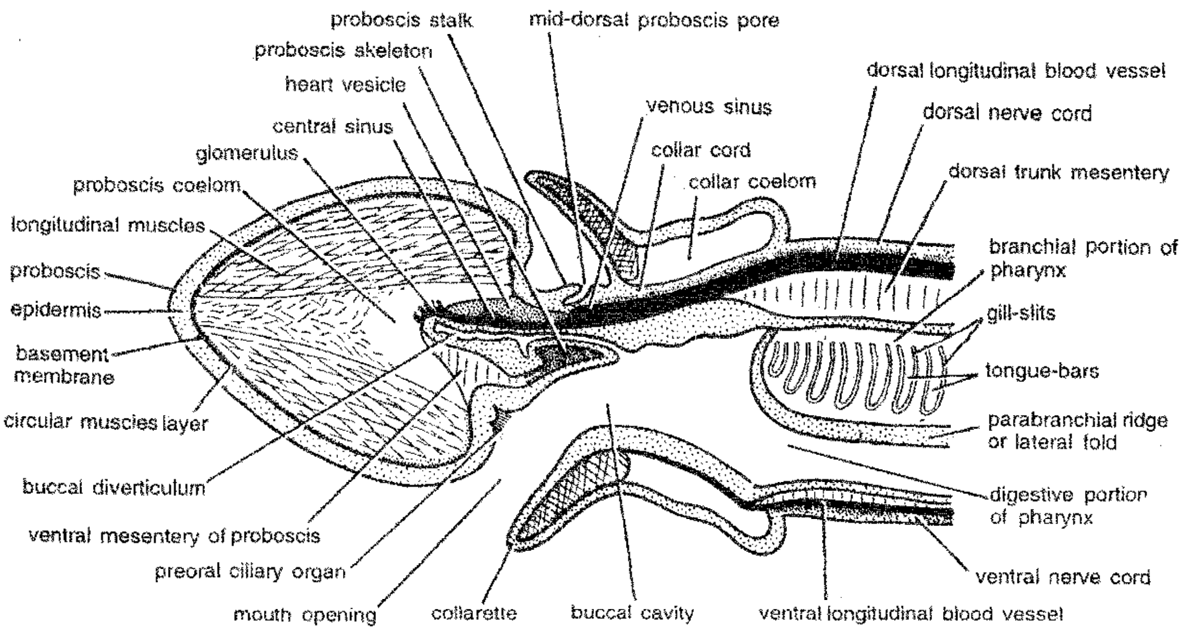


Fig. 7. *Balanoglossus*. V.L.S. Anterior region to show the alimentary canal.

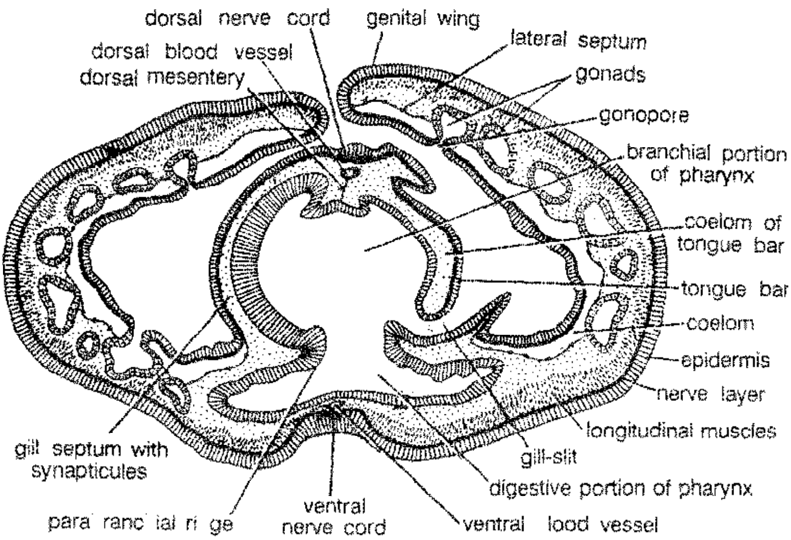


Fig. 8. *Balanoglossus*. T.S. through pharyngeal or branchio-genital region.

membrane, but peculiarly, muscle layers are absent. Alimentary canal comprises of (i) *mouth*, (ii) *buccal cavity*, (iii) *pharynx*, (iv) *oesophagus*, (v) *intestine*, and (vi) *anus* (Fig. 7).

1. Mouth. It is a wide and circular opening situated ventrally in a groove between the proboscis stalk and collarette. According to Knight-Jones (1952), it can be closed or opened and does not remain permanently open as previously supposed. It has two sets of muscle firbres, the radial fibres to open it and the concentric fibres to close it. The mouth leads into buccal cavity.

2. Buccal cavity. The short buccal cavity occupies the collar region. Its epithelial wall contains glandular goblet cells. Anteriorly its dorsal wall forms a short, stiff and hollow *buccal diverticulum* that projects into the proboscis coelom. Posteriorly it extends up to the collar-trunk septum behind which it continues into the pharynx.

3. Pharynx. It lies in the branchial region of the trunk. Externally its wall bears a longitudinal constriction along each lateral side. These lateral constrictions project into its lumen as ridges, called *parabranchial ridges*, consisting of tall columnar cells. These ridges incompletely divide the pharynx into a dorsal *respiratory* or *branchial portion* and a ventral *digestive portion*. The dorsal branchial portion is perforated dorso-laterally by two rows of U-shaped gill-slits, and is concerned with respiration. The ventral digestive portion, lined with ciliated epithelium with gland cells, helps in food concentration (Fig. 8).

4. Oesophagus. Behind the last pair of gillslits the pharynx continues into the short *oesophagus*. The dorsal and ventral divisions of pharynx continue for some distance into oesophagus. In this region, the dorsal part is called *postbranchial canal* which possesses thick, folded and glandular epithelium. The posterior part of oesophagus reduces in diameter and has deeply furrowed epithelium (Fig. 9).

5. Intestine. It occupies the hepatic and posthepatic regions of trunk. The *hepatic region* of the intestine is highly vascular. Its epithelial cells are dark-green or dark brown, and its dorsal wall forms numerous sacculations called *hepatic caeca*. The intestinal wall lies in close contact with the body wall, so that the intestinal sacculations correspond with those of the body wall. The *post-hepatic region* of intestine is connected with the ventral body wall by the pygochord described earlier. It is a simple and straight tube bearing a pair of dorso-lateral grooves lined by tall epithelial cells with long cilia (Fig. 10).

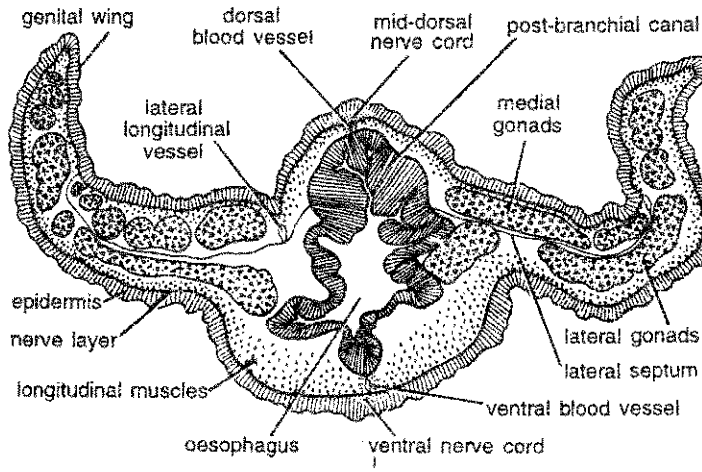


Fig. 9. *Balanoglossus*. T.S. through oesophageal region.

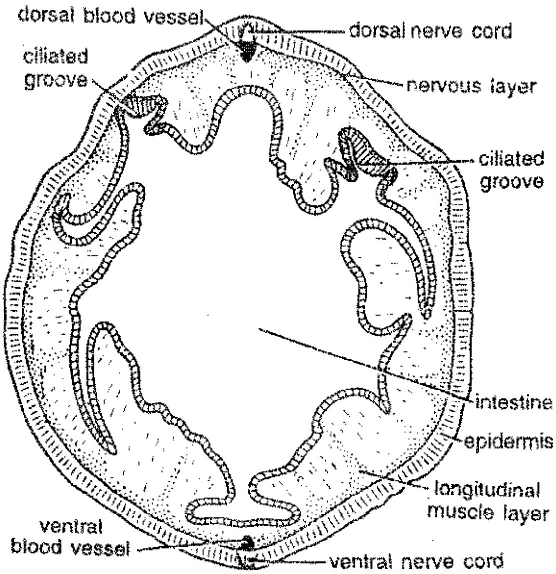


Fig. 10. *Balanoglossus*. T.S. through post-hepatic region of intestine.

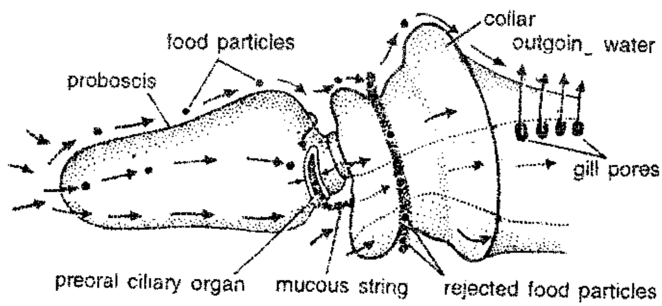


Fig. 12. *Balanoglossus*. Anterior end of body showing feeding current in lateral view. Arrows indicate the direction of the current.

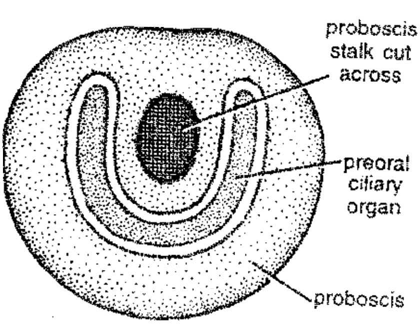


Fig. 11. *Balanoglossus*. Posterior view of proboscis showing.

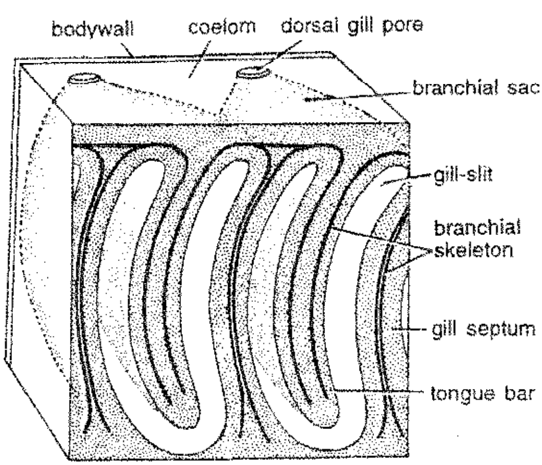


Fig. 13. *Balanoglossus*. Diagrammatic 3-dimentional view of two gill-slits and two branchial sacs.

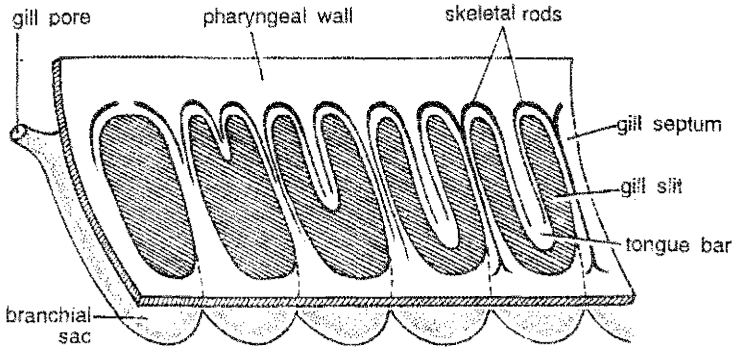


Fig. 14. *Balanoglossus*. Development of tongue bars.

6. Anus. Posteriorly, the intestine opens to the exterior by a terminal circular aperture, the *anus*, at the tip of the trunk. It is often surrounded by a sphincter muscle.

[II] Food, feeding and digstion

Balanoglossus is a 'ciliary feeder'. Its food comprises of microscopic organisms and organic particles present in water and the bottom sand in which it makes its burrows. The lateral cilia lining the gill-slits set up a current of water which enters through the mouth, takes its course through the buccal cavity, pharynx, gill-slits and branchial sacs, and leaves through the gill pores. This is the *respiratory-cum-food current*. Some food particles directly enter the mouth with this current while some come in contact with the proboscis and get entangled in the mucus that covers it. The mucus is secreted by the gland cells of the proboscis epithelium. Cilia covering the proboscis direct the mucous string, containing food particles, towards the pre-oral ciliary organ at the base of the proboscis. From here the mucous string is passed back into the mouth by the action of the proboscis cilia, aided by the main water current entering the mouth. Organic particles present in the sand are ingested directly along with the latter at the time of burrowing (Fig. 12).

The U-shaped *pre-oral ciliary organ*, at the base of proboscis stalk, tests the quality of food and water entering the mouth. Undesirable substances are prevented from entering the mouth by the ventral part of the collarette, which does so by covering the mouth. Thus, the rejected particles, instead of entering the mouth, pass back over the collar.

Backward movement of food through the alimentary canal is maintained by the cilia lining its walls. In the pharynx, the food moves through the ventral digestive portion. Digestion is brought about by enzymes secreted by gland cells of the pharynx, oesophagus and hepatic region of the intestine. The exact process of digestion in *Balanoglossus* is not known. Undigested substances, along with sand and silt, pass out through the anus as 'castings'.

Respiratory System

The respiratory apparatus of *Balanoglossus* comprises : (i) the *branchial portion of pharynx* bearing *gill-slits*, and (ii) the *branchial sacs* that open out through *gill-pores*.

1. Branchial pharynx. As already described, two lateral longitudinal *parabranchial ridges* divide the pharyngeal cavity into a ventral digestive portion and a dorsal respiratory or *branchial portion*. Dorsolaterally, on each side, the branchial portion is perforated by a longitudinal series of numerous U-shaped openings, the *gill-slits*. Their number varies and increases as the animal grows older. To start development a gill-slit is a broad oval slit. Later, a hollow projection of dorsal pharyngeal wall, called *tongue bar*, grows into the slit making it U-shaped. The hollow tongue bars enclose coelomic cavity and do not touch the ventral side of gill-slits. The portions of the pharyngeal wall between two adjacent gill-slits are termed *gill septa*. They are solid, without

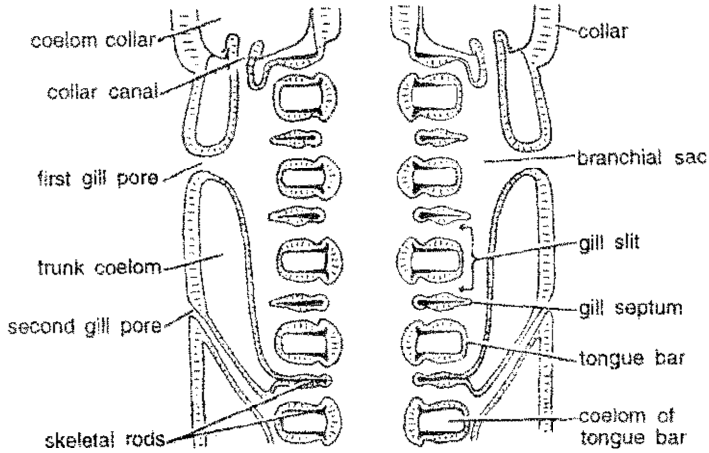


Fig. 15. *Balanoglossus misakiensis*. H.L.S. of branchial portion of pharynx to show first four gill-slits opening by a common gill pore.

enclosing coelom. A tongue bar is connected with adjacent gill septa by short transverse or horizontal connections, the *synapticula*. The development and arrangement of gill-slits is identical with that found in *Branchiostoma*.

As described earlier, the tongue bars and septa are supported internally by a chitinous skeleton forming M-shaped rods. A septum contains the middle arm of an M-rod which is bifurcated at its lower free end. The lateral arms of M-rod lie in adjacent tongue bars so that each bar contains two arms of two adjacent skeletal rods. The gill-slits are richly lined by cilia, called lateral *cilia*.

2. Branchial sacs. Gill-slits do not open directly to outside. Each gill-slit opens into a gill pouch called *branchial sac*, which lies between the bodywall and the pharynx. Each branchial sac in turn opens to the exterior by a small, independent *gill pore*. However, in one species (*B. misakiensis*) the first four pouches become united to open by a common gill pore to outside. The collar coelom also communicates with the common branchial sac of its side through a *collar canal*. The gill-pores are visible externally in two longitudinal rows one on each side of the mid-dorsal ridge in the branchiogenital region of the trunk.

Mechanism of respiration. The lateral cilia lining the gill-slits set up a food-cum-respiratory current of water. It enters the pharynx through mouth, then passes through gill-slits into the branchial sacs and finally leaves through the gill pores. The tongue bars are richly vascular and participate in gaseous exchange. The blood of their capillary networks takes up the oxygen dissolved in water and returns carbon dioxide to it.

Blood Vascular System

The blood vascular system of *Balanoglossus* is of the *open* or *lacunar type*. It consists of : (i) a colourless *blood*, (ii) a *central sinus* and a *heart vesicle*, (iii) distributing vessels or *arteries* and *sinuses*, and (iv) collecting vessels or *veins*.

1. Blood. The blood is a colourless fluid containing few white corpuscles which are possibly detached endothelial cells. A respiratory pigment is probably absent. The functioning of the circulatory system is not properly understood.

2. Central sinus and heart vesicle. The central sinus is a small elongated non-contractile sinus situated in the proboscis just above the buccal diverticulum. Just above it is a closed triangular *cardiac sac* or *heart vesicle*. Its ventral wall is muscular and contracts rythmically thereby producing pulsations in the central sinus that help in the circulation of blood. The central sinus receives blood from collecting vessels that open into its posterior end. Anteriorly, it pumps its blood into several *afferent vessels* which form a plexus in the *proboscis gland* or *glomerulus*, lying

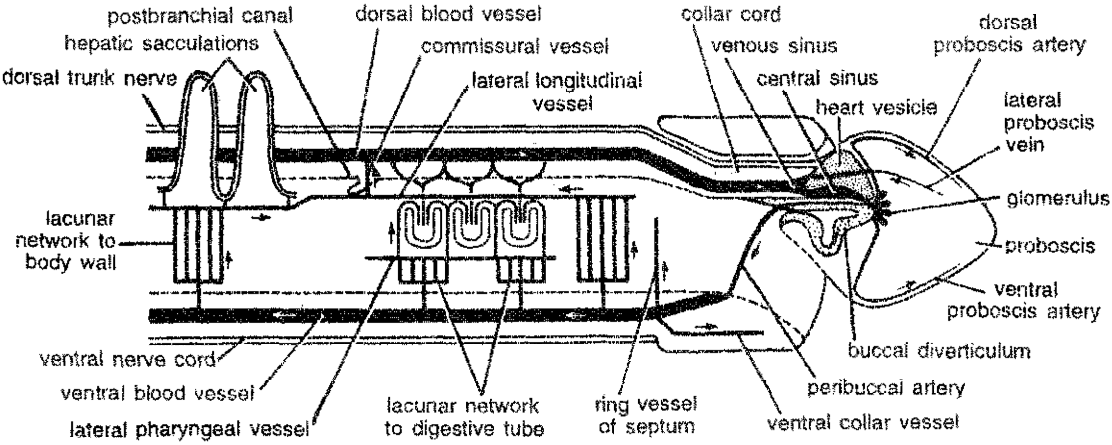


Fig. 16. *Balanoglossus*. Blood-vascular system in anterior end in lateral view.

in front of it. In glomerulus the blood gets rid of its excret_ry wastes.

3. Distributing vessels or arteries. Blood from the glomerulus is carried away by four arteries. Of these two arteries, a *mid-dorsal proboscis artery* and a *mid-ventral proboscis artery*, supply the proboscis. The other two, called *efferent glomerular arteries*, run backward along the two sides of buccal diverticulum, encircle the buccal tube as *peribuccal vessels* (which are actually of the nature of blood plexuses) and unite in a single longitudinal *ventral vessel* that runs up to the posterior end of the body through the ventral mesentery. On its way, the ventral vessel gives out a *ventral collar vessel* to the collar, a *ring vessel* to the collar-trunk septum and an *afferent branchial artery* to each gill septum in which it bifurcates to supply two adjacent tongue bars. All these branches break up into a system of sinuses in their respective structures. All along its length, the ventral vessel also supplies the body wall and gut wall by an elaborate network of sinuses. The ventral vessel has muscular contractile walls and the blood in it flows backwards.

4. Collecting vessels or veins. Blood from body wall, gut wall and branchial apparatus (*efferent branchial vessels*) is collected by a single median *dorsal vessel* which runs through the dorsal mesentery, from posterior end upto the collar. It has muscular and contractile walls and the blood flows in it forwards. At the anterior end

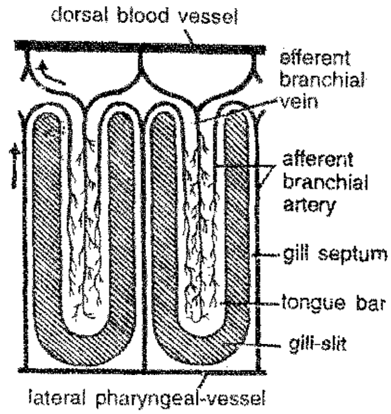


Fig. 17. *Balanoglossus*. Lymph sinusoids in a portion of the branchial wall.

of collar, the dorsal vessel dilates a little to form a *venous sinus*. The latter receives a lateral *proboscis vein* from each side of proboscis and then opens into the central sinus.

Excretory System

The excretory organ is *glomerulus* or *proboscis gland* lying in front of the central sinus and projecting into the proboscis coelom. It is made up of several blind tubular projections formed by the peritoneum covering the buccal diverticulum, central sinus and heart vesicle. The tubular projections contain blood confluent with that of central sinus. The excretory peritoneal cells of glomerulus contain yellow or brown granules, probably of excretory substances. From glomerulus the excretory substances pass on into the proboscis coelom and finally to the exterior through the proboscis pore.

Nervous System

The nervous system is of primitive type resembling that of coelenterates and echinoderms. Throughout the body a plexus or layer of nerve cells and nerve fibres lies just below the epidermis. Nerve fibres are traversed by the filamentous basal portions of epidermal cells, and form synapses with the processes of nerve cells. Nervous layer is thickened along definite strands to form two main *nerve cords*, one *mid-dorsal* and other *mid-ventral,* which runs along the entire length of the trunk. *Ventral cord* extends upto collar-trunk septum where it is connected with the dorsal cord by a circular strand, called *circumenteric nerve ring*. *Dorsal cord* extends anteriorly upto the base of proboscis where it is connected with another circular strand called *anterior nerve ring*. In collar region, dorsal cord leaves the epidermis and traverses the collar coelom as *collar cord*. It is supposed to be the nervous centre of the animal. But unlike brain, it has no concentration of nerve cells and also does not give out nerves. However, it contains some giant nerve cells which help in transportation of impulses over the body and in reflexes. The collar cord contains a cavity called *neurocoel.*

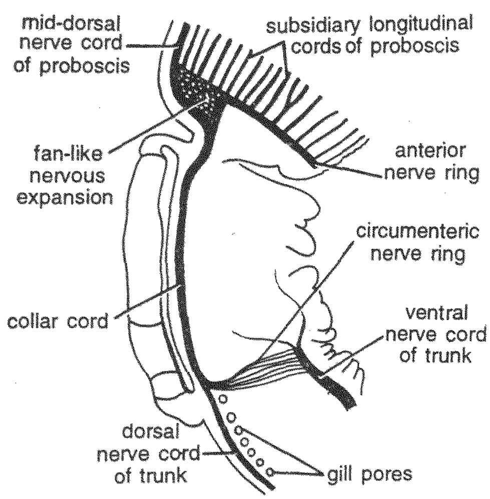


Fig. 18. *Balanoglossus.* Nerve cords in the anterior region of the body.

Sense organs of *Balanoglossus* are simple and comprise : (i) *neuro-sensory cells* in the epidermis of proboscis and anterior part of collar, sensitive to touch and light; and (ii) *preoral ciliary organ* situated ventrally at the base of proboscis, which is a chaemoreceptor.

Reproductive System

Asexual reproduction. Asexual reproduction is rare in enteropneusts. Gilchrist (1923) has described it in one species, *B. capensis*, which lacks hepatic caeca. During summer the young worms (juveniles) cut off small pieces from tail end, each regenerating into a complete sexual adult in winter.

Regeneration. *Balanoglossus* shows great power of regeneration. Proboscis, collar and isolated pieces from trunk can regenerate the lost parts of the body completely.

Sexual reproduction. Sexes are separate. Males and females cannot be identified externally except for the difference in colour of the ripe gonads in the living specimens. *Testes* of male and *ovaries* of female are similar. They are sac-like bodies occurring in several longitudinal rows in the genital wings, on either side of the alimentary canal. Each gonad has a narrow neck or ductule that opens out through a *gonopore*. All gonopores are situated outer to the gill pores. Ova are small with poor yolk content.

Development

Development of *Balanoglossus* is described in chapter 42 in the section 'Vertebrate Embryology'.

Affinities and Systematic Position of *Balanoglossus* (Hemichordata)

The group *Enteropneusta*, to which *Balanoglossus* belongs, was established by Gegenbaur in 1870. Bateson (1885) proposed the name Hemichordata in place of Enteropneusta. Since then, due to their peculiar anatomical organisation and embryology, the Hemichordata (or *Balanoglossus*) have been considered closer to the Chordata as well as most non-chordate phyla by different workers from time to time. Some of these views regarding the phylogenetic relationship (affinities) and taxonomic position of the hemichordates are summarized below.

[I] Affinities with Chordata

Some earlier workers, such as William Bateson (1885), proposed closer affinities between Hemichordata and Chordata. Their resemblance was based on the presence of the three fundamental chordate characteristics in Hemichordata, that is, (i) a notochord, (ii) a dorsal hollow nerve cord and (iii) the pharyngeal gill-slits (pharyngotremy).

Affinities with Urochordata. Hemichordates are nearest to Urochordata, as they exhibit many close resemblances with them. The structure and function of pharynx and branchial apparatus in hemichordates are similar to those of urochordates. Also, the development of the central part of nervous system is quite similar in both.

Affinities with Cephalochordata. Besides similarities in the structure and function of the branchial apparatus, the hemichordates also show similarity with cephalochordates in the arrangement of coelomic sacs and in development.

Due to these similarities Hemichordata had been considered as a subphylum of the phylum Chordata till recently, representing its lowest group, and probably having a common ancestry.

Objection. However, the hemichordates are no longer included under chordates because they do not possess chordate characters in a typical condition. The main objections are :

(1) A true notochord does not occur in hemichordates. Unlike that of the chordates, the so-called 'notochord' is very short, confined to proboscis and without any supporting function. It is ventral to the main (dorsal) blood vessel and not covered by sheaths. Instead of being solid and made of vacuolated cells, it is hollow and lined by epithelial cells. It does not originate from the roof of larval archenteron but as a forward hollow projection of the foregut. Instead of being called notochord (Bateson, 1885) it is now termed the *stomochord* (Willy, 1899). Hyman prefers to name it as *buccal diverticulum*.

(2) The nervous system is distinctly of the invertebrate type being intra-epidermal in position and having a ventral nerve cord and a circumenteric nerve ring which are absent in chordates. In *Balanoglossus*, the dorsal tubular nerve cord is confined to the collar region only.

(3) Gill-slits of *Balanoglossus* are numerous and dorsal in position, whereas they are 5 to 7 and lateral in higher chordates.

Other differences. The hemichordates further differ from the chordates in :

(1) Lacking metameric segmentation, cephalization, paired appendages, postanal tail, exoskeleton, living endoskeleton, dermis, liver, haemoglobin, red blood corpuscles, etc.

(2) Having peculiar division of body and coelom (into proboscis, collar and trunk), single-layered ciliated epidermis, hepatic caeca, dorsal heart, open neurocoel, colourless blood, numerous gonads, etc.

[II] Affinities with Rhynchocephalia (Nemertinea)

Feeding and burrowing habits are similar in *Balanoglossus* and Nemertinea. Body in both is elongated, vermiform, without external metamerism, with terminal anus, with smooth skin containing unicellular glands and ectodermal nerve plexus, and having metamerically arranged simple gonads. But Nemertinea differ in lacking a dorsal nerve cord and in having lateral nerve cords and a protrusible proboscis.

[III] Affinities with Phoronida

Some zoologists like A.T. Masterman (1897) advocated relationship of *Balanoglossus* with *Phoronis* on the following grounds :

(1) Similar nature of epidermal nervous system.

(2) The paired gastric diverticula of *Phoronis*,

like the *buccal diverticulum* of *Balanoglossus*, forming so-called notochord.

(3) Actinotroch larva of *Phoronis* has several enteropneust features of tornaria such as similar disposition of coelom, anus surrounded by a ciliary ring, presence of a proboscis pore and a sensory apical plate with cilia and eye spots.

(4) Both have great power of regeneration.

Objection. But, the chordate features of *Balanoglossus* like pharyngeal gills, are absent in *Phoronis* which also differs in having paired metanephridia. Moreover, Selys-Long Champ's (1940) account of development of *Phoronis* does not coroborate Masterman's observations, so that relationships of these two groups are rejected.

[IV] Affinities with Pogonophora

Marcus (1958) tried to relate Hemichordata with Pogonophora due to following similarities :

(1) Enterocoelous formation of coelom.
(2) Body and coelom divided into three regions.
(3) Mesosome and metasome separated by a septum.
(4) Nervous system intra-epidermal.
(5) Pericardial sac in some pogonophores.
(6) Gonads found in trunk.

Objection. But pogonophores differ in having protocoelic nephridial coelomoducts and lacking an alimentary canal. Moreover, nervous system is concentrated in protosome in Pogonophora, but in mesosome in Hemichordata.

[V] Affinities with Annelida

Spengel (1893) first suggested affinities of Annelida and Hemichordata as follows :

(1) Body vermiform and coelomate.
(2) Burrowing habit, tubicolous life and ingesting mud which is passed out as castings through anus.
(3) Collar of *Balanoglossus* similar to *clitellum* of earthworm.
(4) Proboscis and prostomium similar and preoral.
(5) Similar arrangement of blood vessels with blood flowing anteriorly in dorsal vessel and posteriorly in ventral vessel.
(6) Dorsal position of heart.
(7) Tornaria larva of *Balanoglossus* shows several structural resemblances with the trochophore larva of Annelida in being pelagic, ciliated, with apical plate, eye spots, sensory cilia and well developed alimentary canal with similar parts.

Objection. However, the two groups show striking differences as follows :

(1) Annelids do not have pharyngeal gill-slits, stomochord or buccal diverticulum and dorsal tubular nerve cord found in *Balanoglossus*.
(2) *Balanoglossus* does not have double and solid ventral nerve cords and nephridia found in annelids.
(3) In tornaria larva of *Balanoglossus*, preoral or proboscis coelom is present, nephridia are absent and blastopore becomes anus of the adult (Deuterostomia). In trochophore larva of annelids, preoral coelom is absent, nephridia present and the blastopore becomes the mouth (Proterostomia).

Thus, compared to their great fundamental differences, the similarities of the two groups are only superficial and quite insignificant indicating probably a convergent evolution due to similar habits and habitat.

[VI] Affinities with Echinodermata

Adult resemblances. Adult hemichordates and echinoderms are structurally quite different and it is difficult to suspect any phylogenetic relationship between them. They show few resemblances such as :

(1) Enterocoelic origin of coelom and its division into three successive parts filled with sea water to serve a hydraulic mechanism.
(2) Heart vesicle and glomerulus of enteropneusts are considered homologous to the dorsal sac and axial gland of echinoderms. Both the structures are related and combine vascular and excretory functions.
(3) Nervous system is poorly developed and forms epidermal nerve plexus.
(4) Proteins and phosphagens present in hemichordates closely resemble those of echinoderms.

(5) Common habits and ecological niches and remarkable power of regeneration.

Larval resemblances. The two groups show a strong affinity on embryological ground as the tornaria larva of *Balanoglossus* has a striking structural similarity with an echinoderm larva, in particular the bipinnaria larva of asteroids. In fact, the tornaria was regarded an echinoderm larva for a long time by Johannes Muller (1850), Krohn (1854), Agassiz (1864), etc., till Metschnikoff (1870) proved it to be an enteropneust larva. The larvae of the two groups possess the following common features :

(1) Small, pelagic, transparent and oval.
(2) Identical ciliated bands taking up a similar twisted course.
(3) Enterocoelic origin and similar development of coelom.
(4) Proboscis coelom opening to outside by proboscis pore of tornaria comparable to hydrocoel of echinoderm dipleurula.
(5) Bastopore becomes the anus (Deuterostomia) and digestive tract is complete with mouth, anus and same parts.

Objection. However, the tornaria larva shows presence of apical plate with sensory hairs and eye spots and telotroch which are absent in echinoderm larvae. The protocoel is single in tornaria but paired in echinoderm larva. This raises doubts about the echinoderm affinities of hemichordates. Fell (1963) and others believe that their larval similarities are only because of convergent evolution due to same mode of habits and habitat.

[VII] Systematic position and phylogeny

The peculiar anatomical organisation of *Balanoglossus* or hemichordates makes their systematic position uncertain and controversial. The earlier workers (Bateson, 1885) placed them as a *subphylum* under the phylum Chordata representing its lowest group. But the only chordate feature shown by them is the presence of pharyngeal gill-slits. Therefore, some recent workers like Van der Host (1939), Dawydoff (1948), Marcus (1958) and Hyman (1959) have chosen to remove hemichordates from the phylum Chordata and treat them as an *independent invertebrate phylum*. Since the group comprises only about 80 species, it is included in the category of a *minor phylum*.

The name Hemichordata (Gr., *hemi*, half; *chorde*, cord) means they are 'half' or 'part' chordates, a fact that is undisputed. Therefore, in the present work, Hemichordata has been retained as a subphylum of Chordata to avoid any controversy.

Regarding phylogeny, the close affinities of Echinodermata, Phoronida, Pogonophora, Hemichordata and Chordata have led to the conclusion that they have arisen from a common ancestral stock, probably the dipleurula larva (Bather, 1900). But Berril (1955), Whitear (1957), Carter (1958), Marcus (1958), Hyman (1959), Bone (1960) and many others do not contribute to this view. But still the question that whether *Balanoglossus* should be treated as the 'forerunner' of chordates or not, remains unanswered. In this regard, it may be pointed out that the initiation of the appearance of some chordate characters may apparently give the hemichordates the credit of being a 'forerunner' of the chordates. But still, the absence of notochord, dorsal position of pharyngeal gill slits, external food collection, lack of distinct dorsal tubular nerve chord and many other chordate characters justify that it does not stand on the direct line of chordate evolution. Barrington (1965) has interpreted their views based on the deuterostome line of chordate evolution. According to his explanation, the Echinodermata deviated greatly from the ancestral stock and formed a blind branch. Hemichordata also did not stand on the direct line of ancestry but formed a divergent offshoot from the main line of chordate evolution. Thus, it may be suggested that *Balanoglossus* and other chordates are running on the same field but not on the same track. Since the hemichordates arose from the ancestral line after the divergence of the ancient Echinodermata but before the rise of the true chordates, they are often called the *prechordates*.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the general organization of hemichordates.
2. Give an account of digestive system of *Balanoglossus*.
3. Discuss the affinities and phylogeny of Hemichordata.

» *Short Answer Type Questions*

1. Describe the ecology of *Balanoglossus*.
2. Describe the respiratory system of *Balanoglossus*.
3. Describe the blood vascular system of *Balanoglossus*.
4. Write short notes on — (i) External morphology of *Balanoglossus*, (ii) Body wall of *Balanoglossus*, (iii) Coelom of *Balanoglossus*, (iv) Endoskeleton of *Balanoglossus*.
5. Draw neat and well-labelled diagrams of *Balanoglossus*
   (i) M.L.S. of anterior end, (ii) T.S. proboscis, (iii) T.S. collar region, (iv) T.S. branchio-genital region.

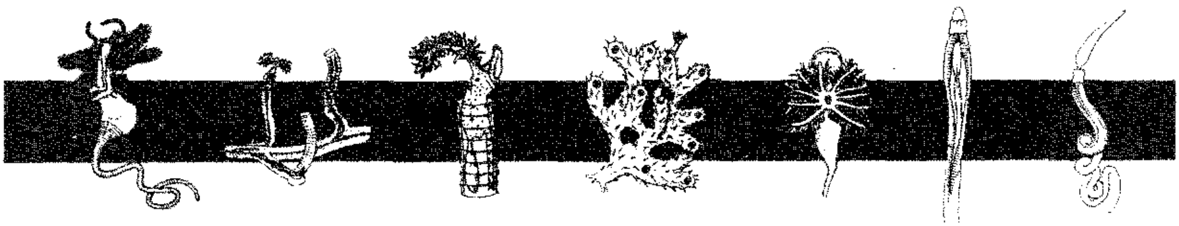
» *Multiple Choice Questions*

1. *Balanoglossus* belongs to the group :
   (a) Platyhelminthes (b) Annelida
   (c) Cephalochordata (d) Hemichordata
2. *Balanoglossus* is commonly known as :
   (a) Snake worm (b) Acorn worm
   (c) Corn worm (d) Earth worm
3. Which of the following is not a protective device of *Balanoglossus* :
   (a) Secretion of foul smelling odour similar to iodoform.
   (b) Phosphorescence
   (c) Lining of burrow with sand mixed with mucous
   (d) None of the above
4. Larval form of hemichordates is :
   (a) Tornaria (b) Crinoidia (c) Nauplius (d) Caterpillar
5. Advanced chordates originated from :
   (a) *Amphioxus* (b) *Tachoglossus*
   (c) *Balanoglossus* (d) Starfish
6. Musculature in *Balanoglossus* in :
   (a) Smooth (b) Cardiac (c) Striated (d) Transverse
7. Which of the following organism is a link between chordates and non-chordates :
   (a) *Herdmania* (b) *Balanoglossus*
   (c) *Amphioxus* (d) *Pheretema*
8. In one of the following notochord is limited to proboscis :
   (a) Hemichordata (b) Urochordata
   (c) Cephalochordata (d) Mammalia
9. Hemichordates have one chordate feature in its typical form :
   (a) Perforated pharynx (b) Buccal diverticulum
   (c) Three types of coelom (d) Ciliated integument
10. Hemichordates do not resemble chordates with respect to :
    (a) Notochord
    (b) Absence of dorsal tubular nerve
    (c) Presence of pharyngeal gill cleft
    (d) None of the above
11. Coelom in *Balanoglossus* is :
    (a) Schizocoel (b) Enterocoel
    (c) Holocentric (d) Metacentric
12. The term stomochord in *Balanoglossus* refers to :
    (a) Nuchal skeleton (b) Branchial skeleton
    (c) Buccal diverticulum (d) Pygochord
13. *Balanoglossus* is :
    (a) Surface feeder (b) Bottom feeder
    (c) Column feeder (d) Ciliary feeder
14. Which of the following is true for blood vascular system of *Balanoglossus* :
    (a) Closed (b) Absence of central sinus
    (c) Blood is colourless (d) Arteries and veins are absent

ANSWERS

1. (d) 2. (b) 3. (d) 4. (a) 5. (c) 6. (a) 7. (b) 8. (a) 9. (a) 10. (a) 11. (b) 12. (c) 13. (d) 14. (c).

3



Subphylum I. Hemichordata

General Characters

1. Exclusively marine, solitary or colonial, mostly tubicolous.
2. Body soft, fragile, vermiform, unsegmented, bilaterally symmetrical and triploblastic.
3. Body typically divided into 3 distinct regions : proboscis, collar and trunk.
4. Body wall of a single layered, epidermis with mucous glands. No dermis.
5. Coelom enterocoelous, usually divided into protocoel, mesocoel and metacoel, corresponding to 3 body regions.
6. Digestive tube complete, straight or U-shaped.
7. Foregut gives out a hollow buccal diverticulum into proboscis, earlier considered as 'notochord'.
8. Dorso-lateral pharyngeal gill slits, when present, one to several pairs. Ciliary filter feeders.
9. Circulatory system simple and open, including a dorsal heart and two longitudinal vessels, one dorsal and one ventral.
10. Excretion by a single proboscis gland or glomerulus connected to blood vessels.
11. Nervous system primitive consisting mainly of a subepidermal nerve plexus. Dorsal collar nerve cord hollow.
12. Reproduction mainly sexual. Sexes usually separate. Gonads one to several pairs.
13. Fertilization external, in sea water. Development direct or indirect with a free-swimming tornaria larva.

Classification

Hemichordata includes about 80 known species which are generally grouped under two classes, *Enteropneusta* and *Pterobranchia*. Besides, two more classes are included by some, as below.

Class 1. Enteropneusta
(Gr. *enteron*, gut + *pneustos*, breathed)

1. Solitary, free-swimming or burrowing animals, commonly called the 'acorn' or 'tongue worms'.
2. Body elongated, vermiform, with no stalk.
3. Proboscis cylindrical and tapering.
4. Collar without ciliated arms (lophophore).
5. Alimentary canal straight. Mouth and anus at opposite ends. Filter feeding.
6. Several pairs of U-shaped gill-slits.
7. Sexes separate. Gonads numerous, sac like.
8. Development includes tornaria larva in some. Asexual reproduction lacking.

Examples : *Balanoglossus*, *Saccoglossus* (= *Dolichoglossus*), *Protoglossus*, *Ptychodera*, *Spengelia*.

Class 2. Pterobranchia
(Gr. *pteron*, feather + *branchion*, gill)

1. Solitary or colonial, sessile and tubicolous animals living inside secreted chitinous tubes.
2. Body short, compact, with stalk for attachment.
3. Proboscis shield like.
4. Collar bearing ciliated arms (lophophore).
5. Alimentary canal U-shaped. Anus dorsal lying near mouth. Ciliary feeding.
6. Gill slits one pair or absent, never U-shaped.
7. Sexes separate or united. Gonads 1 or 1 pair.
8. Development direct or with a larval stage. Asexual reproduction by budding in some.

Order 1. Rhabdopleurida

1. Colonial, zooids connected by a stolon.
2. Collar with two tentaculated arms.
3. Gill-slits absent.
4. Gonad single.

Example : Single genus *Rhabdopleura*.

Order 2. Cephalodiscida

1. Solitary or several zooids living unconnected in a common gelatinous case.
2. Collar with several tentaculated arms.
3. Gill slits single pair.
4. Gonads single pair.

Examples : *Cephalodiscus*, *Atubaria*.

Class 3. Planctosphaeroidea

This class is represented by a few small, rounded, transparent and pelagic larvae, supposed to be specialized tornaria of some unknown hemichordate termed *Planctosphaera pelagica*. The larval body is covered by extensively branched ciliary bands and its alimentary canal is L-shaped.

Class 4. Graptolita

The fossil graptolites (e.g. *Dendrograptus*) were abundant in Ordovician and Silurian periods and often placed as an extinct class under Hemichordata. Their tubular chitinous skeleton and colonial habits show an affinity with *Rhabdopleura*.

Other Hemichordates

1. *Saccoglossus* (= *Dolichoglossus*). It is a typical enteropneust genus very much similar to *Balanoglossus* in habitat, habits and structure. It is a marine, slender, soft-bodied tubicolous tongue worm living in spirally twisted burrows. Body has the usual three divisions-proboscis, collar and trunk. Proboscis is exceptionally longer and pointed than in other tongue worms. The posterior rim of collar hangs like operculum over the anterior end of trunk covering first 3 or 4 pairs of gill pores. Genital wings and hepatic caeca, so well-developed in *Balanoglossus*, are absent. Mature gonads are yellow in male and grey in female and their position marked externally by dorsolateral genital folds in the middle part of the trunk. Synapticula are not present so that tongue bars hang freely in their gill-slits. Development is direct without a free-swimming tornaria larva. It occurs almost universally. *Saccoglossus pygmaeus*, measuring 2 to 3 cm in length, represents the smallest known species of Enteropneusta (Fig. 1A)

2. *Ptychodera*. This genus also bears a close resemblance to *Balanoglossus*, ecologically as well as morphologically and embryologically. Its proboscis and collar are somewhat shorter, but the trunk possesses conspicuous genital wings and hepatic sacculations. Development is indirect involving a free-swimming tornaria larva (Fig. 1B).

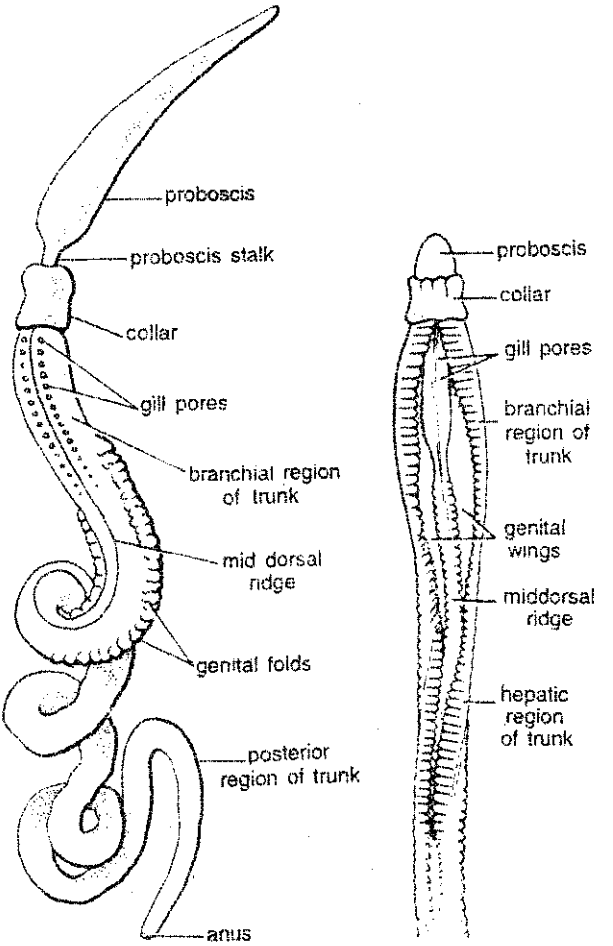


Fig. 1. A—*Saccoglossus*. B—*Ptychodera*.

3. ***Rhabdopleura.*** It is a marine, sedentary and colonial pterobranch mainly found in the North Atlantic. The colony consists of horizontal branching gelatinous tubes, forming the *coenoecium*, which remain attached on hard substratum such as stones, corals, mollusc shells, sponges, etc. Erect tubes, about 6-7 mm in height, arise at short intervals, each housing an individual or zooid of the colony. The tubes are ringed, membranous and secreted by the zooids. A zooid is minute, hardly 1 mm long and occupies the distal part of the tube. Proboscis is disc-shaped. Collar bears a pair of hollow elongated arms beset with numerous fine ciliated tentacles for food collection. Alimentary canal is U-shaped so that anus lies near mouth. Gill-clefts and glomerulus are absent. Sexes are separate but a colony has both male and female individuals. A single gonad is present on the right side of the trunk. Basally the trunk of each zooid is attached by a long contractile muscular *stalk* to a common cord of living substance, called *black stolon* or *pectocaulus*, running inside the horizontal tubes. The stalks can quickly contract spirally so as to withdraw the zooids into coenoecium for protection. The black stolon also forms new individuals asexually by budding (Figs. 2A & B).

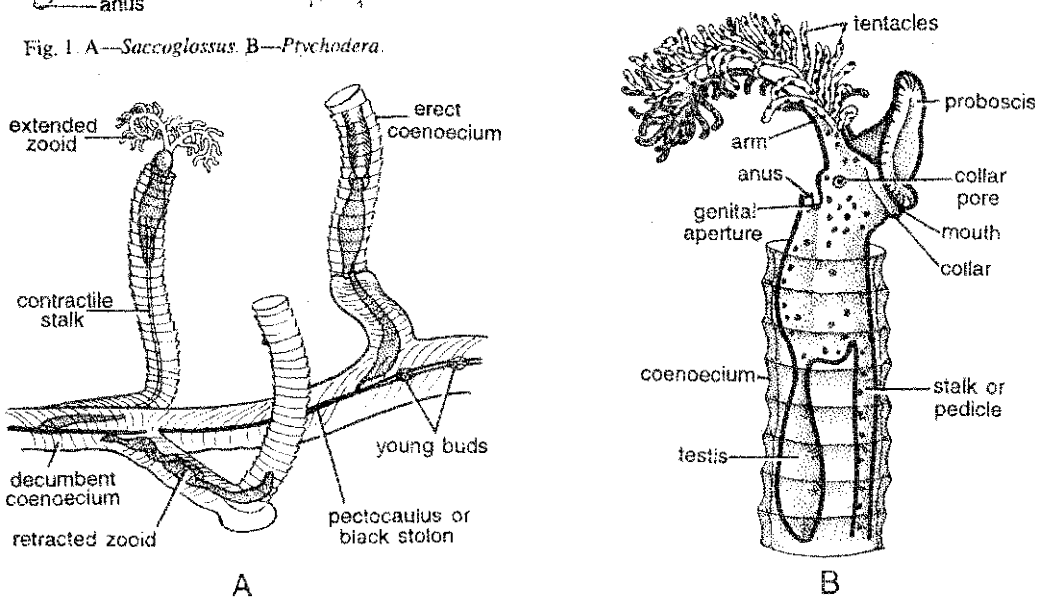


Fig. 2. *Rhabdopleura*. A—A portion of colony. B—An individual zooid.

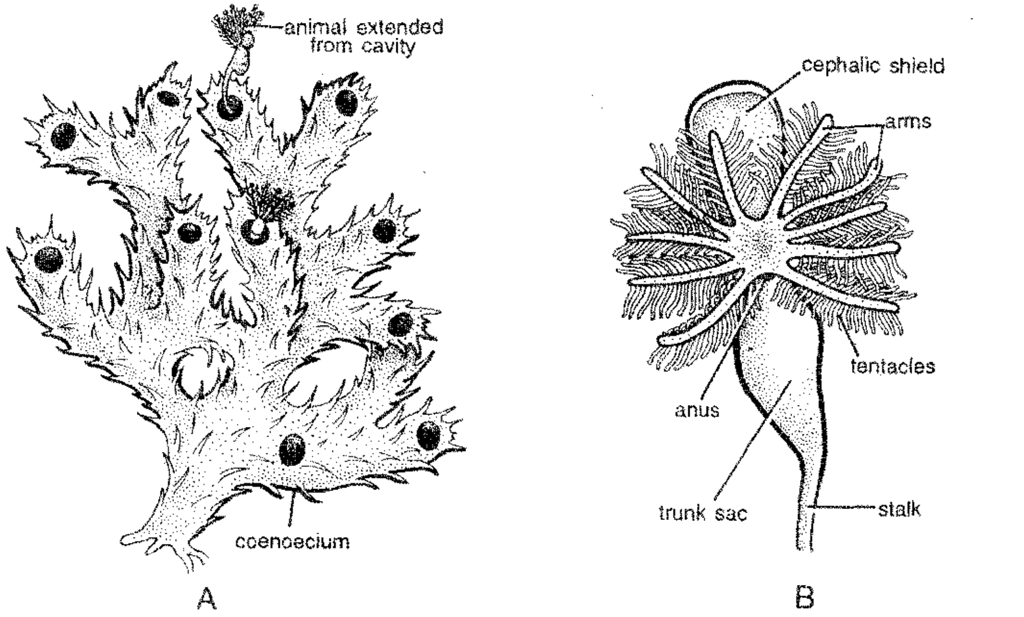


Fig. 3. *Cephalodiscus*. A—A part of colony. B—An individual zooid.

4. *Cephalodiscus*. It is a sedentary and gregarious pterobranch found mainly in the seas of Southern Hemisphere at depths of 50 to 650 m. Several zooids live in separate upright gelatinious tubes secreted by them and embedded in a common matrix called *coenoecium*, fixed permanently to substratum. Foreign materials such as sand grains, sponge spicules, molluscan shells, etc. also adhere to the coenoecium. The zooids remain unconnected organically and thus do not constitute a true colony. Each zooid is 2 to 3 mm long and has the usual three body divisions-proboscis, collar and trunk. Proboscis is shield-shaped, overhanging the mouth. Its cavity, the proboscis coelom, opens out through two proboscis pores. The collar bears 8-16 hollow arms (lophophore), which in female are beset with numerous fine, pinnately arranged and heavily ciliated tentacles used for food capture. The tips of tentacles bear glandular knobs. The trunk is short and plump, bearing a single pair of gill-slits without skeletal support. Aliminatary canal is U-shaped, with ventral mouth and dorsal anus located at the distal end. A narrow elongated contractile stalk arising from the aboral end attaches the zooid to its tube. Sexes are separate, gonads single pair and development direct. Asexual reproduction also takes place by buds arising from stalk and soon becoming free.

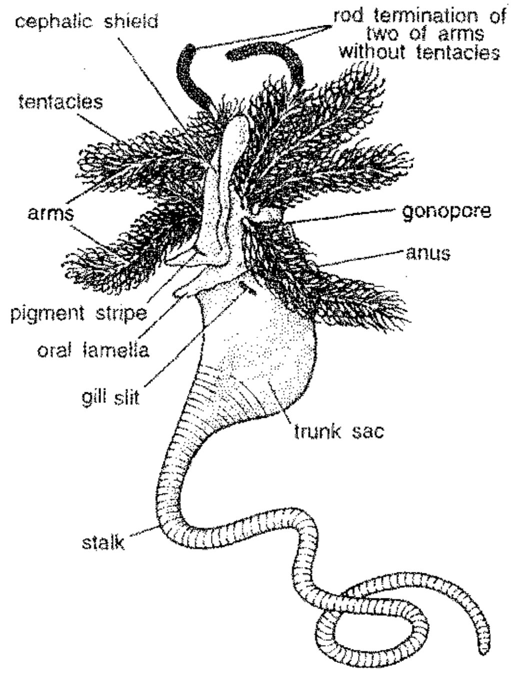


Fig. 4. *Atubaria*.

5. *Atubaria*. Sato first described *Atubaria* in 1936. It is a sedentary and solitary pterobranch genus clinging to hydroid colonies by its long stalk and closely resembling with *Cephalodiscus*. A coenoecium is lacking. The zooid measures 1-5 mm in length with usual three divisions of the body. The collar carries four pairs of tentaculated arms of which second pair distally has rod-like terminations devoid of tentacles. One pair of pharyngeal gill-slits are present.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give characters and classification of phylum Hemichordata upto orders.

» *Short Answer Type Questions*

1. Write short notes on—(i) *Balanoglossus*. (ii) *Cephalodiscus*. (iii) *Rhabdopleura*.

» *Multiple Choice Questions*

1. In hemichordates body is typically divided into :
   (a) Head, neck and trunk (b) Head, trunk and tail
   (c) Probosis, collar and trunk (d) Probosis, collar and tail
2. Body in hemichordates is :
   (a) Segmented (b) Radially symmetrical
   (c) Diploblastic (d) Triploblastic
3. Notochord in hemichordates is actually :
   (a) Buccal diverticulum (b) True notochord
   (c) Derivative of nerve chord (d) Fore gut
4. Hemichordates are :
   (a) Filter feeders (b) Ciliary filter feeders
   (c) Ciliary feeders (d) Bottom feeders
5. Circulatory system in hemichordates :
   (a) A dorsal heart, one dorsal and one ventral blood vessels
   (b) A ventral heart, one dorsal and two ventral blood vessels
   (c) A dorsal heart, one dorsal, one lateral and one ventral blood vessels
   (d) A lateral heart, one dorsal and one ventral blood vessels
6. Excretion in hemichordates takes place by :
   (a) Mesonephron (b) Glomerulus
   (c) Metanephron (d) Pronephron
7. Nervous system in hemichordates consists mainly of :
   (a) Sub dermal nerves (b) Sub epidermal nerve plexus
   (c) Sub epidermal nerve cord (d) Sub cutaneous nerves
8. Reproduction in hemichordates in mainly :
   (a) Asexual (b) By budding (c) Sexual (d) Regeneration
9. Coelom in hemichordates is divided into :
   (a) Ectocoel, mesocoel and endocoel
   (b) Protocoel, metacoel and endocoel
   (c) Ectocoel, mesocoel and metacoel
   (d) Protocoel, mesocoel and metacoel
10. Body wall of hemichordates lacks :
    (a) Epidermis (b) Mucous glands
    (c) Mucous glands and dermis (d) Dermis
11. Hemichordates are :
    (a) Marine (b) Freshwater forms
    (c) Both marine and freshwater forms
    (d) Brackish water forms
12. Digestive tube in hemichordates is :
    (a) H shaped (b) Y shaped (c) V shaped (d) U shaped
13. Fertilization in hemichordates is :
    (a) Internal (b) External, in freshwater
    (c) External, in sea water (d) External
14. Genus *Rhabdopleura* is not characterized by :
    (a) Colonial forms (b) Collar with three tentacular arms
    (c) Absence of gill slits (d) Single gonad
15. Order Cephalodiscida has animal with :
    (a) Several zooids living unconnected in a common gelatinous case
    (b) Collar without tentaculated arms
    (c) Four pairs of gill slits
    (d) Three pairs of gonads
16. Class Planctosphaeroidea is represented by specialized larva with :
    (a) C shaped alimentary canal
    (b) J shaped alimentary canal
    (c) L shaped alimentary canal
    (d) T shaped alimentary canal

ANSWERS

1. (c) 2. (d) 3. (a) 4. (b) 5. (a) 6. (b) 7. (b) 8. (c) 9. (d) 10. (d) 11. (a) 12. (d) 13. (c) 14. (b) 15. (a) 16. (c).

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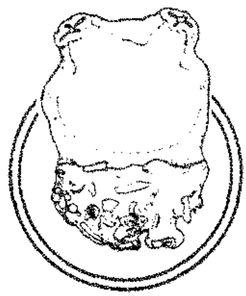

Type 2. *Herdmania* : A Sea Squirt

The members of the subphylum *Urochordata* or *Tunicata* are mostly sessile and exclusively marine animals inhabiting all seas universally from arctic to antarctic, and at all depths from littoral zone down to abyssal depths of over 5 Km. The genus *Herdmania* (= *Rhabdocynthia*) belongs to the class Ascidiacea popularly called the '*ascidians*' or '*sea squirts*'. The genus *Rhabdocynthia* was first established by Herdman in 1891. But, in 1910, Hartmeyer changed it to *Herdmania* according to the law of priority as it was originally proposed by Lahille in 1888. It is now prescribed for study in almost all the universities of India and neighbouring countries. The description that follows is based mainly on the work of S.M. Das on *Herdmania pallida* first published in 1936.

Systematic Position

Phylum	Chordata
Subphylum	Urochordata
Class	Ascidiacea
Subclass	Pleurogona
Order	Stolidobranchia
Family	Pyuridae
Type	*Herdmania* (Sea squirt)

Derivation of Names

The urochordates are characterized by the confinement of the 'notochord' and the nerve cord to the tail of their tadpole larva, hence the name *Urochordata* (Gr. *uros*, tail; *chorda*, cord). Urochordates are commonly called 'ascidians' since their general appearance is similar to 'askidian' the Greek name for a primitive wine sac made of goat's skin. The other name of the subphylum, i.e., *Tunicata* (L. *tunica*, outer covering), is due to a protective leathery case, called *tunic* or *test*, which surrounds the entire body of the degenerate adult. The ascidians, when disturbed, forcefully eject two jets of water from the two siphons by sudden contraction, hence the popular name '*sea squirts*'. In Tamilnadu, the fishermen refer to *Herdmania* or an ascidian as '*undapasi*' (*unda*, round; *pasi*, weed) meaning 'round weed', because its more or less oval body is covered by a green sea-alga. Another Tamil name given to it is '*mulaikanna*' (*mulai*, breast; *kanna*, teats) which signifies the two teat-like projecting siphons at the free end of the ascidian.

Geographical Distribution

Genus *Herdmania* is of world-wide occurrence, represented by 12 known species. Of these, only 4 species, found in Indian Ocean, are *H. pallida*, *H. mauritiana*, *H. ceylonica* and *H. ennurensis*. The first two are shallow coastal water species while the last two deep water species. Besides Indian Ocean, *H. pallida* is also distributed in the Pacific, Atlantic Oceans and Carribean Sea.

Habits and Habitat

Herdmania pallida is an exclusively marine and very common ascidian found in shallow waters all along the Indian sea coast. It is a solitary and sedentary ascidian, found attached to a rocky sea bottom by a broad *base* or embedded in the sandy floor by its extended *foot*. Often 10 to 12 individuals of various ages are seen attached in a group at one spot. Sometimes an individual becomes attached as a *commensal* to the shell of a living gastropod mollusc such as *Turbinella pyrum, T. rapa, Xancus*, etc. The mollusc carries about the sedentary ascidian, from place to place, providing it with better opportunities of food, oxygen and dispersal. In return, *Herdmania* conceals and protects the mollusc from enemies, being unpalatable on account of its spicules. A large number of organisms, such as lamellibranch, gastropod molluscs, diatoms, algae, hydroids, sea anemones, polyzoans, barnacles, flatworms, crustaceans, etc. inhabit the outer covering or test of *Herdmania*. A green sea algae commonly grows on the test or tunic so much that it may hide the ascidian completely. *Herdmania* is a *ciliary feeder*. It is a *microphagus* animal, feeding on microscopic plants and animals like diatoms, algae, infusorians, etc. The water current bringing food and oxygen enters the body through the branchial aperture and leaves through the atrial aperture carrying away undigested food, carbon dioxide, excretory wastes, and sex cells. *Herdmania* can suddenly contract its body to squirt water simultaneously or independently through its branchial and atrial apertures, hence the common name *'sea-squirt'*. *Herdmania* is hermaphrodite. Fertilization is external, taking place in the sea water, and development is indirect. From the egg, a free-swimming tadople larva hatches out. After a brief existence, the larva settles upon a substratum and undergoes retrogressive metamorphosis to become the degenerate sessile adult.

External Morphology

Shape, size and colouration. The body is laterally compressed and somewhat oblong or rectangular in shape with the attached end slightly narrower than the free end. The whole animal looks like a purse, bag or potato. An average adult measures about 9.5 cm long, 7 cm broad and 4 cm thick. The foot, when present, measures 3 to 4 cm long. The size, however, increases with age and some older individuals as large as $13 \times 8 \times 4.5$ cm have been recorded. Fresh specimens are pinkish in colour due to distribution of superficial blood capillaries in the test. It shows scattered bright red patches due to vascular ampullae, which is a characteristic feature of *Herdmania* (ascidians). Preserved specimens appear yellowish-brown colour (Fig. 1).

Division of body. The body is covered by the test and divisible into two parts : *body proper* and *foot*.

1. Body proper. The distal free part of the animal is *body proper*. It is broader and longer than the basal part or foot. The free end of the body proper is drawn into two short cylindrical projections called the *branchial* and *atrial siphons* or *funnels*. Both the siphons are situated at the same level. The *branchial* or *oral siphon* is smaller, about 1 cm long and directed outwards. It bears a terminal opening called the *branchial aperture* or *mouth* or *incurrent opening*. The *atrial* or *cloacal siphon* is larger, about 1.5 cm long and directed upwards. Its terminal opening is called the *atrial* aperture or *excurrent opening*. Each aperture is guarded by four distinct lobes or *lips* formed by the much elastic test. At the slightest disturbance, they contract and close the aperture. The margin of each aperture is marked by a bright red line when fully expanded. The branchial aperture is considerably wider in comparison to the atrial aperture, to allow better influx of water carrying food, oxygen, etc.

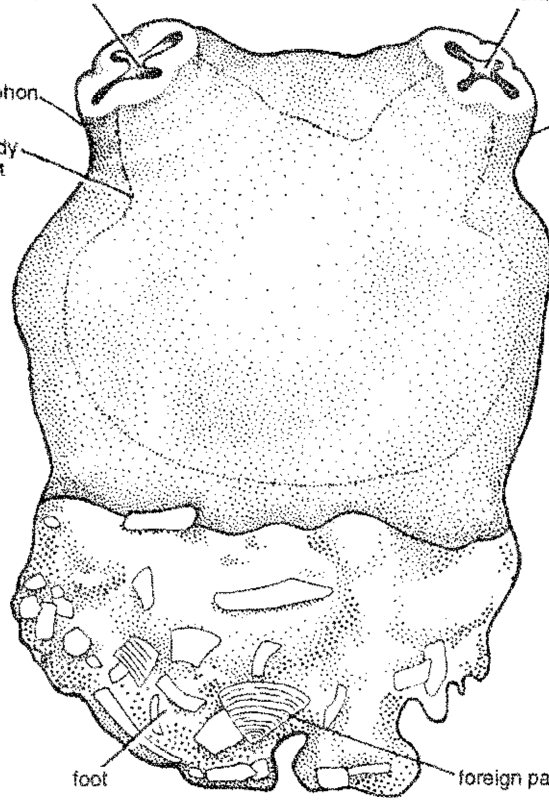

Fig. 1. *Herdmania*. External features in left view.

2. Foot. The foot is entirely made by the test or tunic. It is dirty in colour and rough due to sand particles, shell pieces and other foreign bodies attached to it. Its shape and size is variable. If the substratum is quite hard, such as a rock or a mollusc shell, the body proper becomes attached by forming a broad, flat or concave *base*, and the foot is absent. On a sandy bottom, the animal anchores its body by extending a foot which may be narrow, elongated, oval or irregular depending on the nature of substratum. A fully extended foot may attain a length of 3 to 4 cm. Besides attachment and anchorage, the foot acts as a balancer (being heavier than body) to keep the body erect when detached.

Orientation. The body of *Herdmania* has a definite but peculiar orientation. The two flat surfaces represent the *right* and *left lateral sides*. The *anterior* and *dorsal ends* are demarcated by the branchial and atrial apertures, respectively. Their opposite sides correspondingly represent the *posterior* and *ventral ends* which are partly free and partly attached. This unusual orientation is caused by the rotatory changes undergone by the larva during metamorphosis.

Test or Tunic

The test or tunic forms a protective jacket (covering) around the body and also acts as an accessory respiratory organ and a receptor organ. It is soft, 4-8 mm thick, leathery and transluscent. It is almost transparent in young stage but becomes opaque in the adult due to thickening. The test is wrinkled in appearance with a number of folds and depressions running all over the surface. It wears off continuously from the outer surface and replaced from inside by the epidermis of mantle which secretes it. The entire foot is made of test only. As already described, the test harbours a large number of organisms such as algae, hydroids, anemones, molluscs, barnacles and other nonascidians (Fig. 2).

The test cuts like soft cartilage and is composed of (i) a clear gelatinous matrix in which cells are embedded, (ii) corpuscles of various types, (iii) interlacing fibrils, (iv) branching blood vessels, and (v) calcareous spicules.

1. Matrix. The gelatinous matrix or ground substance is made of a poly-saccharide called tunicine* which is similar to plant cellulose, some proteins and minerals.

2. Corpuscles. The cells found in matrix are ...es...er...al in .rigin an. are .f 6 .r 7 .ifferent types : (i) *large eosinophilous* cells are spherical in shape and fewer in number. These cells stain bright red with eosin. (ii) small *amoeboid* cells are small cells, amoe oid in nature, without any constant shape. (iii) *small eosinophilous* cells possess an eccentric nucleus and are more numerous. (iv) spherical *vacuolated* cells are small in size, possessing vacuoles and nucleus is invisible. (v) *granular* receptor cells are probably sensory in function. These cells are less abundant and are surrounded by nerve fibers. (vi) small branched *nerve* cells are small and .ossess two to six long processes (dendrites). These cells are more numerous than the receptor cells. Nerve cells are supposed to play an important role in communication of the stimuli from the receptor cells to the other parts of the test. According to Das (1936), the sensitiveness of *Herdmania* is due to the presence of nerve cells in the test, and (vii) *squamous epithelial* cells (Fig. 3).

3. Interlacing fibrils. These from a fine network in the test. Some of them are like smooth muscle fibres, while others resemble nerve fibres.

4. Blood vessels. These form an anastomosing system in the test. Numerous branches near the

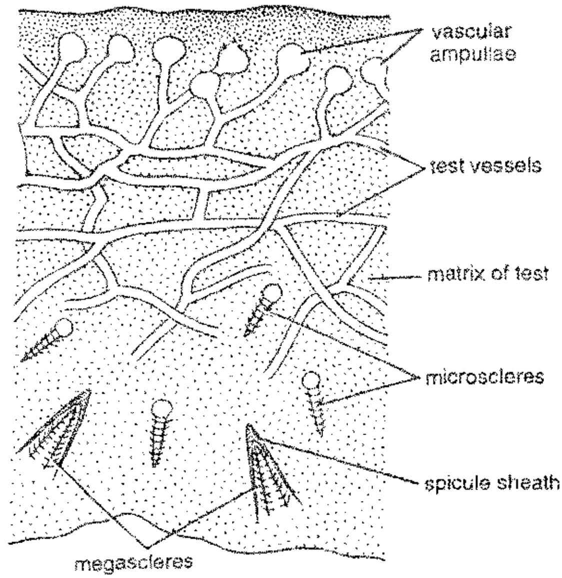

Fig. 2. *Herdmania*. V.S. test.

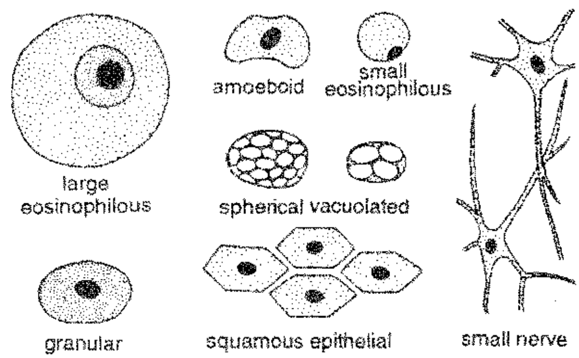

Fig. 3. *Herdmania*. Different types of cells found in test.

surface form oval or pear-shaped *terminal knobs* or *ampullae* responsible for red patches visible on the surface of test. The ampullae serve as accessory respiratory as well as receptor organs, being connected to nerve cells.

5. Spicules. *Herdmania* has large numbers of calcareous spicules of two types. All the spicules bear several equi-distant rings of minute spines all pointing in the same direction all along their length (Fig. 4).

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* Tunicine was supposed to be confined to the tunicates only. Preston (1960) by x-ray techniques has shown it to occur widely among vertebrates, even in human skin. It is composed of a carbohydrate, tunicin (chemically similar to cellulose), glycoprotein and minerals. It is secreted by epidermal cells.

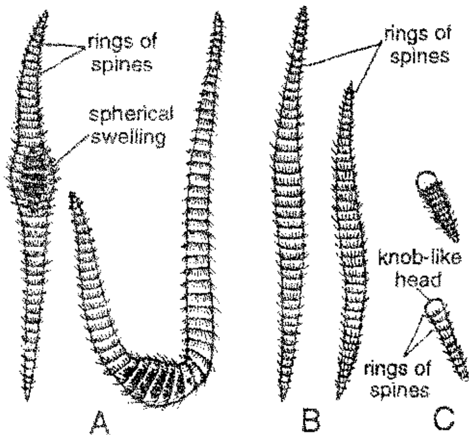

Fig. 4. *Herdmania*. Types of spicules. A — Pipette-shaped megascleres, B—spindle-shaped megascleres, C —Micro scleres.

(a) Megascleres. The large sized megascleres occur in all the parts of body except the heart. They are again of two varieties. (i) *Pipette-shaped* megascleres reach upto 3.5 mm in length. They may be straight or curved with pointed ends. Each has a large spherical swelling in the middle acquiring the characteristic pipette-like appearance. (ii) *Spindle-shaped* megascleres are only 1.5 to 2.5 mm long, more abundant and usually present in bundles. Equipped with 20-60 equally spaced rings of spines.

(b) Microscleres. These are very small in size, only 40 to 80μ long, and confined to the test only. Each resembles a paper pin having a rounded knob-like *head* and a tapering *body*. The body is beset with 5-20 equidistant rings of spines.

The spicules provide an internal rigid supporting framework like endoskeleton*, keep the mantle firmly fixed to the test, stiffen the walls of blood vessels to avoid their collapse, and ward off the predators.

Mantle or Bodywall

Beneath the test lies the *bodywall* or *mantle* which is visible on removal of the test which it secretes. The mantle is suspended inside the test and attached only at the branchial and atrial apertures forming the corresponding siphons. It is not developed uniformly throughout the body, being thick, highly muscular and opaque on the antero-dorsal side but thin, transparent and almost without muscles on the postero-ventral side where the internal organs (viscera) are quite visible through it. Mantle encloses a large water-filled cavity, the *atrium*.

Histologically, the mantle is composed of three cellular layers : outer epidermis, middle mesenchyme and inner epidermis.

1. Outer epidermis. The outer epidermis is made of single layer of flat, hexagonal cells. At the branchial and atrial apertures it is inturned to reach up to the base of the siphons and forming stomodaeum and proctodaeum, respectively. The outer epidermis secretes the test.

2. Mesenchyme. It lies below the outer epidermis and is derived from mesoderm. It consists of connective tissue fibres traversed by nerve fibres, muscle fibres and extensive blood sinuses. Muscle fibres are unstriated and arranged in three sets. *Annular muscles* surround each siphon in several circular rings. They cause the contraction of the siphon. The more numerous *longitudinal muscles* start from branchial and atrial apertures and radiate beneath annular muscles up to the middle of body on each side. They bring about the contraction of the body. A few *branchio-atrial* muscles extend deeper between the two siphons. The connective tissue cells present in the middle layer are mostly amoeboid as vacuolated cells.

3. Inner epidermis. It is the inner ectodermal single layer of flat polygonal cells lining the atrial cavity.

Internal Organs (Viscera)

The foot has no soft part of the body inside, being entirely made of test. All the soft *internal* or *visceral organs* are present inside the body proper

* Spicules obstruct in dissection and cause much undesirable laceration of tissue. For their removal before dissection, the test is cut away an animal left overnight in 2% acid alcohol or acid water. HCl or HNO_3 may be used for this purpose.

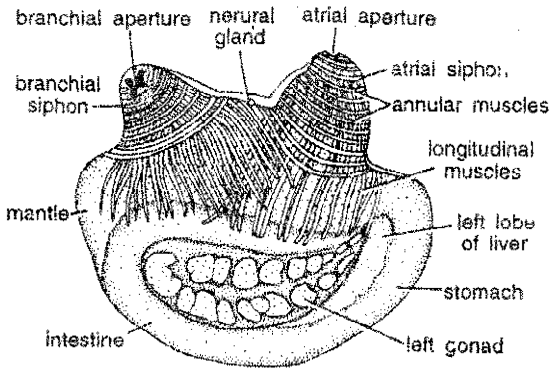

Fig. 5. *Herdmania*. Viscera seen from left side after removal of test.

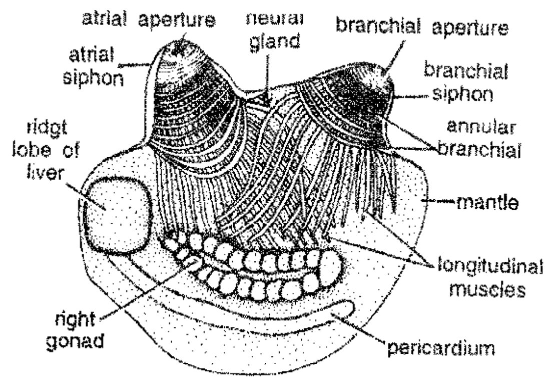

Fig. 6. *Herdmania*. Viscera seen from right side after removal of test.

enclosed within the somewhat transparent bodywall or mantle. Viscera is visible when the test is removed. The structures visible from the left side are : (i) The two *siphons* with their outer annular and internal longitudinal *muscles*, and respective apertures each guarded by four lips; (ii) stomach, intestine and rectum, the *intestine* forming a wide loop; (iii) chocolate-coloured *left liver lobe* in front of stomach; (iv) pink-coloured *left gonad* lying in the intestinal loop; and (v) opaque rod-like *endostyle* along the ventral margin of pharynx (Fig. 5).

On examination of the viscera from the right side, the structures visible are : (i) The two *siphons* with their *musculature* and *apertures*, (ii) *neural gland* in the inter-siphonal region, (iii) *right liver lobe*, (iv) *pericardium*, (v) *right gonad*, and (vi) the *endostyle* (Fig. 6).

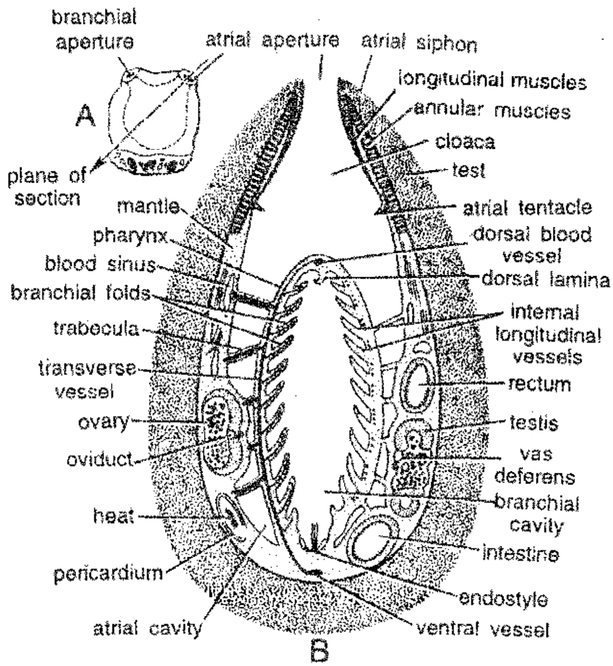

Fig. 7. *Herdmania*. A —Plane of section. B —Section of body showing relations of atrial cavity, pharynx, mantle and test.

Coelom and Atrium

True coelom in ascidians is greatly reduced due to over development of atrium, and exists in few doubtful derivatives like pericardial cavity, gonads, and neural gland. Reduction of coelom is regarded to be a result of degeneration.

The spacious cavity lying between the mantle and the pharynx, and enclosing the visceral organs, is called *atrium*. It is lined by the inner epidermis of mantle. The atrial cavity is continuous throughout the body except in the anterior and ventral regions where the pharynx and mantle become fused. It is narrow on the two lateral sides of the pharynx and called the *peribranchial cavity* which communicates with the cavity of pharynx through *stigmata* in the wall of pharynx. Above pharynx, the atrial cavity is wide and known as *cloaca* into which open the anus and the gonopores. The cloaca leads to exterior through the atrial siphon and *atrial aperture* or *atriopore*. Around the base of atrial siphon is a strong *sphincter muscles*, near which a ring of slightly serrated processes, called *atrial tentacles*, project into the siphon (Fig. 7).

Locomotion and Movement

Adult *Herdmania* is sessile. Only visible movements noticed during the contraction of body, while squirting out of water through atrial and branchial siphons. For this contraction three set of specialized muscles-oral muscle group, atrial muscle group and atrio-oral muscle groups operate.

Both oral and atrial muscle groups are formed of annular and longitudinal muscles. The atrio-oral muscle group is composed of our muscle band running between oral and atrial funnels and two pairs of muscles situated on either sides of the neural gland. These muscles extend longitudinally from one funnel to another. Contraction of body is caused by contraction of longitudinal muscles and contraction of funnel is effected by the annular muscles.

Digestive System

The digestive system of *Herdmania* includes the *alimentary canal* and the *digestive glands*.

[I] Alimentary canal

The digestive tract of *Herdmania* is coiled and complete, beginning at the mouth and terminating at the anus. The following parts form the alimentary canal.

1. Mouth. The *mouth* or *branchial aperture* opens on the top of the branchial siphon marking the anterior end of the body. It is bordered by four lips or lobes formed by the test and leads into the branchial siphon.

2. Buccal cavity. The short narrow and laterally compressed cavity of branchial siphon, lined by epidermis, is called the *stomodaeum* or *buccal cavity*. A strong *branchial sphincter* present near the base of the siphon regulates its opening. The base of the siphon is provided with a circlet of highly branched, delicate *branchial tentacles* richly supplied with nerves. Their number is about 64 which are broadly in four sizes, such as 8 large (5 mm), 8 medium (2.5 mm), 16 small (1.5 mm) and 32 very small (0.5 mm).

A branchial tentacle is sickle-shaped, attached by its broad base. Its upper and thicker border bears numerous paired lateral branches, called *tentaculets*, each in turn bearing smaller secondary and tertiary branches. The lower border of tentacle is thin, lobed, notched and covered by glandular epithelium. The free ends of tentacles meet at the centre forming a sort of strainer which prevents entry of larger food particles into pharynx.

3. Pharynx. Buccal cavity or branchial siphon is followed by the pharynx. It occupies the major

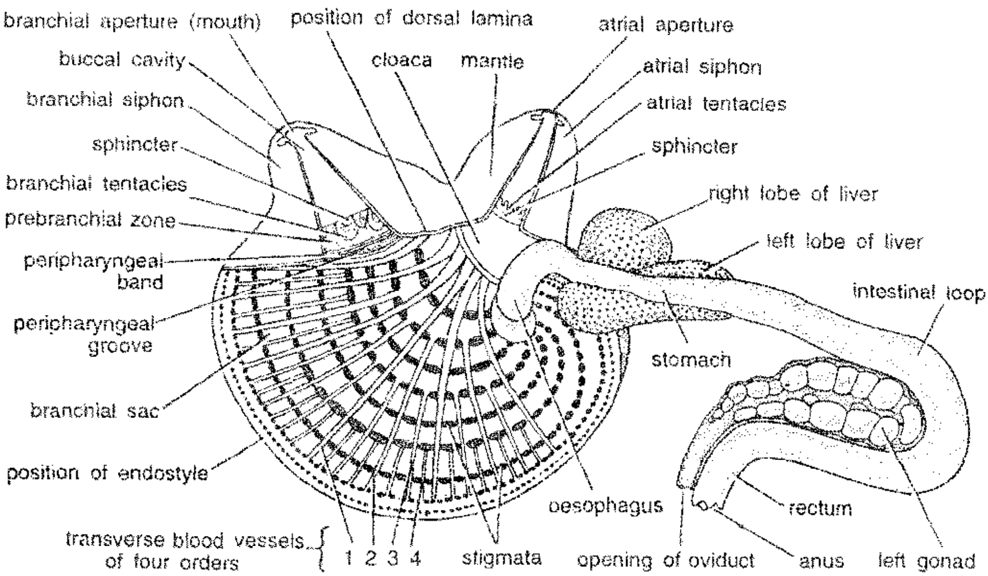

Fig. 8. *Herdmania.* Alimentary canal in left view, after removal of test and mantle.

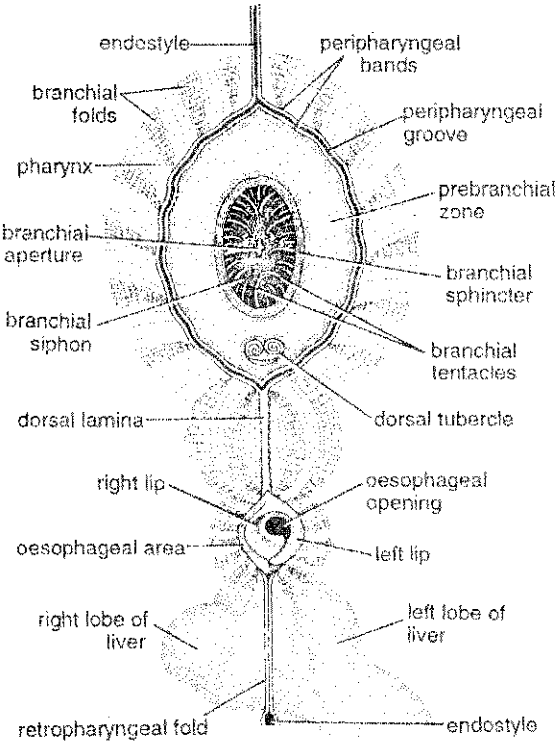

Fig. 9. *Herdmania*. Diagram showing relations of branchial, siphon branchial folds, peripharyngeal bands with groove, oesophageal area, dorsal lamina and endostyle.

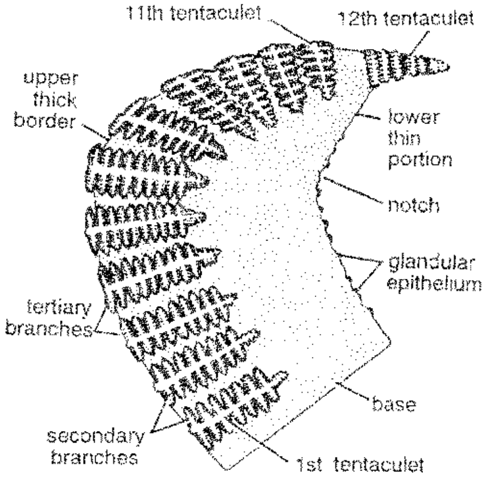

Fig. 10. *Herdmania*. A branchial tentacle in side view.

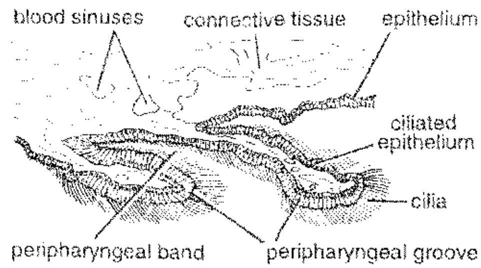

Fig. 11. *Herdmania*. Peripharyngeal bands and groove in T. S.

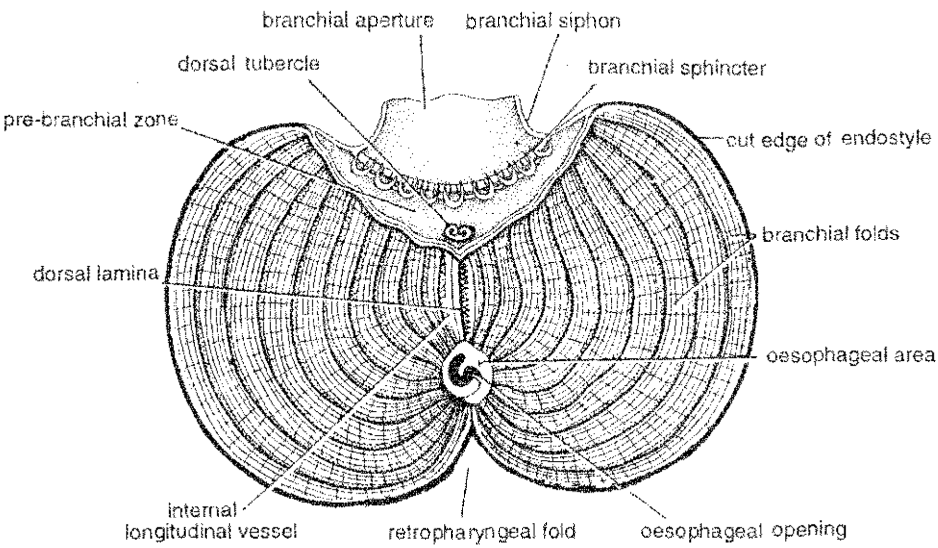

Fig. 12. *Herdmania*. Pharynx cut longitudinally along mid-ventral line (endostyle) to show internal structure.

part of the body or atrial cavity. It is differentiated into a *prebranchial zone* and a *branchial sac.*

(a) Prebranchial zone. It is the smaller anterior region having smooth walls without folds, cilia and stigmata or gill-slits. It is demarcated from the branchial sac by two circular, thin, parallel and ciliated ridges, called *anterior* and *posterior peripharyngeal bands*, enclosing a narrow ciliated *peripharyngeal groove.* The two bands bear larger cilia while the groove has smaller cilia. The anterior peripharyngeal band is a complete ring and middorsally in front of it lies a swollen *dorsal tubercle* made of two spiral coils. The posterior peripharyngeal band is interrupted mid-dorsally by the *dorsal lamina* and mid-ventrally by the *endostyle.*

(b) Branchial sac. It is the larger posterior region of pharynx. It is also known as the *branchial basket* because of its looks, as its lateral walls are perforated by numerous elongated *gill-slits* of *stigmata* through which the cavity of pharynx communicates with the atrial cavity. Each side of branchial sac bears about 200,000 stigmata arranged in several transverse rows. The epithelium lining the stigmata bears long cilia, called *lateral cilia.* The pharyngeal wall consists of a network of broad *longitudinal* and *transverse bars* at regular intervals, enclosing many square or rectangular areas, called *stigmatic areas*, each having 5 or 6 stigmata. The pharyngeal wall is richly vascular and the bars contain their corresponding blood vessels, i.e., *internal longitudinal* and *external transverse vessels.* The adjacent stigmata are also separated from each other by thin longitudinal *intersegmental bars* and *vessels.* Besides, a thin transverse *intrastigmatic bar* and *vessel* transversely cross through each row of stigmata (Figs. 13–14).

(i) Trabeculae. The inner wall of branchial sac becomes folded longitudinally to increase its surface area. The number of *branchial folds* is 9 or 10 on either side. The inner surface is nonciliated. The outer wall of branchial sac is connected to mantle by several hollow strands, called *trabeculae*, each containing a blood vessel.

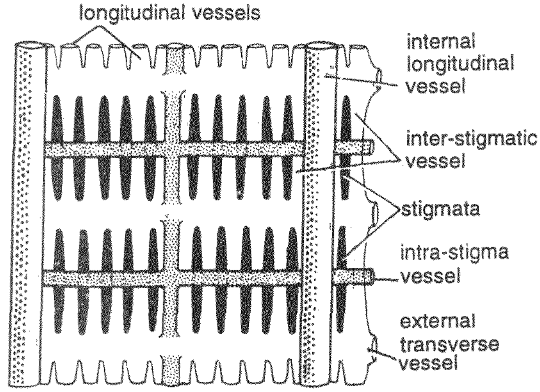

Fig. 13. *Herdmania.* Plan of branchial vessels and four stigmatic areas in a portion of pharyngeal wall.

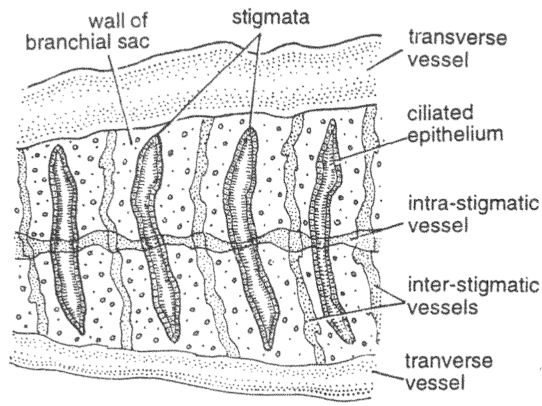

Fig. 14. *Herdmania.* One stigmatic area enlarged to show ciliation.

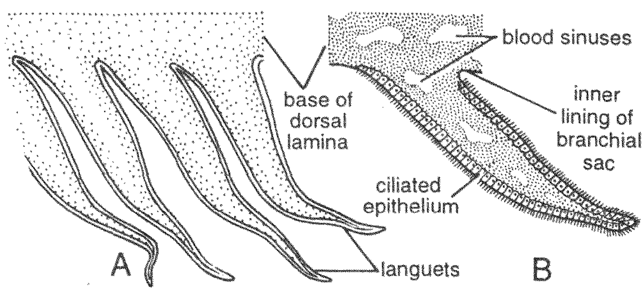

Fig. 15. *Herdmania.* A — Part of dorsal lamina. B — One languet in section.

(ii) Dorsal lamina. A thin flap or fold, 1 to 1.5 cm long, is suspended from the short mid-dorsal border of the roof of branchial sac. It is called the *hyperpharyngeal band* or *dorsal lamina.* It extends from the posterior

peripharyngeal band to the right lip of oesophageal opening. A row of 20 to 30 conical, tapering tongue-like processes, the *languets*, hang down from dorsal lamina into the cavity of the branchial sac. The languets are covered by ciliated epithelium. In the living animal, the dorsal lamina and its languets are bent to the right side forming a sort of gutter for conducting food (Fig. 15).

(iii) Endostyle. Similarly, a shallow longitudinal mid-ventral groove, called *endostyle*, is present on the floor of the branchial sac. Anteriorly, the endostylar groove is continuous with the peripharyngeal groove, while the marginal folds of endostyle merge with the posterior peripharyngeal band. Posteriorly, the groove terminates before reaching oesophageal opening, while its folds reach up to oesophageal opening as thin *retropharyngeal folds* (Fig. 16). Structurally, endostyle consists of five longitudinal ciliary tracts (1 median, 2 lateral pairs) alternating with four longitudinal tracts of mucus-secreting glandular cells. The cilia of the median tract are the longest of all. The endostyle of urochordates is homologous with the hypopharyngeal groove of cephalochordates and thyroid glands of vertebrates.

(iv) Oesophageal area. The posteriormost region of branchial sac has a small circular *oesophageal area* made of two semicircular lips guarding the oesophageal opening. This area is devoid of blood vessels, folds are stigmata.

4. Oesophagus. The branchial sac postero-dorsally leads into the *oesophagus* which is a very short, curved and thick-walled tube opening into stomach. Its narrow lumen is produced into four longitudinal ciliated grooves for the passage of food (Fig. 17).

5. Stomach. It is wider than oesophagus, thinwalled, sphinctered at both ends, has a smooth inner surface, and is surrounded on either side by the right and left lobes of liver.

6. Intestine. The stomach leads into the intestine which is a thin-walled, U-shaped tube formed by a proximal, ventral or *descending limb* and a distal, dorsal or *ascending limb*, both united anteriorly. The intestinal loop, thus formed, encloses the left gonad (Fig. 18).

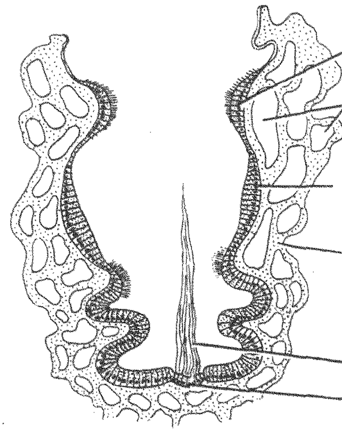

Fig. 16. *Herdmania.* Endostyle in T. S.

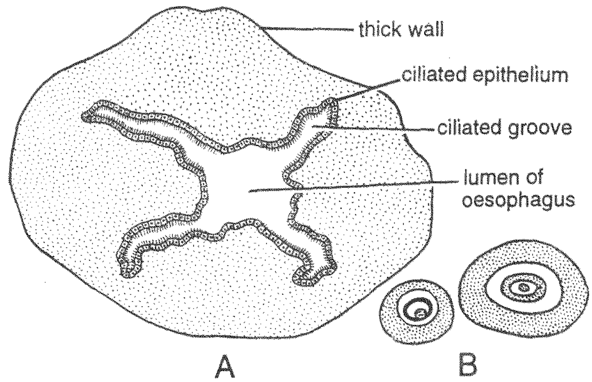

Fig. 17. *Herdmania.* A—Oesophagus in section. B—Starch granules in walls of oesophagus, stomach and liver.

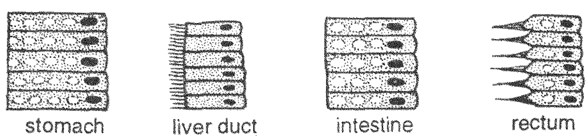

Fig. 18. *Herdmania.* Gut epithelial lining cells.

7. Rectum. Posteriorly the terminal part of intestine leads into a short, narrow tube, the *rectum*, internally lined by cilia. It curves dorsally to open into the atrium or *cloaca* through the *anus* which is bounded by four lips.

8. Cloaca. The atrial cavity or cloaca leads dorsally into the atrial siphon which opens to the outside through the atrial aperture. The atrial siphon is lined internally by ectoderm and thus represents the proctodaeum.

[II] Digestive glands

1. Liver. Liver of *Herdmania* is a large dark brown bilobed digestive gland made of a larger left lobe and a smaller right lobe attached on either side of the stomach. Liver is composed of a large number of tubules or caeca embedded in a connective tissue matrix containing blood sinuses. Tubules unite to form 11 or 12 hepatic ducts which open independently into the stomach. Liver secretion contains a strong amylase, a protease and a mild lipase.

2. Pyloric gland. It consists of a large number of branching tubules in the walls of stomach and intestine. They open by a single duct into the middle of the proximal limb of intestine. The pyloric gland of *Herdmania* probably performs a dual function, that of a vertebrate pancreas and of an excretory organ.

[III] Food, feeding and digestion

1. Food. Due to sedentary habit, *Herdmania* is a *ciliary* or *filter feeder.* The food consists of microscopic planktonic organisms such as algae, diatoms, infusorians, etc.

2. Feeding or food collection. Outward beatings of lateral cilia lining, the stigmata set up a constant water current which enters through the mouth and buccal cavity into the pharynx, passes through stigmata into the atrial cavity and leaves the body through atrial siphon (cloaca) and atrial aperture. The branchial tentacles, forming a sort of sieve or strainer, prevent larger particles but allow minute food particles to enter the pharynx along with the water current. The tentacles probably also act as chemoreceptors and keep out the impurities present in sea water. The larger particles and impurities are thrown out of the mouth by producing a strong *reverse current*. The lateral cilia of stigmata retain the food particles inside the branchial sac, which settle on its wall. Enormous quantity of viscid mucus secreted by the gland cells of endostyle is whipped up along the inner lateral walls of branchial sac by the lashing movements of the endostylar cilia. The food particles entangled with this mucus are also shifted dorsally by the frontal cilia that beat upwards. The food-laden mucus finally reaches the dorsal lamina, rolled up into a cylindrical mass. Here, it is driven backwards by ciliary action in the form of a string or cord, in the groove formed by the curved languets of dorsal lamina and passes into the oesophagus aided by the oesophageal lips. From oesophagus the food passes into the stomach.

3. Digestion. In stomach, food is digested by the enzymes present in the liver secretion. *Amylase* hydrolyses starch into maltose, *protease* breaks down proteins, and *lipase* acts on fats. Secretion of pyloric gland probably has an accessory digestive function similar to that of pancreas. Digestion is completed and the digested food absorbed in the intestine. The undigested food material passes into rectum and driven out by rectal cilia into cloaca through anus as a much coiled faecal cord with mucus. It is expelled out forcefully up to a distance of 10-12 cm through atrial aperture by the sudden contractions of the body.

Reserve food in the form of concentrically striated starch-like granules is present in the liver and the walls of oesophagus, stomach and intestine.

Respiratory System

The water current entering the pharynx also brings dissolved oxygen in sea water. The *pharyngeal wall* is highly vascular traversed by a rich network of blood vessels and is also very thin enabling gaseous exchange. Some CO_2 of blood diffuses into water and O_2 from water into blood. The respiratory surface is increased by the longitudinal folds and papillae. The respiratory pigment of blood seems to be incapable of absorbing any oxygen. Gaseous exchange also takes place in the *vascular trabeculae*, present in the atrium. Besides, the *test* also acts as an accessory respiratory organ containing *vascular ampullae* and blood vessels which help in gaseous exchange through the surface of test.

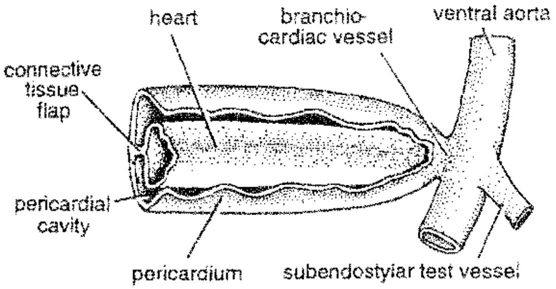

Fig. 19. *Herdmania.* Pericardium cut open to show the attachment of the heart.

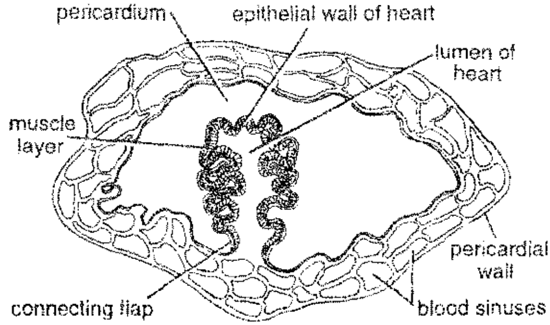

Fig. 20. *Herdmania.* Heart and pericardium in T.S.

Blood Vascular System

The circulatory system of *Herdmania* is well developed and greatly modified. It includes : (i) *Heart* and *pericardium*, (ii) *blood vessels*, and (iii) *blood*.

1. Heart and pericardium. The *pericardium* is a noncontractile, elongated and transparent tube about 7 cm long and 3 mm wide, running obliquely below the right gonad. It is closed at both the ends and filled with a colourless pericardial fluid with corpuscles similar to those of blood. Its thick wall is made of connective tissue, contains blood sinuses and is internally lined by squamous epithelium (Figs. 19 & 20).

The *heart* is enclosed within the pericardium and attached to its wall along its entire length by a thin mesentery-like connective tissue flap. It is a cylindrical highly contractile and thin-walled structure with striated muscles. It is formed by an infolding of the pericardium. Both ends of heart are open. There are no valves but a *pear-shaped body* present midway in the pericardial body probably regulates the flow of blood in the heart.

2. Blood vessels. Blood vascular system is elaborate. While the major blood vessels have

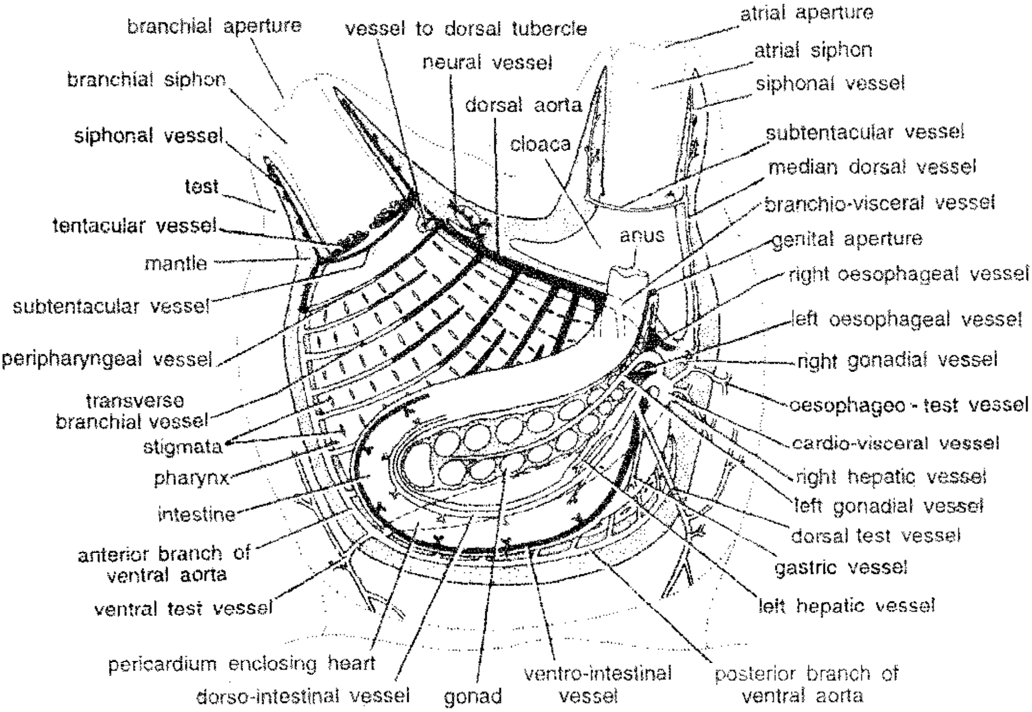

Fig. 21. *Herdmania.* Heart and blood vessels.

definite walls, the smaller ones lack them. The larger blood vessels and their branches are as follows :

(a) ***Ventral aorta.*** The *ventral* or *subendostylar* vessel is the largest vessel of the body, arising from the ventral end of the heart. At its point of origin, it first gives out a stout *ventral test vessel*, supplying the ventral side of the test, and then bifurcates into an anterior and a *posterior hypobranchial branch* running first below the entire length of the endostyle. Both, the branches give off several paired *transverse vessels* (40 to 56 pairs) to the wall of branchial sac between rows of stigmata, and numerous fine vessels to the endostyle and mantle. The anterior branch joins two circular vessels at the base of branchial siphon—(i) a *peripharyngeal vessel* that runs below the peripharyngeal groove, and (ii) a *subtentacular vessel* that runs below the bases of branchial tentacles. The latter sends a *tentacular branch* in each tentacle and 6-8 *siphonal vessels* into the branchial siphon. The posterior branch of ventral aorta sends a minor vessel to oesophageal area (Fig. 21).

(b) Dorsal aorta. It is a stout vessel lying mid-dorsally, just above dorsal lamina in the dorsal wall of branchial sac. It is not connected to the heart but communicates with the ventral vessel through 5-7 pairs of *transverse vessels* of the branchial sac, and the circular *peripharyngeal* and *subtentacular* vessels. From its middle portion, a *neural vessel* is given into the neural complex. The anterior end of dorsal aorta also sends a small branch to *dorsal tubercle* and 6-8 *siphonal vessels* into the mantle of branchial siphon.

(c) Branchio-visceral vessel. It is a very short vessel in posterior continuation of dorsal aorta. It immediatel divides into two branches. The right branch or *right oesophageal vessel* is short and supplies the right liver lobe and right side of oesophagus. The left branch or *ventro-intestinal vessel* is stout, long and supply blood to left side of oesophagus, stomach, intestine, rectum, left gonad and left liver lobe.

(d) Cardio-visceral vessel. It arises from the dorsal end of the heart and supplies blood to several organs through different branches. Immediately near origin, it sends a *right hepatic vessel* to right liver lobe and an *oesophageo-test vessel* to oesophagus and test. (i) The main dorsal branch sends a *test vessel*, a *left oesophageal* and a *right gonadial* to respective organs. It further extends to form a circular *subtentacular vessel* at the bases of atrial tentacles and 6-8 *siphonal vessels* into the wall of atrial siphon. (ii) The main middle branch or *left gonadial vessel* passes obliquely into the left gonad. (iii) The main ventral branch soon divides into a *dorso-intestinal vessel* to left liver lobe, stomach and intestine, a *gastric vessel* to stomach and a *dorsal test vessel* to test.

3. Blood. Blood is slightly reddish, transparent and hypertonic to sea water. It contains a few colourless amoeboid *leucocytes*, 6 or 7 types of *coloured corpuscles* with or without nucleus and without or with one, few or several vacuoles and the *nephrocytes* having vacuoles and colloidal cytoplasm. The pigment found in corpuscles may be orange, yellowish-brown or yellowish-green, but never red. Most tunicates can extract the rare metal *vanadium* from sea water and store it in green blood corpuscles called *vanadocytes*. But its oxygen absorbing power is very low and real function is uncertain. Some tunicates, including *Herdmania*, can not extract vanadium from sea water. In ascidians capillaries are absent but sinuses are present. Therefore, there is no distinction between blood and tissue fluids due to free intermixing (Fig. 22).

Course of circulation. No valves are present in the heart of *Herdmania* to regulate the flow of blood which is maintained by *peristaltic waves* and the small pear-shaped body. However, the

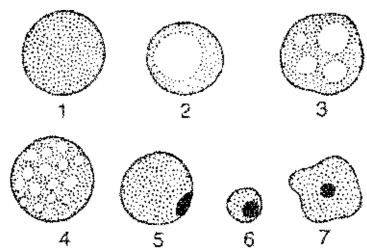

Fig. 22. *Herdmania.* Types of blood corpuscles.

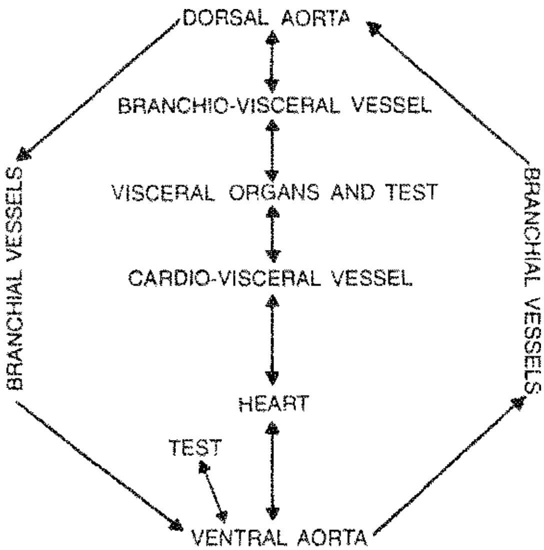

Fig. 23. *Herdmania*. Course of blood circulation.

ascidian heart is unique in the animal kingdom for changing the direction of flow of blood through it by reverse peristalsis at regular intervals. The arteries and veins change their roles when reversal of flow of blood occurs periodically.

When the heart beats ventro-dorsally, its *oxygenated blood*, collected through ventral aorta from branchial sac and test, is pumped into the cardiovisceral vessel and distributed to the various parts of the body (test and viscera). The *deoxygenated blood* from viscera is collected by the branchio-visceral vessel which passes it to the dorsal aorta from where it goes into the transverse branchial vessels to become *oxygenated* once again to undergo a fresh cycle.

During reversal of heart beat in dorso-ventral direction, the *deoxygenated blood* collected through cardio-visceral vessel from viscera, is pumped into ventral aorta and distributed into transverse branchial, peripharyngeal, subtentacular and test vessels. The blood now *oxygenated*, is collected by dorsal aorta and distributed once again to viscera through branchiovisceral vessel. *Deoxygenated blood* from viscera is collected by cardio-visceral vessel and brought back to the heart to restart the cycle (Fig. 23).

Excretor" S"stem

According to Das (1936), the only definitive excretory organ of *Herdmania pallida* is the *neural gland*. It is a light brown, and elliptical structure, 4 mm long and 1 mm thick. It lies mid-dorsally embedded in the mantle just above the nerve ganglion or brain. It consist of numerous branching *peripheral tubules* arising from a few *central tubules* which open into a longitudinal *canal* running through its entire length. Anteriorly, the canal leads into a short narrow *duct* that passes ˆetween tˆe anterior nerves to open ˆy a ciliated funnel in the prebranchial zone at the base of dorsal tubercle. The excretory cells are in fact the *nephrocytes* of blood. They collect waste proˆucts, mainly xanthine and urate particles, pass through the lumen of neural gland and its duct and finally discharge into the prebranchial zone of pharynx through the aperture (Fig. 24).

According to Julin (1881), Metcalf (1901), Bacq, Florkin and Das (1956), neural gland also secretes a hormone that controls oviposition, development and metamorphosis, and is considered homologous to the vertebrate pituitary gland.

Nervous System

The adult nervous system is quite simple and degenerate. It includes a pinkish, elongated, about 4 mm long, solid *nerve ganglion*, the so-called brain or cerebral ganglion, lying embedded in the mantle on the dorsal side between the two siphons. In most tunicates, it is present dorsal to neural gland, but in *Herdmania* (fam. Pyuridae) it lies just below the neural gland. The brain consists of bipolar and multipolar nerve cells and a network of ramifying nerve fibres. It controls the body reflexes. From the brain three *nerves* emerge out anteriorly to innervate the branchial siphon and two nerves posteriorly to atrial siphon (Fig. 25).

Neural Complex

Three structures—(i) the neural gland, (ii) nerve ganglion or brain, and (iii) the dorsal tubercle are collectively referred to as *neural complex* (Fig. 26).

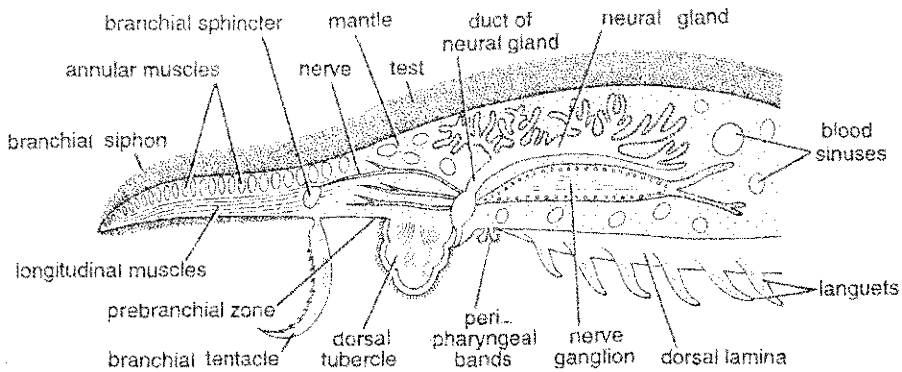

Fig. 24. *Herdmania*. L.S. of body through neural complex (neural gland, nerve ganglion and dorsal tubercle).

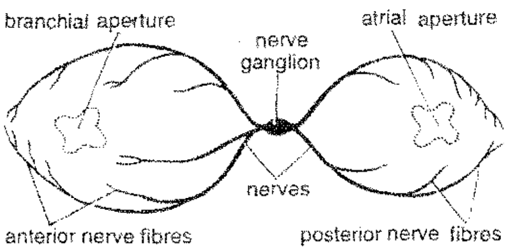

Fig. 25. *Herdmania*. Nervous system.

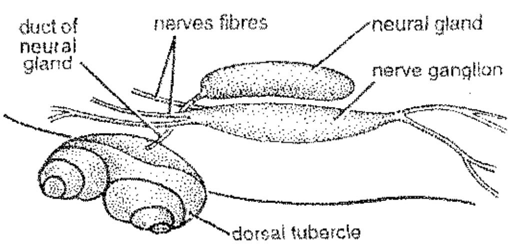

Fig. 26. *Herdmania*. Neural complex.

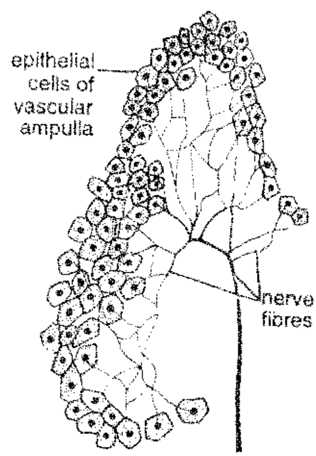

Fig. 27. *Herdmania*. Nerve supply of a vascular ampulla.

Sense Organs

Special sensory organs are lacking. However, several simple structures in the form of isolated or aggregated cells, with nerve endings represent the receptors (Fig. 27).

1. Tangoreceptors. Sensitive to touch, these cells are scattered throughout non-vascular areas of test along margins of siphons, over tentacles and covering vascular ampullae.

2. Photoreceptors. Sensitive to light, these are pigmented cells (ocelli) containing red pigment granules, located on the margins of siphons and vascular ampullae.

3. Rheoreceptors. Sensitive to water currents, these cells line the apical margins of siphons.

4. Thermoreceptors. Sensitive to temperature, these cells line the siphons.

5. Chaemoreceptors. Sensitive to chemicals, these include the tentacles and the dorsal tubercle.

(a) Tentacles. The branchial tentacles due to their rich nerve supply are considered olfactory in nature. They test the quality of incoming water and also the size of food particles entering the pharynx.

(b) Dorsal tubercle. It is a small sensory structure suspended mid-dorsally in the prebranchial zone, just anterior to the junction of peripharyngeal bands and dorsal lamina. It consists of two conical, spirally coiled projections or lobes, each carrying a similarly coiled and ciliated, narrow open channel running from its base to the tip. Both the channels are continuous at the broad, convex, dome-like base of the dorsal tubercle. The surface of dorsal tubercle is covered by ciliated columnar epithelium, rich in nerve supply. The dorsal tubercle serves to smell and taste the water entering the pharynx, thus functioning both as an olfactory and a gustatory receptor.

Reproductive System

Herdmania is hermaphrodite or bisexual, but *protogynous* so that self-fertilization is ruled out.

Gonads. There are two large *gonads* embedded in the mantle and bulging into the peribranchial or atrial cavity. The right gonad is situated just parallel and dorsal to pericardium, while the left gonad lies within the intestinal loop.

Structure of a gonad. Each adult gonad is an elongated, lobulated and hermaphrodite gland measuring 3 to 4 cm long, 1 cm wide and 2 to 3 mm thick. There are 10 to 25 distinct oval or rounded lobes, arranged in two rows one on either side of a *central axis*. The *median lobe* present at the proximal end is the largest, unpaired and crescentic or bean-shaped. Each lobe is made of a larger, brick-red, cortical, peripheral or outer *testicular region* and a smaller, pinkish, medullary or inner *ovarian region*. The testicular zone is made up of closely packed *spermatic caeca* or *tubules* lined by germinal epithelium, forming spermatogonia, spermatocytes and spermatozoa. The ovarian zone has a lobulated surface due to formation of *ovarian follicles*, containing rounded ova in various stages of development. Each lobe of gonad is thus an *ovotestis* or a *hermaphrodite gland* (Figs. 28 & 29).

Gonoducts. Each gonad has two gonoducts, *oviduct* and *spermatic duct*, running along the central axis. The *oviduct* is a wider tube formed by the union of *ovarian ductules* one from ovarian zone of each lobe. It extends beyond the gonad for a short distance and opens into cloaca or

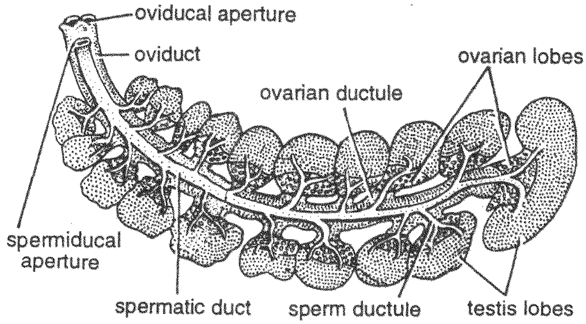

Fig. 28. *Herdmania.* Left gonad seen from inner side.

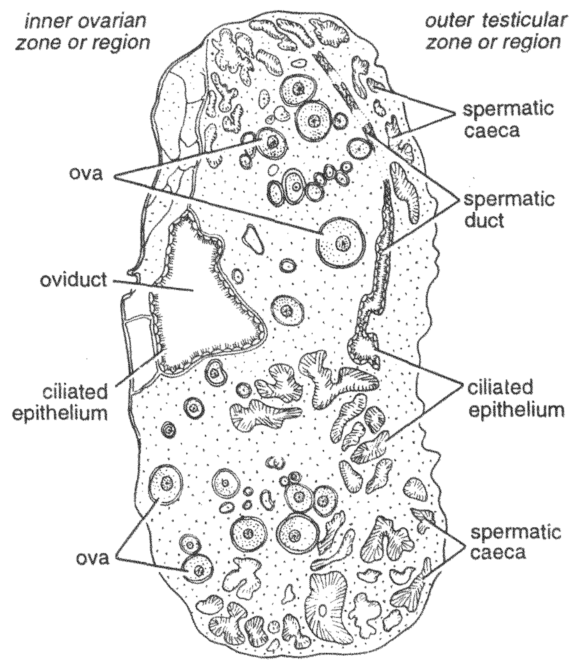

Fig. 29. *Herdmania.* T.S. gonad.

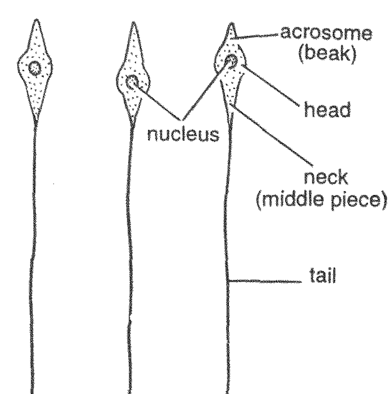

Fig. 30. *Herdmania.* Kinds of sperms.

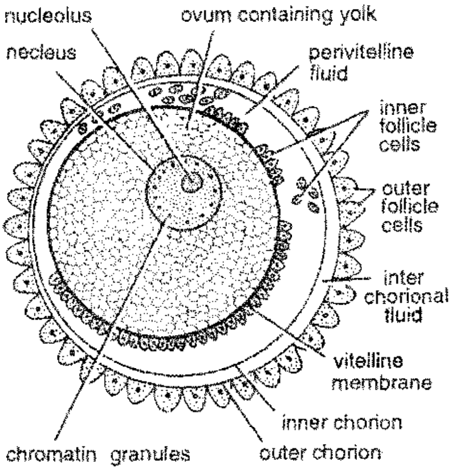

Fig. 31. *Herdmania*. A mature ovum.

dorsal atrial cavity, a little behind the anus, by an *oviducal aperture* bordered by four thick *lips*.

The *spermatic duct* or *vas deferens* is a much narrower duct formed by the union of *spermatic ductules* one from testicular zone of each lobe. It runs along the inner (branchial) side of the oviduct and opens independently into cloaca by a *spermiducal aperture* a little behind the oviducal aperture. Both the gonoducts are lined by cilia internally.

Gametes. The testicular lobes produce spermatozoa. A mature *spermatozoon* or *sperm* is microscopic, about 4 micra in length. Each has an anterior broad and nucleated *head* capped by a beak-like *acrosome* in front, a middle piece or *neck* and a very long straight *tail*. The sperms are polymorphic with at least three types having acrosome shorter, equal or longer than head.

The ovarian lobes produce ova or eggs. A mature *ovum* is large about 0.3 mm in diameter. Considerable amount of yellowish granulated *yolk* is distributed in its cytoplasm. The large *nucleus*, situated on one side, contains a conspicuous eccentric *nucleolus* and a dense layer of *chromatin granules* beneath the nuclear membrane. Three membranes surround the ovum; (i) *Vitelline membrane*, (ii) *inner chorion*, and (iii) *outer chorion*. The thin *vitelline membrane* is secreted by the ovum itself and closely applied forming its wall. The follicular cells of the ovary secrete the two *chorion membranes*. T..e ovum lies eccentrically in the *perivitelline fluid* enclosed by the space between the vitelline membrane and the *inner chorion*. The space also contains a large nu...ber of s...all sized inner *follicle cells*, some floating in the fluid but mostly attached to vitelline membrane. These cells nourish the ovum and secrete an enzyme which digests the chorions to facilitate hatching. The narrow space between the two chorions is filled with an *inter-chorional fluid*. Attached to the outer surface of outer chorion are many vacuolated large-sized *outer follicle cells* which serve to keep the ovum floating in water (Fig. 31).

Fertilization

Although *Herdmania* is hermaphroditic but self fertilization is rare because the ovarian region mature earlier (Protogynous condition), when gametes become mature, they are expelled out in sea water through atrial current. Exernal fertilization takes place is sea water.

Development

Development of *Herdmania* has been described in chapter 43 in Vertebrate Embryology section.

Affinities and Systematic Position of *Herdmania* (Urochordata)

[I] Systematic position

The systematic status of Urochordata had long remained controversial. Lamarck (1816) first called them *Tunicata*. Cuvier (1817) classified them along with *Mollusca*, but Lamarck put them between *Radiata* and *Vermes*. Milne Edwards (1843) established the class *Molluscoidea* to include Bryozoa with Tunicata, to which Huxley (1853) also added Brachiopoda. However, Kowalevsky (1886) put an end to the controversy when he described the development of a simple ascidian and established their chordate nature. Since then, the urochordates have been placed as a class or subphylum under the phylum Chordata with certainty.

[II] Affinities with nonchordates

In some features, urochordates show some similarities with certain nonchordate groups.

(1) Porifera, Coelenterata and urochordates are sessile in nature.
(2) Mechanism of filter feeding and respiration through a water current is parallel with that of sponges, molluscs (oysters) and lophophorates.
(3) Budding chain of new zooids is common with coelenterates and annelids.
(4) Larval eyes and otocysts are found in many invertebrates.
(5) Colonial mode of life of simple and composite fixed ascidians is observed in a number of invertebrates.
(6) Presence of typhlosole in intestine.

None of the above features establishes any nonchordate relationship. These similarities are only due to similar mode of life and parallel evolution.

[III] Affinities with chordates

As already mentioned, the chordate affinities of urochordates are beyond any doubt. The ascidian tadpole larva possesses all the basic chordate characters such as : (i) rod-like *notochord* forming axial skeleton of tail, (ii) dorsal tubular nerve cord, and (iii) gill-slits in the pharyngeal wall. This is probably because both urochordates and the other chordates have originated from a common ancestor.

1. Affinities with Hemichordata. The assumption that nearest relatives of urochordates are the exisiting hemichordates, is based on the following similarities :

(1) Same structural plan of pharynx perforated by gill-slits and having similar accessories.
(2) Similar development of central part of nervous system.
(3) Occurrence of restricted notochord.

Objections. However, the two groups have important differences. (i) *Balanoglossus* lives in burrows, but urochordates may be fixed, inert or pelagic. (ii) Hemichordate body is divisible into proboscis, collar and trunk which is not found in urochordates. (iii) A true notochord is present in the tail of ascidian larva, whereas the buccal diverticulum of *Balanoglossus* is no longer considered a notochord. Thus, even inclusion of hemichordates as true chordates has become doubtful so that they are considered nowadays as an independent nonchordate phylum. The similarities of both the groups are probably because of their remote phylogenetic relationship with the ancestral common stock.

2. Affinities with Cephalochordata. The adult urochordate bears the following structural similarities with *Branchiostoma* :

(1) Similar ciliary filter feeding or food concentration mechanism and respiratory mechanism.
(2) Large pharynx with similar accessories.
(3) Branchial tentacles are similar to velar tentacles.
(4) Similar endostyle and associated parts.
(5) Similar atrial complex.

Besides the fundamental three chordate characteristics (notochord, dorsal tubular nerve cord and pharyngeal gill-slits), the ascidian tadpole larva and *Branchiostoma* also share the following similarities :

(1) Identical early stages of development.
(2) Tail with median vertical fins without fin rays.
(3) Median sensory organs (otocyst, ocellus, statocyst).
(4) Pharynx with endostyle.
(5) Atrial complex similar.

Objections. The important differences between the two groups are as shown in the Table below :

While their resemblances point out to a probable remote common ancestry, their differences demand their taxonomic arrangement in two separate subphyla under the phylum Chordata.

3. Affinities with Vertebrata. The ascidian tadpole larva can be compared with a larval fish. It resembles higher chordates in having (i) dorsal tubular nerve cord, (ii) axial skeletal notochord, (iii) pharyngeal gill- slits, (iv) postanal tail covered

	Characters	Urochordates	Cephalochordates
1.	Adult	Sedentary	Free-swimming
2.	Segmentation	Absent	Present
3.	Notochord	Absent in adult	Present
4.	Nerve cord	Absent in adult	Present
5.	Coelom	Absent	Present
6.	Test	Present	Absent
7.	Liver	Present	midgut diverticulum
8.	Heart	Present	Absent
9.	Nephridia	Absent	Present
10.	Sex	Bisexual	Unisexual
11.	Metamorphosis	Retrogressive	Progressive

by vertical caudal fin and (v) type of cleavage and gastrulation.

Besides, in the adult ascidian, (i) neural gland is homologous with vertebrate pituitary, (ii) endostyle with vertebrate thyroid, and (iii) typhlosole comparable to intestinal spiral valve of elasmobranch fishes.

Conclusion. From above discussion it is obvious that urochordates are primitive and degenerate descendants of ancestral chordates. The tadpole larva represents the relic of a free-swimming ancestral chordate. Degeneration is a secondary modification due to sedentary and sessile mode of adult life.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the external morphology of *Herdmania*.
2. Describe the structure and function of the tunic of *Herdmania* in detail.
3. Describe food, feeding and digestion of a sea squirt.
4. Describe the digestive system of *Herdmania*.
5. Describe the Blood vascular system of a sea squirt.
6. Discuss the affinities of Urochordata in detail.

» *Short Answer Type Questions*

1. List the internal organs visible from the left and right side respectively after the removal of test in *Herdmania*.
2. Describe the histology of mantle in *Herdmania*.
3. Write note on — (i) Respiratory system, (ii) Excretory system, (iii) Nervous system and (iv) Reproductive system in *Herdmania*.
4. Write short notes on — (i) Atrium, (ii) Dorsal tubercle, (iii) Endostyle, (iv) Neural gland, (v) Tunic.

» *Multiple Choice Questions*

1. Urochordates inhabit :
   (a) Estuarine habitat (b) Fast streams
   (c) Marine habitat (d) Freshwater lakes
2. Which of the following terms is not used for *Herdmania* :
   (a) Undapasi (b) Mulaikanna (c) Sea squirt (d) Sea skirt
3. Fertilization in *Herdmania* is :
   (a) Internal (b) Internal and self fertilization
   (c) External (d) External and cross fertilization
4. Body of *Herdmania* is divided into :
   (a) Head, body proper and foot
   (b) Head, abdomen and foot
   (c) Body proper and foot
   (d) Body, tail and foot
5. The aperture of siphons in *Herdmania* is guarded by :
   (a) 4 lips (b) 3 lips (c) 2 lips (d) 1 lip
6. Matrix in test of *Herdmania* is made up of :
   (a) Starch (b) Tunicine (c) Luciferine (d) Metacine
7. Megascleres occur through out the body in *Herdmania* except in :
   (a) Heart (b) Liver (c) Pharynx (d) Kidney
8. Annular muscles are found near :
   (a) Pharynx (b) Siphons (c) Heart (d) Liver
9. True coelom in *Herdmania* is greatly reduced due to the development of :
   (a) Body wall (b) Intestine
   (c) Atrium (d) Mesentries

10. Branchial sac is called :
    (a) Atrial basket (b) Atrial flower
    (c) Branchial feather (d) Branchial basket
11. Intestine in *Herdmania* is :
    (a) U shaped (b) V shaped (c) C shaped (d) L shaped
12. Pyloric glands in *Herdmania* are present in :
    (a) Stomach and intestine (b) Stomach and pharynx
    (c) Pharynx and intestine (d) Oesophagus and intestine
13. Accessory respiratory organ in urochordates is :
    (a) Pharynx (b) Stomach (c) Test (d) Liver
14. Most tunicates, except Herdmania are able to extract rare metal :
    (a) Mercury (b) Vanadium (c) Platinum (d) Silver

ANSWERS

1. (c) 2. (d) 3. (d) 4. (c) 5. (a) 6. (b) 7. (a) 8. (c) 9. (c) 10. (d) 11. (a) 12. (a) 13. (c) 14. (b).

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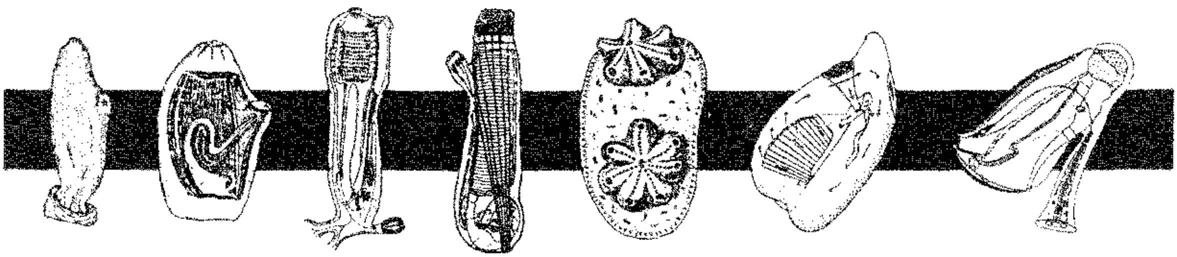

Subphylum II. Urochordata

General Characters

1. Exclusively marine and cosmopolitan, found in all seas and at all depths.
2. Mostly sedentary (fixed), some pelagic or free-swimming.
3. Simple (solitary), aggregated in groups or composite (colonial).
4. Size (0.25 to 250 mm), shape and colour variable.
5. Adult body degenerate, sac-like, unsegmented, without paired appendages and usually without tail.
6. Body covered by a protective tunic or test composed largely of tunicine, $(C_6H_{10}O_5)_n$, similar to cellulose, hence the name *Tunicata*.
7. A terminal branchial aperture and a dorsal atrial aperture usually present.
8. Coelom absent. Instead, an ectoderm-lined atrial cavity present which opens to outside through atrial aperture.
9. Notochord present only in larval tail, hence the name *Urochordata*.
10. Alimentary canal complete. Pharynx (branchial sac) large, with endostyle and two to several pairs of gill-slits. Ciliary feeders.
11. Respiration through test and gill-slits.
12. Blood-vascular system open. Heart simple, tubular and ventral. Flow of blood periodically reversed. Special vanadocytes in blood extract vanadium from sea water.
13. Excretion by neural gland, pyloric gland and nephrocytes.
14. Dorsal tubular nerve cord only in larval stage, reduced to a single dorsal nerve ganglion in adult.
15. Mostly hermaphrodite. Fertilization cross and external.
16. Development indirect including a free-swimming tailed larva with basic chordate characters. Metamorphosis retrogressive.
17. Asexual reproduction by budding common.

Classification

Subphylum Urochordata or Tunicata includes about 2,000 fixed and nearly 100 pelagic species exhibiting high degree of diversity. These have been variously classified by Herdman (1891), Lahille, Garstang (1895), Perrier (1898), Hartmeyer (1909-11) and S.M. Das (1957). But these have some drawbacks and are at times too complicated for students. The classification given below has been adopted from Storer and Usinger as given in their book *General Zoology* of 1965 edition. As usual, the subphylum Urochordata is divided into 3 classes.

Class 1. Ascidiacea

1. Solitary, colonial or compound. Bottom living.
2. Body form and size variable.
3. Test permanent, well developed and thick.
4. Atrium opens dorsally by atriopore.
5. Pharynx large with many persistent gill-slits.
6. Sexes united. Larva free-swimming and highly developed.
7. Adults usually sessile after retrogressive metamorphosis when larval notochord, nerve cord and tail are lost and brain reduced to a solid dorsal ganglion.
8. Stolon simple or none.

Order 1. Enterogona

1. Body sometimes divided into thorax and abdomen.
2. Neural gland usually ventral to ganglion.
3. Gonad 1, lying in or behind intestinal loop.
4. Larva with 2 sense organs (ocelli and otolith).

Suborder 1. Phlebobranchia

1. Pharynx with internal longitudinal vessels.
2. Budding rare.

Examples : *Ascidia, Ciona, Phallusia.*

Suborder 2. Aplousobranchia

1. Pharynx without longitudinal vessels.
2. Budding common.

Example : *Clavelina.*

Order 2. Pleurogona

1. Body compact, undivided.
2. Neural gland dorsal or lateral to ganglion.
3. Gonads 2 or more embedded in mantle wall.
4. Larva with otolith. Separate eye absent.

Examples : *Herdmania, Botryllus, Molgula, Styela.*

Class 2. Thaliacea

1. Adults free living, pelagic, in warm and temperate seas. Solitary or colonial.
2. Body shape and size variable.
3. Tunic permanent, thin and transparent, with circular muscle bands.
4. Atriopore located posteriorly.
5. Pharynx with 2 large or many small gill-slits.
6. Sexes united. Larva formed or absent.
7. Adult without notochord, nerve cord and tail.
8. Asexual budding from a complex stolon.
9. Life history with an alternation of generations.

Order 1. Pyrosomida

1. Colony compact, tubular, closed at one end and phosphorescent throughout the life, due to the invasion of its egg by a symbiotic luminescent bacteria.
2. Zooids embedded in a common test.
3. Muscle bands confined to body ends.
4. Gill-slits tall, numerous, upto 50.
5. No free-swimming larval stage.
6. Reproduces by budding.

Examples : Single genus, *Pyrosoma.*

Order 2. Doliolida (= Cyclomyaria)

1. Body characteristically barrel-shaped.
2. Muscle bands form 8 complete rings.
3. Gill-slits small, few to many.
4. A tailed larva with notochord present.

Examples : *Doliolum, Doliopsis.*

Order 3. Salpida (= Desmomyaria)

1. Body cylindrical or prism-shaped.
2. Muscle bands incomplete ventrally.

3. Pharynx communicates freely with atrium t rough a large gill-slit.
4. Tailed larva absent.
   Examples : *Salpa, Scyclosalpa.*

Class 3. Larvacea (= Appendicularia)

1. Small (5 mm long), solitary, free-swimming, pelagic, neotenic, larva-like forms with persistent tail, notochord, nerve cord and brain.
2. Test forming a temporary house, renewed peri ically.
3. Atrium and atrial aperture absent.
4. Gill-slits 2, opening directly to outside.
5. Sexes united. No metamorp osis.

Order 1. Endostylophora

1. House bilaterally symmetrical, with separate inhalent and exhalent apertures.
2. Pharynx with endostyle.
   Examples : *Oikopleura, Appendicularia.*

Order 2. Polystylophora

1. House biradially symmetrical, with single aperture.
2. Pharynx without endostyle.
   Example : *Kowalevskia.*

Other Urochordates

1. *Ascidia.* *Ascidia* is cl s l si ilar t *Herdmania*. It is a common marine, solitary and sedentary tunicate, inhabiting temperate seas at all depths forming large groups attached to rocks. The body, 10 to 15 cm long, appears like a wrinkled sac or cylinder attached by a broad base. Test is thick, tough and brown, and siphons short and not at the same level. Branchial aperture is terminal while atrial aperture half way down the right lateral side. Spacious pharynx has numerous gill-slits arranged in transverse rows, but internal longitudinal folds are lacking. Intestine has a typhlosole and anus is two-lipped. There is no liver. Brain lies dorsal to neural gland. Dorsal tubercle is horseshoe shaped. Excretory vesicles are present on the stomach and intestine. A single hermaphrodite gonad is present in the loop of intestine. Life-history includes a tailed tadpole larva which undergoes retrogressive metamorphosis to become the inert, sessile adult (Figs. 1 & 2).

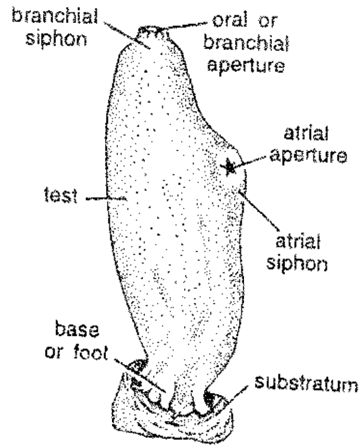

Fig. 1. *Ascidia.* Entire animal seen from right side.

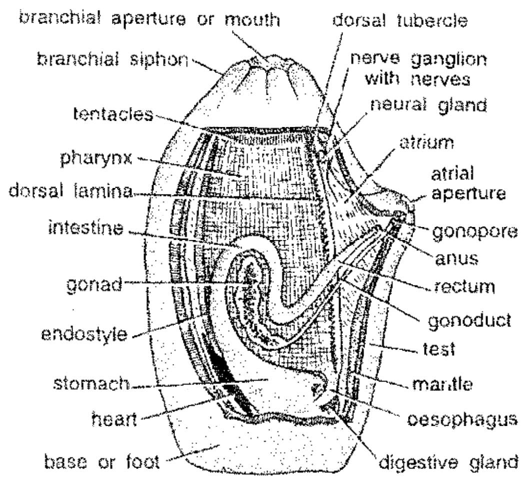

Fig. 2. *Ascidia.* Dissection to show viscera in left view.

2. *Ciona.* Its popular name is *tube sea-squirt*. It is a simple, solitary tunicate distributed in cold and temperate seas. The body is elongated, cylindrical, 10-12 cm long and attached to rocks by a broad base. Test is thin, elastic and transparent. The siphons are cylindrical. The terminal branchial aperture is eight-lobed, while somewhat lower atrial aperture is six-lobed. Mantle has longitudinal and circular muscle bands. The well-formed and perforated pharynx is without internal folds. Dorsal tubercle is simple and horseshoe shaped. Intestine has a typhlosole. Heart

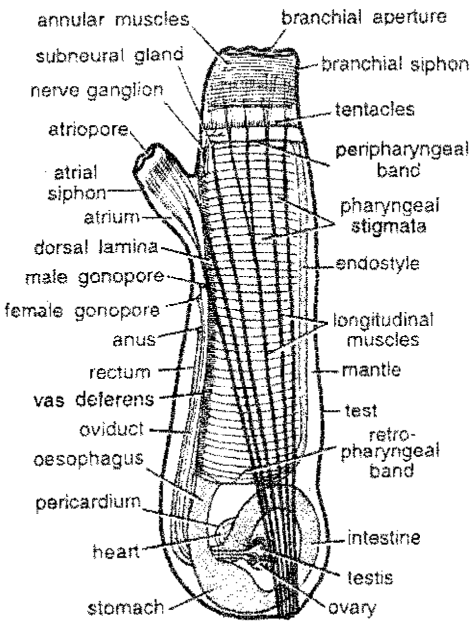

Fig. 3. *Ciona*, from right side.

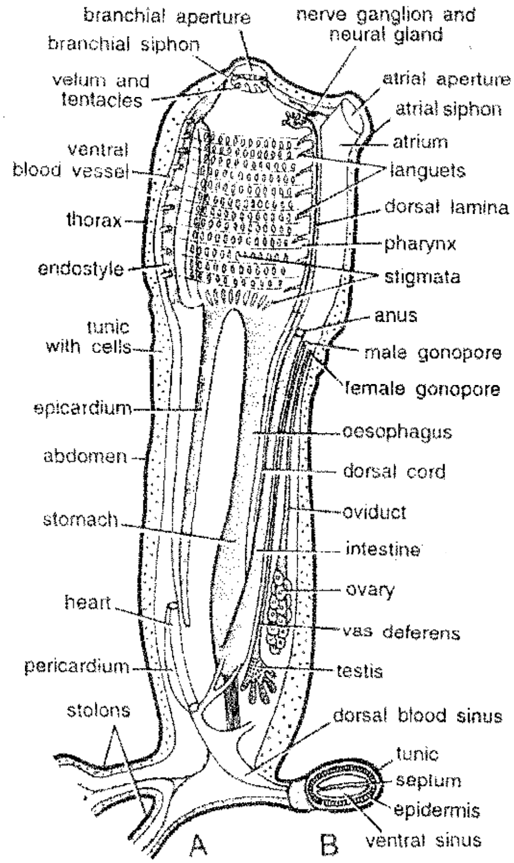

Fig. 4. *Clavellina*. A—Single zooid. B—Stolon in T.S.

is V-shaped. Gonad is single, hermaphrodite and in the intestinal loop. Visceral organs lie below the pharynx instea. of its si.e. Brain lies dorsal to neural gland. The well-formed tadpole larva undergoes retrogressive metamorphosis to become adult (Fig. 3).

3. *Clavellina*. *Clavellina* is a colonial ascidian inhabiting shallow coastal waters of European seas. Large clusters of individuals, called zooids, occur attached on hard rocks, connected basally to a branching creeping stolon. Each zooid is elongated, about 2.5 cm long, 6 mm broad and covered by a transparent test. Body has two distinct regions, an upper thorax and a lower abdomen, connected by a middle narrow waist. The thorax lodges the pharynx with endostyle and dorsal lamina, neural complex, atrium and two short siphons. The narrower and longer abdomen lodges the remainder of alimentary canal, heart, gonad and stolon. Posteriorly, the pharynx extends as a narrow tubular epicardium into abdomen and stolon. Gonad is hermaphrodite and lies in the intestinal loop. Fertilized eggs develop within the atrial cavity so that *Clavellina* is viviparous. Tailed tadpole larvae escape through the atrial aperture, lead a free-swimming life of hardly three hours, then settle and undergo metamorphosis each forming a young *oozooid*. Stolon contains two blood channels, partitioned by a mesodermal septum. Asexual reproduction occurs by budding from the stolon, forming *blastozooids*. Before winter zooids disappear, their substance form food laden *trophocytes*, which bud off new zooids after winter. *Clavellina* is significant as it forms a connecting link between simple and compound ascidians (Fig. 4).

4. *Botryllus*. *Botryllus* is sedentary, compound or colonial ascidian, widely distributed in shallow waters of European seas. It is specially abundant in harbours attached to rocks, wharfs, piers and ship's bottom. The test forms a flat, common gelatinous mass, several centimetres wide, with embedded small zooids arranged in star-like or

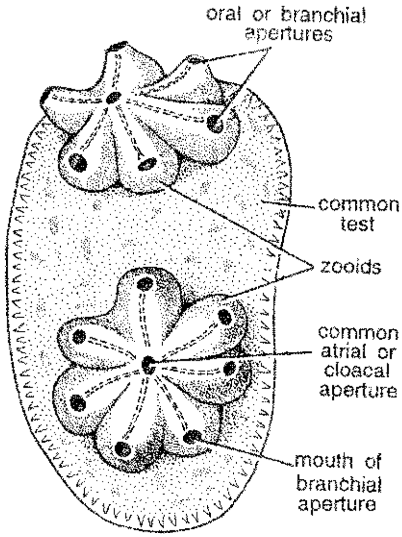

Fig. 5. *Botryllus.* Showing two groups of zooids.

stellate groups or systems. In each group, the zooids are arranged radially. Each zooid has a separate branchial apertures directed outwards, while their atrial apertures opening inwards into a common cloacal cavity at the centre. The structure is like that of a typical simple ascidian. Dorsal lamina is without languets. Gill-slits are rectangular. Neural gland is dorsal to nerve ganglion. Two hermaphrodite gonads are present. Asexual reproduction by budding occurs inside the atrial cavity. The buds remain permanently attached to the colony (Fig. 5).

5. *Molgula.* *Molgula* is a small, solitary monoacidian and sessile ascidian found in clusters attached to wharfs, piers, stones and ship's bottoms in shallow coastal waters of Atlantic ocean. Body is oval or spherical in outline 1 to 3 cm in diameter and thin test thickly encrusted with sand grains and shell pieces. Branchial siphon is shorter with a 6-lipped aperture, while atrial siphon is longer with a 4-lipped aperture. Branchial tentacles are branched and dorsal tubercle C-shaped. Dorsal lamina is without languets. Large pharynx has spirally arranged gill-slits. Heart is bean-shaped and a large renal vesicle storing excretory nitrogenous particles lies above the heart. One hermaphrodite protandrous gonad lies on either side in the body. Viviparity is common and the tadpole larva is without tail in some species (Fig. 6).

6. *Pyrosoma.* *Pyrosoma* (Gr., *pyro* = fire) is a free-swimming pelagic, colonial thaliacean, so called for being luminiscent. It is distributed in Indian, Pacific and Atlantic oceans, represented by two species. Each colony includes several individuals or *blastozooids* embedded in the wall of a common cylindrical hollow tubular gelatinous test, upto 100 cm long. The branchial aperture of each zooid opens outwards guarded by a tongue-like buccal appendage. But the atrial apertures of all the zooids open into the large common central cloacal cavity of the tubular

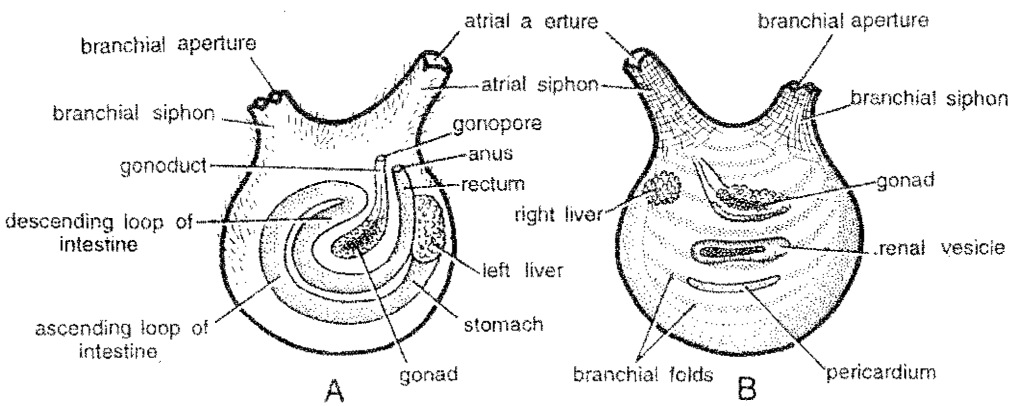

Fig. 6. *Molgula.* A—Left view. B—Right view.

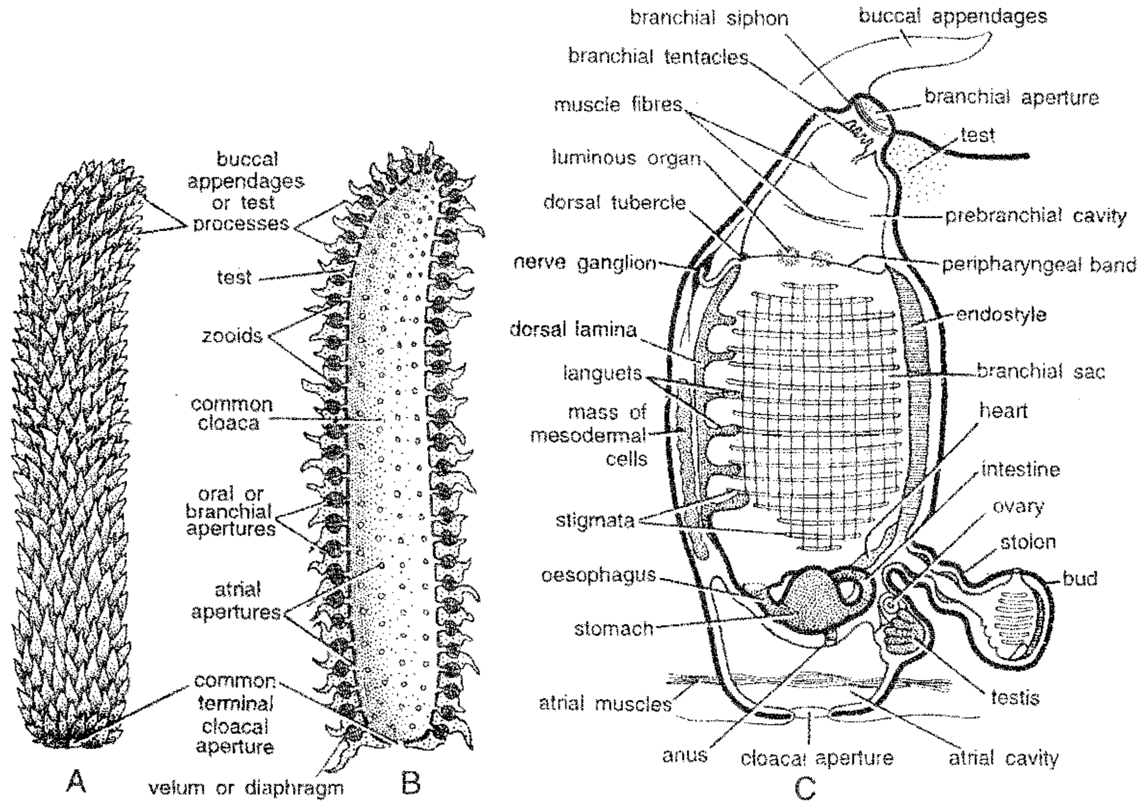

Fig. 7. *Pyrosoma*. A—Entire colony. B—Colony in L.S. C—Single zooid.

colony which is closed at one end (posterior) by a cloacal aperture controlled by a diaphragm or velum. Colony moves forward by jet propulsion as a stream of water is shot out from the cloacal aperture. General organization of a zooid is like that of a simple ascidian. Pharynx is large, oblong and equipped with dorsal lamina with languets, endostyle and several gill-slits. Heart and a stolon lie just behind the pharynx. Oral or branchial apertures are surrounded by muscular sphincters. An ocellus and a subneural gland are present. Gonad is hermaphrodite made of a single yolky ovum and a lobed testis. Development is direct without a tailed larval stage. Stolon reproduces asexually by budding new zooids. *Pyrosoma* probably emits the strongest light among marine organisms. The light is emitted by photogenic cells situated on either side of pharynx. These organs are made of photoganic cells. These cells contain numerous curved inclusions in their cytoplasm. Possibly some symbiotic luminiscent bacteria, found in photogenic mesodermal cell masses present on the peripharyngeal bands, produce light when the zooids are disturbed even by rough sea waves (Fig. 7).

7. *Doliolum*. *Doliolum* is a cosmopolitan, marine, free-swimming and pelagic, thaliacean inhabiting all seas. Reproduction is highly specialized and life cycle includes two distinct phases : a solitary sexual *gonozooid* alternating with a colonial asexual gregaria or *oozooid* (Fig. 8).

(a) Gonozooid. The sexual individual or gonozooid is cask or barrel-shaped, 1 to 1.5 cm long, having wide branchial (mouth) and atrial (anus) apertures at opposite ends each surrounded by 10-12 lobes, lodging sense organs. Test is extremely thin and transparent through which internal structures are clearly visible. The mantle contains 7 to 8 muscle bands completely encircling the body (Cyclomyaria), the terminal ones serving as sphincters. The animal moves by jet propulsion

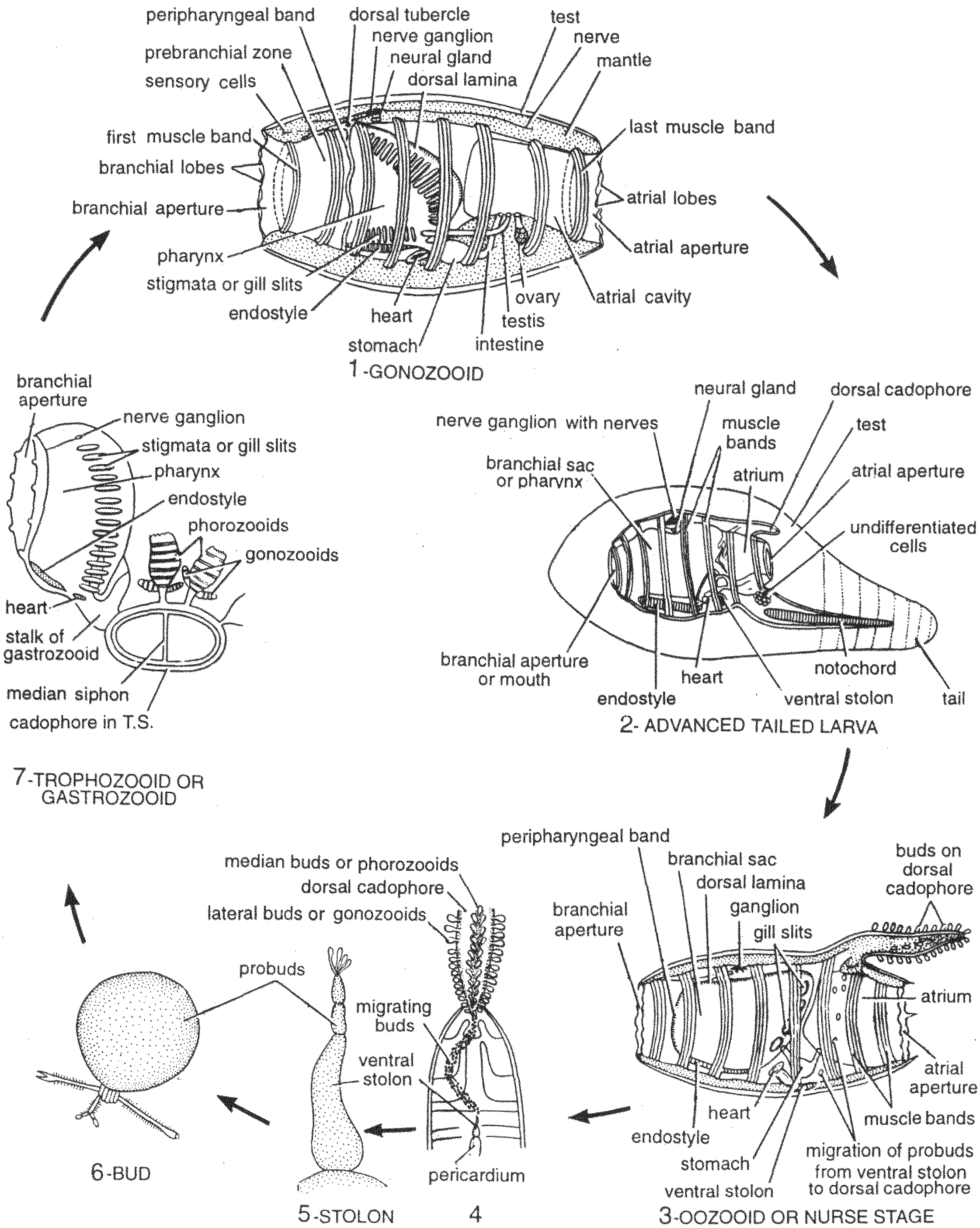

Fig. 8. *Doliolum.* Structure and life cycle. 1-Sexual gonozooid in lateral view. 2-Advanced tailed larva. 3-Asexual oozooid or nurse stage. 4-Dorsal view of posterior aspect of oozooid showing migratory path of buds from ventral stolon to dorsal cadophore. 5-Ventral stolon giving out buds. 6-A young migratory bud. 7-Trophozooid developing sterile phorozooids and sexual gonozooids.

driving out water through atrial aperture by contraction of muscles. The spacious pharynx is perforated posteriorly by dorsal and ventral rows of gill-slits. Dorsal lamina is absent but endostyle, peripharyngeal bands and dorsal tubercle occur. A dorsal nerve ganglion and subneural gland lie behind the third anterior muscle band. Heart lies mid-ventrally, posterior to endostyle. Sexes are united. Testis lies near the endosytle and ovary behind it. Ovary matures first. Fertilization is external. Zygote develops into a tailed larva which acquires eight muscle bands and metamorphoses into the asexual gregaria phase called the *burse* or *oozooid*.

(b) Oozooid. It resembles the gonozooid in form (barrel-like) and anatomy, but lacks gonads. Branchial and atrial apertures have 10 and 12 lobes respectively and muscle bands are 9. Gill-slits are few but large. The most characteristic features are two processes—a large postero-dorsal *cadophore*, and a small ventral *stolon* arising behind the 5th muscle band. The stolon gives rise to a large number of *probuds* which crawl over body to reach the cadophore on which they arrange into three rows. The buds of the two lateral rows are converted into *trophozooids* or *gastrozooids*. They are sterile, remain attached with the parent colony and serve for its nutrition and respiration. Some buds of the median row develop into *phorozooids*. These are also sterile, but detach from the parent colony. They serve as nurses for other median buds which become attached to their stalks and develop into sexual *gonozooids*. After attaining sexual maturity the gonozooids break off to become independent solitary phase. Thus, life-history of *Doliolum* exhibits polymorphism and alternation of generations.

8. *Salpa.* *Salpa* is a cosmopolitan, marine, and typical pelagic ascidian distributed in almost all

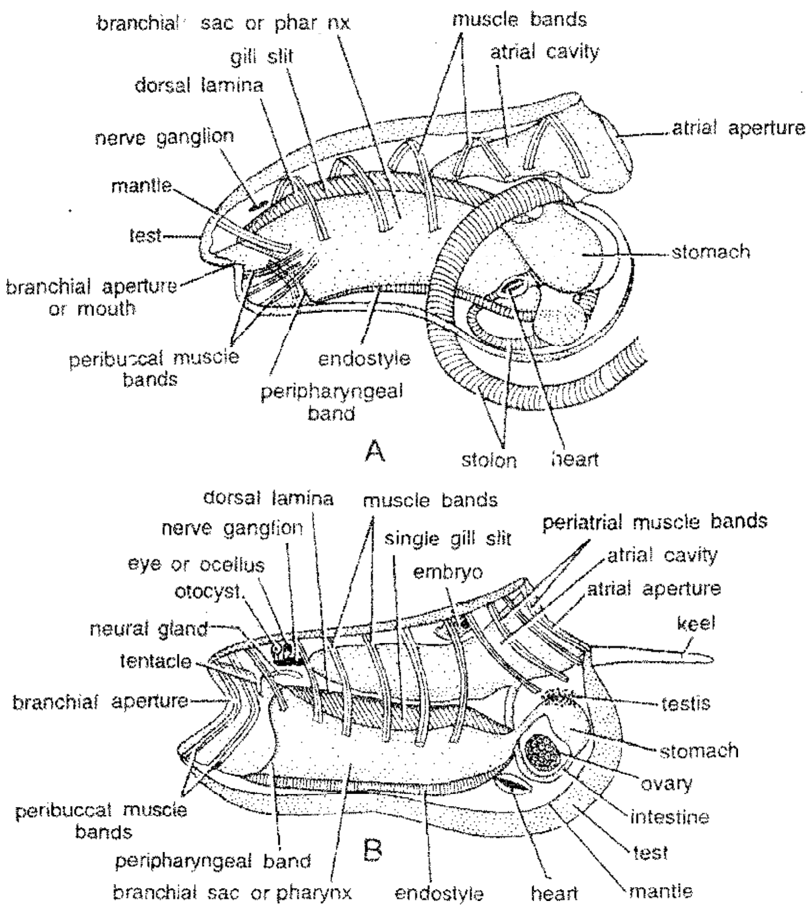

Fig. 9. *Salpa*. A—Oozooid in left lateral view. B—Blastozooid in left lateral view.

seas. It is dimorphic, exhibits alternation of generations and superficially resembles *Doliolum*, but there are several differences. Its solitary phase is asexual *oozooid*, while gregaria phase is sexual *gonozooid* or *blastozooid*. In contrast, in *Doliolum*, the solitary phase is sexual gonozooid and gregaria phase, asexual oozooid (Fig. 9).

(a) Oozooid. The solitary asexual individual or oozooid is prism-like or quadrangular, bilaterally symmetrical and having branchial (mouth) and atrial (anus) apertures at opposite ends. Test is thin and transparent. Except the first and ninth muscle bands, which are complete and form sphincters, the remaining seven muscle bands are incomplete ventrally. The mouth, bounded by dorsal and ventral lips, leads into a large pharynx with endostyle and a dorsal lamina forming a ciliated gill bar. The pharynx communicates laterally on either side with the atrium through a single large gill-slit. Oesophagus, stomach, intestine and pyloric gland form a compat mass called *nucleus*. Heart lies mid-ventrally behind the endostyle. An eyespot (ocellus) is present above the nerve ganglion. A complex process, the *stolon*, arises between heart and endostyle, projects near the atriopore and forms a chain of buds which break off to become the gregaria sexual gonozooids or blastozooids.

(b) Blastozooids. The sexual phase or blastozooid differs from the asexual oozooid in being smaller and asymmetrical, having fewer muscle bands, without stolon and test processes, and having gonads (ovary and testis). Ovary produces a single ovum at a time. Fertilization and development are internal and a tailed larval stage is absent. Embryo is nourished by a diffused placenta and directly develops into an asexual oozooid with stolon which escapes into the surrounding water. *Salpa* is thus viviparous. In course of time the oozooid develops a chain of blastozooids from its stolon.

9. Oikopleura. *Oikopleura* is a neotenous, free-swimming, pelagic, tiny and solitary larvacean genus distributed in all seas except the polar regions. It consists of a house containing the body proper (Fig. 10).

(a) House. The gelatinous enclosure or house is transparent, loosely attached and not made of tunicin. It is somewhat egg-shaped with a projecting beak and is much larger than the body proper. It is secreted by the animal itself oikoplastic epithelium a special part of body and renewed periodically. The house is designed as an elaborate food filtering device with several openings. The water flow is maintained by the

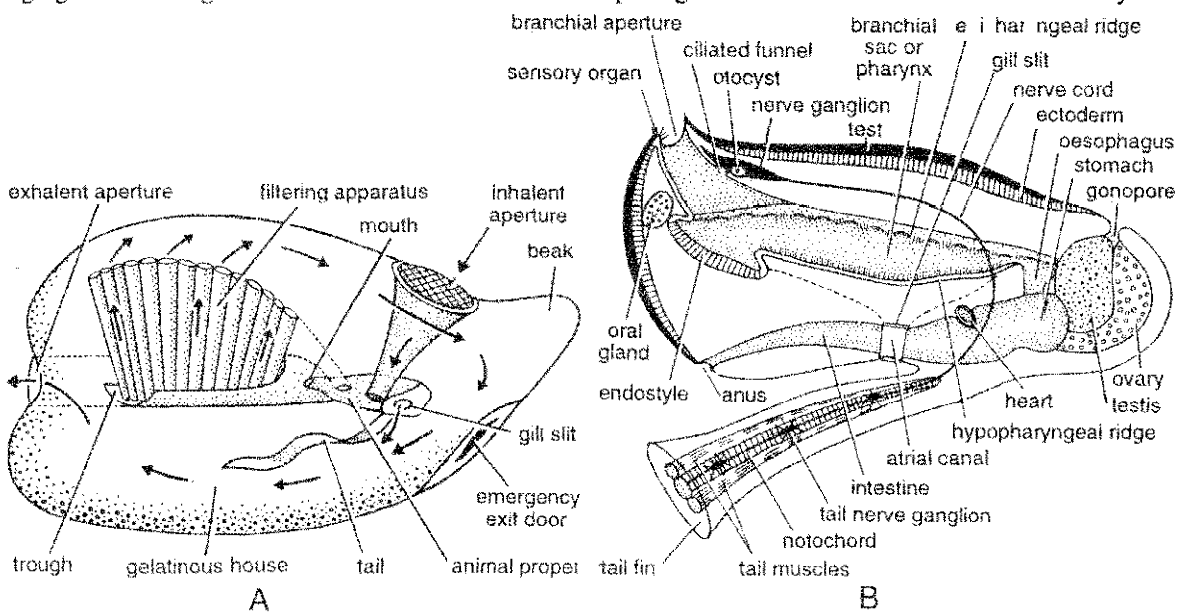

Fig. 10. *Oikopleura*. A—Animal enclosed in a secreted house. B—Animal in sagittal section.

undulating movements of the tail. Water-enters the house through a pair of *inhalent apertures*, each covered by a filter to prevent sand and larger particles. An efficient *filtering apparatus* made of sieve tubes present in the middle of the house further filters minute organisms which are sucked into the mouth. The water current leaves the house through a posterior *exhalent aperture* with a valve. An *emergency exit door* serves for the escape of animal in danger. The animal never re-enters the house but secretes a new one.

(b) Body proper. It measures about 2 mm in size. It includes a stout rounded *trunk* and a laterally compressed and forwardly directed ventral *tail*. The anterior mouth leads into a wide pharynx, having two large gill-slits, a short endostyle, peripharyngeal bands and a mid-ventral retropharyngeal ridge, but no dorsal lamina. Alimentary canal is V-shaped and the anus opens antero-ventrally. Atrial cavity is absent. A cerebral ganglion and an otocyst lie above pharynx but a neural gland is absent. Heart is present below the stomach. A large hermaphrodite gonad occupies the posterior trunk region and the animal is protandrous. The tail is narrow at the base, supported by a notochord, contains a nerve cord and unsegmented muscles, is surrounded by a wide and continuous tail fin, and forms an efficient locomotory organ. The larva has a straight tail which is bent underneath the trunk in the adult. The larva is neotenous as it does not undergo metamorphosis but becomes sexually mature by developing gonad.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Classify the subphylum Urochordata up to orders, giving characters of each group.

» *Short Answer Type Questions*

1. List the important characteristic features of subphylum Urochordata.
2. Write short notes on—(i) *Botryllus*, (ii) *Doliolum*, (iii) Larvacea, (iv) *Molgula*, (v) *Salpa*.

» *Multiple Choice Questions*

1. Urochordates are mostly :
   (a) Sedentary (b) Pelagic (c) Nektons (d) Benthos
2. Adult urochordates have :
   (a) Sac-like body with paired appendages
   (b) Degenerate, sac-like, unsegmented body
   (c) Unsegmented body, with a prominent tail
   (d) Well developed, segmented body
3. In urochordates notochord is present :
   (a) Throughout the body (b) In the abdominal region
   (c) Only in larval tail (d) Larval pharynx
4. In urochordates respiration occurs through :
   (a) Test and gill slits (b) Test
   (c) Gill slits (d) Branchial basket
5. Excretion in urochordates is through :
   (a) Nephrocytes (b) Neural glands
   (c) Glomerulus
   (d) Neural glands, pyloric glands and nephrocytes
6. Dorsal tubular nerve cord of the larval stage is changed to :
   (a) A single dorsal nerve ganglion in adult
   (b) A pair of nerve ganglion in adult
   (c) A single ventral nerve ganglion in adult
   (d) A single lateral nerve ganglion in adult
7. In urochordates development is :
   (a) Indirect with retrogressive metamorphosis
   (b) Direct with retrogressive metamorphosis

(c) Indirect with progressive metamorphosis
(d) Direct with progressive metamorphosis

8. Which of the following shows phosphorescence :
(a) *Herdmania* (b) *Pyrosoma* (c) *Doliolum* (d) *Salpa*

9. Which of the following urochordates is viviparous :
(a) *Herdmania* (b) *Ascidia* (c) *Ciona* (d) *Clavellina*

10. Name the connecting link between simple and compound ascidians :
(a) *Herdmania* (b) *Clavellina* (c) *Cliona* (d) *Molgula*

11. Which of the following exhibits polymorphism and alteration of generation :
(a) *Clavellina* (b) *Doliolum*
(c) *Molgula* (d) *Botryllus*

12. Which muscle bands are complete in oozoid of *Salpa*.
(a) 1st and 5th (b) 5th and 9th
(c) 1st and 9th (d) 1st and 7th

13. Which of the following urochordates is pelagic in habit :
(a) *Herdmania* (b) *Botryllus*
(c) *Molgula* (d) *Salpa* and *Oikopleura*

14. The body proper of *Oikopleura* is enclosed in :
(a) Test (b) House
(c) Cocoon (d) Pupa

ANSWERS

1. (a) 2. (b) 3. (c) 4. (a) 5. (d) 6. (a) 7. (a) 8. (b) 9. (d) 10. (b) 11. (b) 12. (c) 13. (d) 14. (b)

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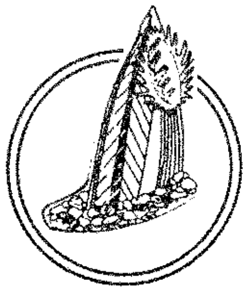


Type 3. *Branchiostoma* (=*Amphioxus*) : The Lancelet

The members of the subphylum Cephalochordata are small, marine and superficially fish-like chordates. They are of special significance because they possess the three distinctive or primary chordate characters such as notochord, dorsal tubular nerve cord and pharyngeal gill slits, in simple condition throughout life. Thus, they display the simple primitive chordate condition and are considered a blueprint of the phylum Chordata. The most extensively studied cephalochordate type, and also the best known example of protochordates is *Branchiostoma* (= *Amphioxus*) commonly called as '*lancelet*' or '*lancet*'. It was first described by the German scientist Pallas in 1778. He considered it to be a slug (phylum Mollusca) and named it *Limax lanceolatus*. An Italian scientist Costa (1834) first recognized its chordate nature and described it as *Branchiostoma lanceolatum*. Two years later (1836), Yarrel named it as *Amphioxus lanceolatus*.

Systematic Position

Phylum	Chordata
Group	Acrania
Subphylum	Cephalochordata
Class	Leptocardii
Family	Branchiostomidae
	Type *Branchiostoma* (=*Amphioxus*)
	(The Lancelet)

Derivation of Names

The name of the subphylum Cephalochordata (Gr., *kephale*=head + *chorde* = cord) is derived from the fact that the notochord extends forward inside rostrum even beyond the so-called brain. This feature is encountered no where else in chordates. As they lack a skull, the cephalochordates are also called *Acrania* (Gr., *a*=absent + *kranion* = skull). The old generic name *Amphioxus* (Gr., *amphi*= double + *oxys* = sharp) and the common name 'lancet' or 'lancelet' (a little lance) refer to both ends of the body which are sharp, pointed and lance-like. The correct generic name is *Branchiostoma* according to the law of priority, and the name 'Amphioxus' is retained as a common name for cephalochordates in general. However, the name *Amphioxus* is more famous and familiar to zoologists many of whom still use it as a synonym for *Branchiostoma*.

Geographical Distribution

Branchiostoma with about 9 species is almost cosmopolitan, reported from different oceans of the world. It is more common in warmer seas, such as Mediterranean, and especially abundant near the coasts of China and Japan where it is sold as food. The species common on the Indian sea coasts are *Branchiostoma indicum, B. pelagicum* and *B. ceribbaeum*. The following description is based on *B. lanceolatum* which is the best known species.

Habits and Habitat

Branchiostoma is a marine animal commonly found in shallow waters, preferably brackish or salt water, on the sandy coasts. It leads a double mode of life. Mostly it is buried in sand in an upright condition with only the anterior end protruding above the sand. However, at night or dusk, it comes out of the sand and swims actively by lateral undulating movements of its body caused by muscles. It swims vertically in water. When disturbed, it jumps out of its burrow, swims a short distance, dives back into sand keeping head downwards, makes a U-turn inside so that the anterior end comes up again above the sand. *Branchiostoma* is a typical ciliary feeder. It feeds on planktonic micro-organisms brought along with a respiratory-cum-food water current which constantly enters the mouth placed on its projecting anterior end, and leaves through the atriopore. Male and female individuals are separate. They release their gametes in water where fertilization takes place. Development is indirect involving a free-swimming larval stage which gradually changes in to adult (Fig. 1).

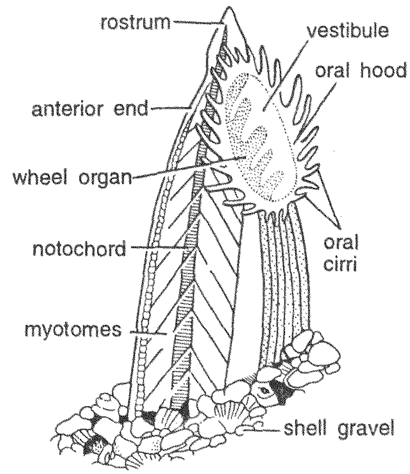


Fig. 1. *Branchiostoma* in natural habitat, partly buried in shell gravel with anterior end protruding.

External Features

Shape, size and colour. *Branchiostoma* is a small elongated narrow and fish-like animal 5 to 8 cm in length. Body is whitish, somewhat translucent, laterally compressed, and pointed at both the ends, hence the common name "lancelet" which means "a little lance". The streamline body is well-suited for burrowing as well as swimming. The posterior end is more tapering and pointed than the anterior end.

Division of body. A true *head* is degenerate and absent. The body is divisible only in two regions. The greater anterior region constitutes the *trunk*, and a much shorter postanal posterior region is the *tail*. The anterior end of trunk projects in front as a pointed *snout* or *rostrum*.

Apertures. The trunk bears three openings : *mouth, atriopore* and *anus*. Anteriorly, below the rostrum is a tentaculated structure, the *oral hood*, formed by dorsal and lateral projections of the body. It shall be described later as a part of the digestive system. *Mouth* is a very wide antero-ventral aperture, bordered by the free margin of oral hood. *Atriopore* is a small mid-ventral rounded aperture, lying just in front of the ventral fin. The large atrial cavity surrounding the pharynx opens to outside through atriopore. Another small

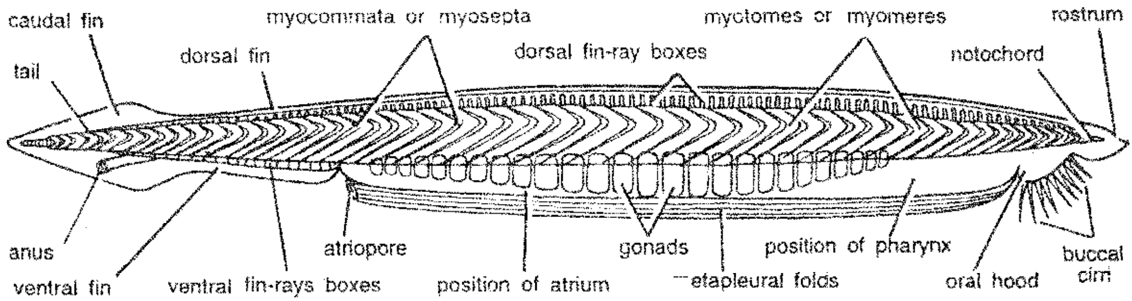


Fig. 2. *Branchiostoma*. Entire animal in right side view.

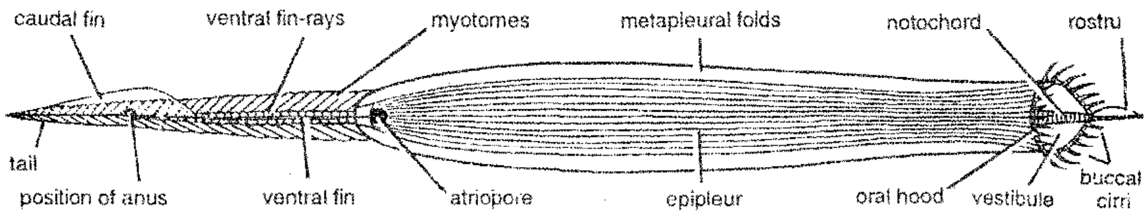


Fig. 3. *Branchiostoma*. Entire animal in ventral view.

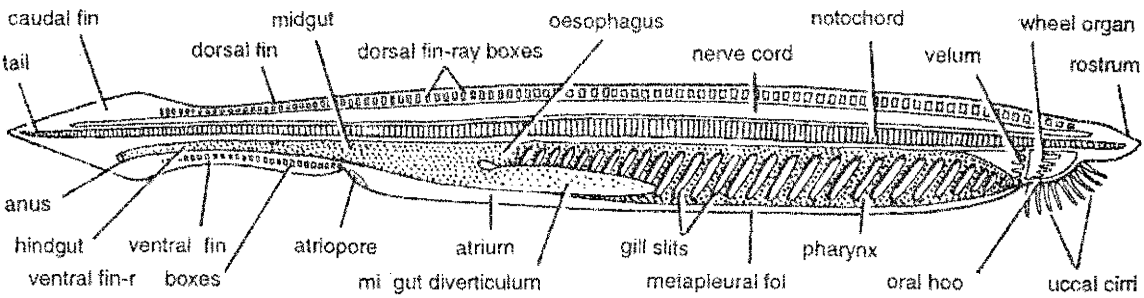


Fig. 4. *Branchiostoma*. General anatomy dissected in left lateral view.

aperture, the *anus*, lies somewhat asymmetrically to the left of mid-ventral line at the base of caudal fin. The small posterior body region behind the anus is the tail.

Fins and folds. *Branchiostoma* bears three longitudinal median or unpaired fins : *dorsal, caudal* and *ventral*. The *dorsal fin* runs as a low, mid-dorsal fold along the entire length of trunk. It is continuous behind, and joins a much broader *caudal fin* around the tail. The *ventral fin* runs mid-ventrally from caudal fin upto atriopore along the posterior trunk region. It is slightly wider than the dorsal fin. The dorsal and ventral fins are internally supported respectively by one and two rows of small rectangular *fin-ray boxes*, each formed by stiff connective tissue containing a central nodule. Fin rays are lacking in the caudal fin. The structure of fins and fin-ray boxes is different from that in fishes (Figs. 2–4).

Paired fins are absent. But, running longitudinally along the ventro-lateral margins of the anterior two-third part of trunk, from oral hood to atripore, there are two hollow membranous *metapleural folds*. These possibly help in burrowing in sand rapidly due to turgescence caused by flow of body lymph in their cavities.

The two folds are connected by a horizontal fold of bodywall, called *epipleur*, which forms the floor of the atrial cavity inside. Thus, the anterior two-third of the body, in the region of metapleural folds, appears roughly triangular in cross-section, while the posterior one-third, in the region of ventral and caudal fins, nearly oval.

Myotomes and gonads. On each lateral side of body a series of ← shaped muscle bands, called *myotomes* or *myomeres* can be seen through the transparent body wall. Between mouth and atriopore, can also be seen on either side below the myotomes, a series of *gonads*.

Body Wall

The body wall includes from outside (i) a thin, delicate and transparent *skin*, (ii) a well-developed *musculature*, and (iii) a parietal *peritoneum* (Fig. 5).

1. Skin. The skin or integument consists of an outer thin *epidermis* made of a single layer of columnar epithelial cells resting on a *basement membrane*. It is ciliated in young individuals, but in mature individuals the cilia are lost and a thin layer of non-pigmented, chitin-like *cuticle*, perforated at places, is secreted externally. The epidermis contains sensory cells but gland cells and pigment cells are absent. Immediately beneath the epidermis is a tough thin, and compact, fibrous connective tissue layer, called *cutis*. Underneath cutis is a thick spongy *subcutis* made of a gelatinous matrix, containing nerve fibres, cells and blood vessels. A few scattered distributed nomadic cells, similar to fibroblasts of vertebrates, secrete both these layers. Both cutis and subcutis are traversed by a system of canals. Being single layered, the epidermis is simple and similar to that of invertebrates as it is stratified in all higher chordates.

2. Musculature. The muscles lying just beneath the skin form the greater part of body wall. They are very thick in the dorso-lateral regions enclosing the nerve cord and notochord. The muscles show distinct metameric segmentation and arranged throughout the length of body in a series of characteristic V-shaped muscle blocks or segments, called *myotomes* or *myomeres*. The

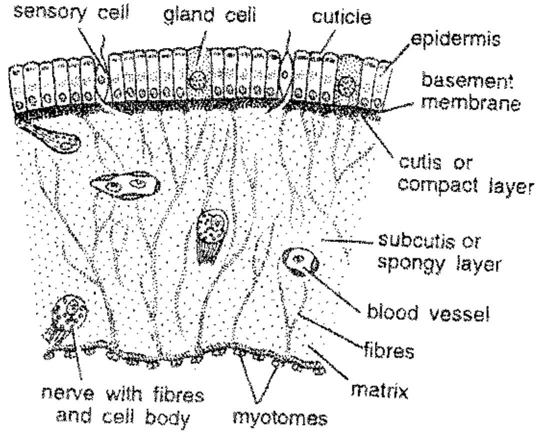


Fig. 5. *Branchiostoma*. V.S. of bodywall.

pointed apex of the V is directed anteriorly. In *B. lanceolatum*, there are 60-62 myotomes on either side and they alternate with those of the opposite side. Myotomes are enveloped in a thin connective tissue layer and separated from adjacent myotomes by connective tissue partitions called *myosepta* or *myocommata*. Due to their peculiar arrangement several myotomes and myocommata are cut in a cross section of the body. In each myotome, the muscle fibres are striped, arranged longitudinally and attached at both the ends to two successive myocommata. The myotomes help in lateral undulating movements of body as they can be twisted sidewise rapidly. There are also *transverse muscles* running across the ventral surface of trunk between the two metapleural folds. Their contractions help in driving water of atrial cavity out of the atriopore.

3. Peritoneum. The muscle layer is lined internally by a thin layer of parietal paritoneum. It is not continuous in the pharyngeal region but restricted to a few patches.

Skeleton

Branchiostoma has no exoskeleton. A number of endoskeletal structures are present but they are neither bony nor cartilaginous (Fig. 6).

1. Notochord. The chief axial endoskeleton is the *notochord*, also known as *chorda dorsalis*. It is an elongated, narrow, cylindrical and rod-like

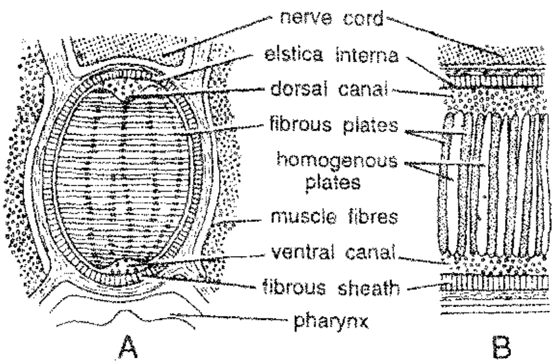


Fig. 6. *Branchiostoma*. Notochord. A—In T.S. B—In L.S.

structure with tapering ends extending from the tip of snout to the tail end. It lies mid-dorsally above the gut and beneath the nerve cord. Its prolongation into snout beyond the brain is remarkable in the chordates and is associated with its burrowing habit. Notochord in early stages of development is made up of large vacuolated cells filled with fluid like secretions. But in adults is composed of a linear series of alternate disc-like fibrous and homogeneous gelatinous plates which make it tough and turgid. Each plate develops from a single highly vacuolated embryonic cell with its nucleus pushed to one side. Externally, the notochord is surrounded by a laminated tough fibrous connective tissue *notochordal sheath* covered by a thin elastic membrane. Notochord does not support the myotomes and other visceral structures like that of vertebral column. The elasticity of notochord permits bending body movements but its rigidly prevents shortening of body when longitudinal muscles contract during locomotion.

2. Other skeletal structures. These include (i) the *fin-ray boxes* supporting the fins. The fin rays are formed of modified connective tissue containing gelatinous substance. The dorsal fin is supported by a single row of fin rays but the ventral fin is supported by two rows of fin rays, (ii) *oral ring* supporting the oral hood and its cirri. The oral ring is made of separate rod like pieces. These lie at the base of the oral cirri, from each of this, rod like prolongations are given out to support the corresponding cirrus. Entire oral

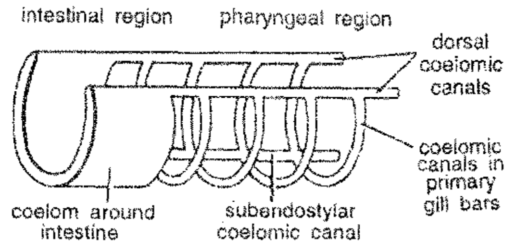


Fig. 7. *Branchiostoma*. Diagrammatic representation of coelom.

hood skeleton is made up of fibrous connective tissue modified into a gelatinous substance, resembling with soft cartilage, (iii) *gill-rods* supporting the gill-bars of the gill-slits. Gill rods are made up of gelatinous substance. They are of two types— *primary rods* and *secondary rods*. Primary gill rods are bifurcated ventrally and secondary rods are single. Dorsally each rod is united with each other. Besides this, cross bars called synapticulae are also found supporting the gill bars. (iv) *endostylar plates* are two in number, supporting the endostyle, and (v) tough fibrous *connective tissue* covering the various organs, beneath epidermis and parietal peritoneum, provides support and rigidity.

Coelom

The body cavity in *Branchiostoma* is a true coelom, lined with the somatic and splanchnic layers of mesoderm and filled with a lymph-like coelomic fluid. It is enterocoelic in origin. Coelom is a spacious cavity around the intestine which remains suspended in it by a dorsal mesentery. On the right side of hindgut, coelom is reduced by a posterior extension of atrial cavity, beyond atriopore and upto the anus. In higher chordates coelom is totally absent in the pharyngeal region, but it is present in a much reduced condition around pharynx of *Branchiostoma*. A pair of *dorsal longitudinal coelomic canals* are present one on either side above the pharynx enclosing the brown funnels. A mid-ventral longitudinal *subendostylar coelomic canal* runs below the endostyle. Connecting the two on either side are *vertical coelomic canals* running through the primary gill bars. Besides, small coelomic spaces are also present within the gonads (*gonocoel*) and around the midgut or liver diverticulum (Fig. 7).

Atrium

The atrial cavity or atrium is a large body space other than coelom, lined by an atrial epithelium of ectodermal origin. It is formed by a pair of metapleural folds, one on either side above the gill-slits of embryo, growing downwards and united ventrally by a transverse fold, thus enclosing an outside space lined by ectoderm within the body. In the adult, the atrium surrounds the pharynx and the intestine laterally as well as ventrally. Thus, in *Branchiostoma*, the gill-slits open into the atrium and not directly to the exterior as in other chordates. In turn, the atrium opens to outside through a small rounded mid-ventral aperture, the *atriopore*, lying just in front of the ventral fin. Posteriorly, the atrium further extends behind the atriopore as a blind pouch on the right side of intestine up to anus. Anteriorly, the atrium projects into each dorsal coelomic canal on either side of pharynx forming the *brown funnel* or *atriocoelomic* canal, whose function is unknown. The atrium protects the delicate pharyngeal region.

Movement and Locomotion

By nature, *Branchiostoma* is a sluggish animal. However, it swims, by the contraction of longitudinal muscle fibers of the myotomes, if disturbed. The contraction of myotomes causes transverse motion of the body at different angles, because of which, the animal can move in the forward direction. All the myotomes contract rhythmically in the antereo-posterior direction, i.e., a myotome contracts after that in front of it. The animal moves forward by the propulsive movement of myotomes. The myotomes produce waves of contraction from anterior to posterior side through water. The location of myotomes on the lateral sides of the notochord forms a supporting structure. The notochord prevents shortening of the body length, during the contraction of muscle fibers of myotomes. The elasticity of the notochord makes the contraction of the body more efficient. Since the notochord acts as a lever upon which the myotomes work. Although the myotomes lack direct connection with the notochord, the myocommas are attached to the notochordal sheath.

Because of absence of elaborate fin system, the *Branchiostoma* cannot move very fast. The caudal fin is feebly developed. It resists transverse movements of the body, but can accelerate transverse movement in times of emergency.

Digestive System

The digestive system consists of an *alimentary canal* and *digestive glands*.

[I] Alimentary canal

The alimentary canal is a straight and complete tube from mouth to anus. It is lined throughout by ciliated epithelium and its diameter varies in different parts (Figs. 8–24).

1. Mouth. Mouth is a large oval median aperture situated antero-ventrally below the rostrum or anteriormost tip of the trunk. It is bordered by a frill-like membrane, the *oral hood*.

2. Oral hood and buccal cavity. The oral hood is formed by the dorsal and lateral projections of the anterior end of trunk (Fig. 10).

(a) Buccal cirri. Free ventro-lateral edge or margin of oral hood is beset with 10 to 11 pairs of stiff, slender and ciliated *oral* or *buccal cirri* (or *tentacles*) which bear sensory papillae. Their number increases with age. The buccal cirri and the edge of oral hood are internally supported by stiff, gelatinous *skeletal rods*. The buccal cirri form a sieve or filter to prevent entry of larger particle with food current.

(b) Vestibule. The oral hood encloses a large funnel-shaped cavity called *buccal cavity* or *vestibule* into which opens the mouth. As this cavity is lined with ectoderm, it is regarded as *stomodaeum* and its external opening the *true mouth*.

(c) Wheel organ. Basally, the epithelial lining of oral hood forms 6 to 8 pairs of finger-like folds

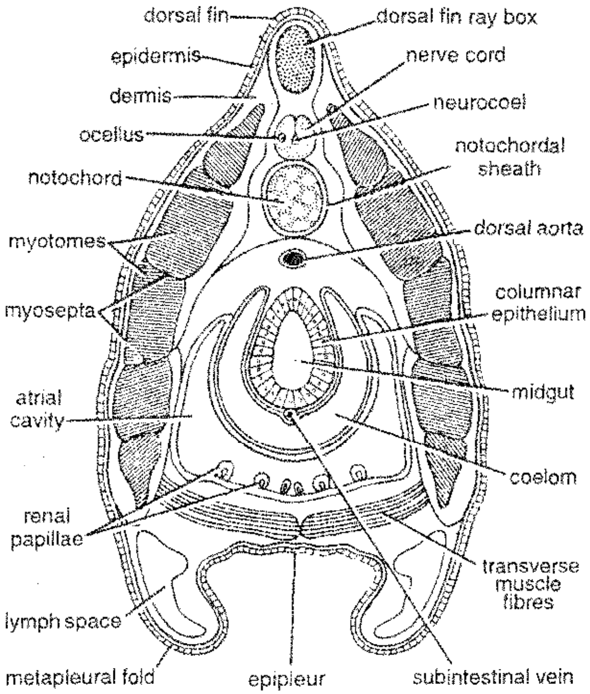


Fig. 8. *Branchiostoma*. T.S. through midgut in front of atriopore.

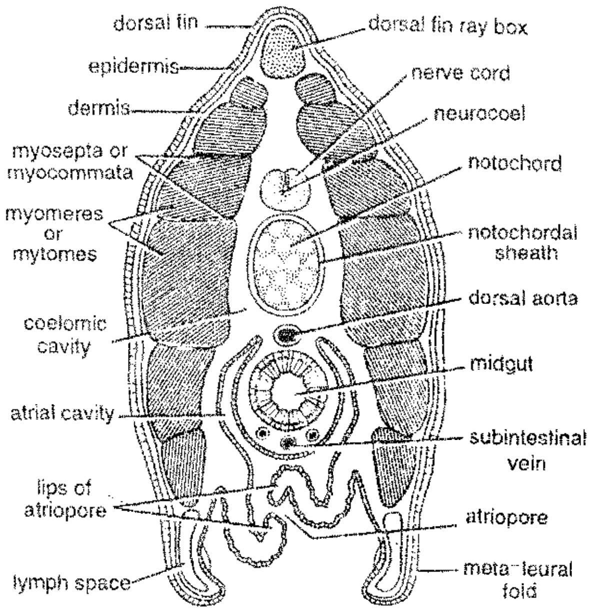


Fig. 9. *Branchiostoma*. T.S. through atriopore.

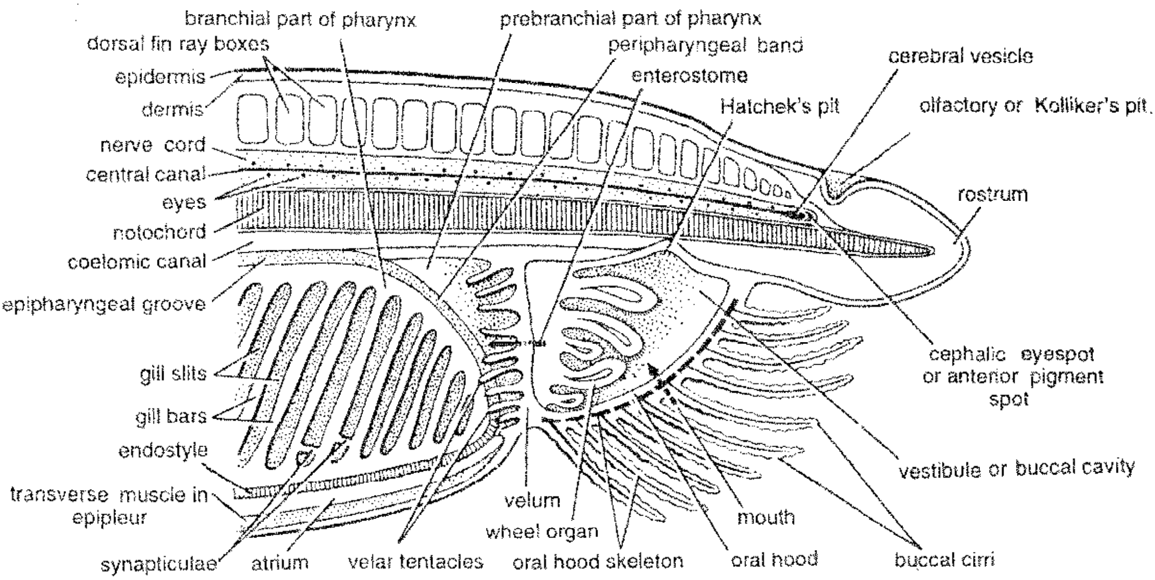


Fig. 10. *Branchiostoma*. Enlarged L.S. of anterior end in right lateral view.

or patches each formed by a ciliated groove bounded by a ciliated ridge. Collectively these form a *wheel organ* or *rotatory organ* or *Muller's organ*. As in rotifers, the cilia of wheel organ set up a vortex or whirling water current to sweep food organisms into mouth. The mid-dorsal groove is the largest which ends in a small depression on the roof of buccal cavity. These are named

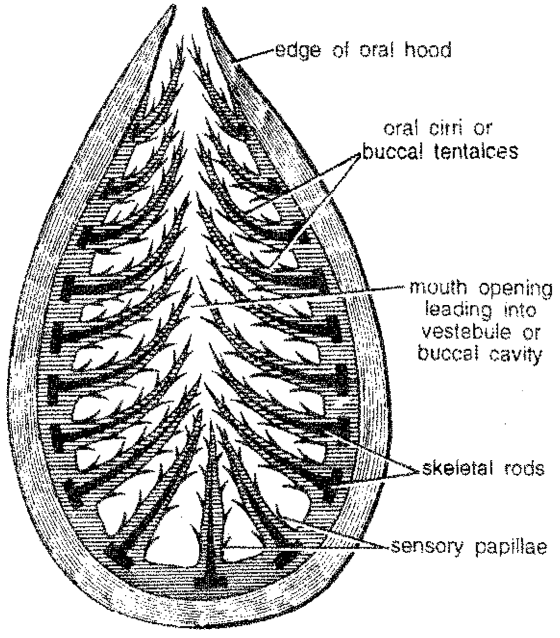


Fig. 11. *Branchiostoma.* Oral hood.

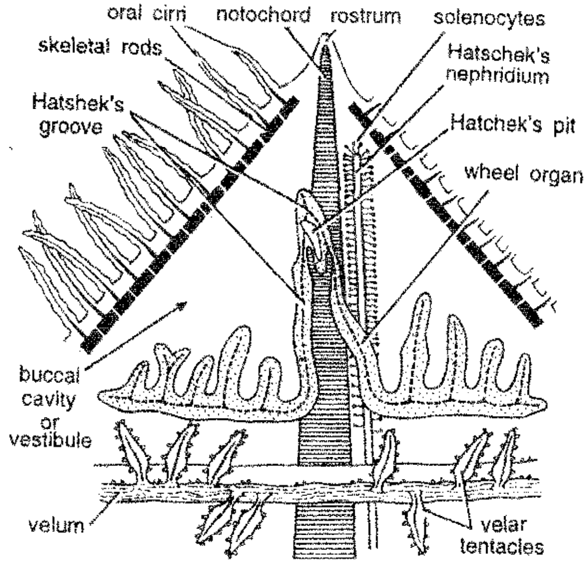


Fig. 13. *Branchiostoma.* Dorsal wall of oral hood in ventral view to show wheel organ and Hatschek's pit, groove and nephridium.

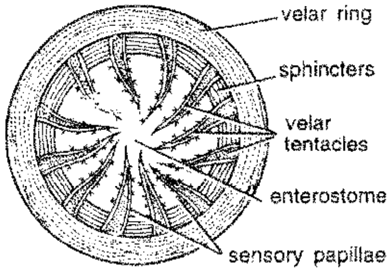


Fig. 14. *Branchiostoma.* Wheel organ.

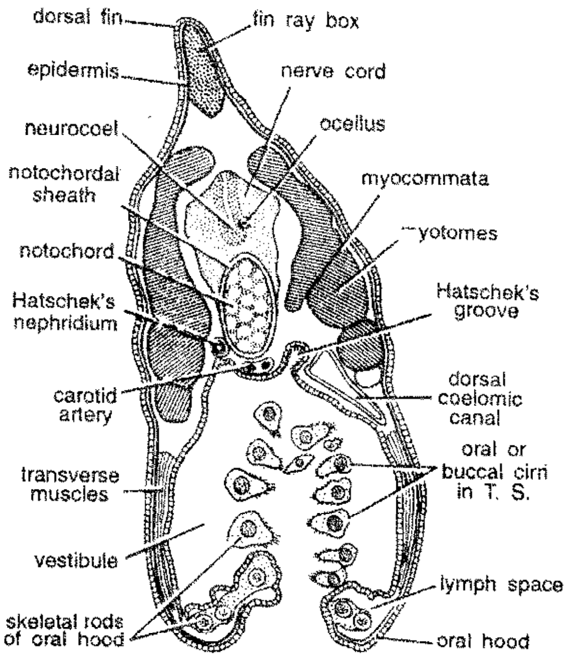


Fig. 12. *Branchiostoma.* T.S. through oral hood.

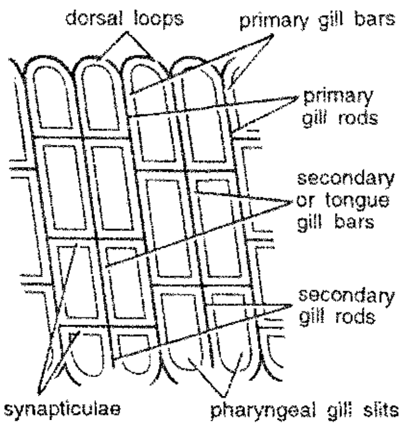


Fig. 15. *Branchiostoma.* A part of pharyngeal wall to show gill slits, gill bars and skeletal rods.

Hatschek's groove and *Hatschek's pit,* respectively. Both are ciliated, glandular and secrete mucus, while the pit is also considered a sensory organ of unknown function.

3. Velum and enterostome. Posteriorly, the vestibule is closed by a circular ring-like vertical membrane, the *velum.* It is perforated by a central circular aperture, the *enterostome*, leading into the pharynx behind. The enterostome is erroneously called mouth by some authors, but it does not correspond to the mouth of other chordates because it opens into pharynx lined with endoderm. The true mouth opens into stomodaeum lined with ectoderm. The velum is provided with a *sphincter* to open or close the enterostome. The posterior border of velum is produced into 10 or 12 slender, ciliated and sensory *velar tentacles.* They also serve to strain the water current entering through the enterostome.

4. Pharynx. Pharynx is a very large, spacious and laterally compressed chamber forming the largest part of alimentary canal. It occupies nearly one-half anterior part of body and remains suspended in the atrial or peribranchial cavity which surrounds it on all sides except the dorsal.

(a) Pharyngeal wall and gill slits. The lateral walls of pharynx are perforated by 150 to 200 pairs of closely and obliquely set narrow and vertical openings called *branchial apertures, gill-slits* or *gill-clefts,* through which the pharyngeal cavity communicates with the atrial cavity. The gill-slits bear no gills and their number increases with the age of the animal on the posterior side of pharynx. The portion of pharyngeal wall between two adjacent gill slits is called a *branchial lamella* or *gill bar.*

A gill bar consists of a ciliated epithelial covering, both ectodermal and endodermal, enclosing a mesodermal core containing fibrous connective tissue, blood vessels and a supporting galatinous *skeletal rod.* The *ciliation* over the gill bars is not uniform. The outer or atrial surface is covered by sparsely ciliated ectodermal epithelium.

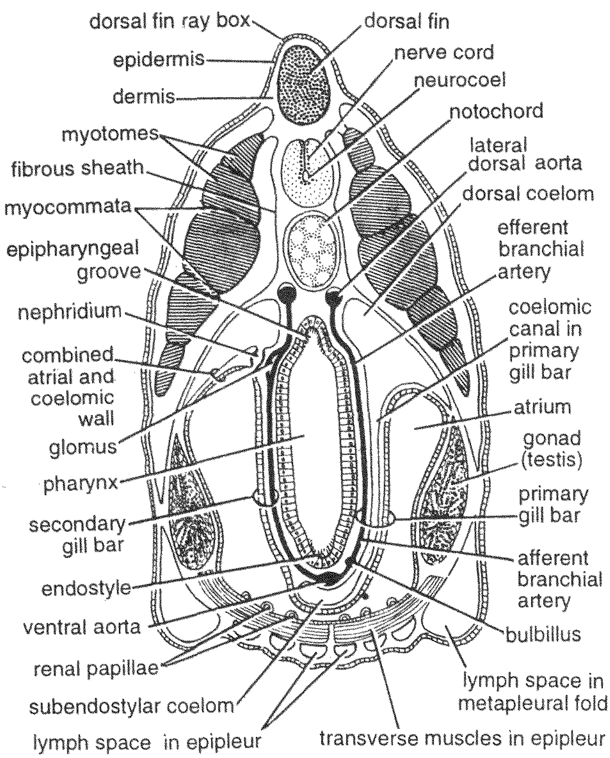


Fig. 16. *Branchiostoma.* T.S. pharyngeal region passing through primary gill bar on right, a secondary gill bar on left and gonads (testes).

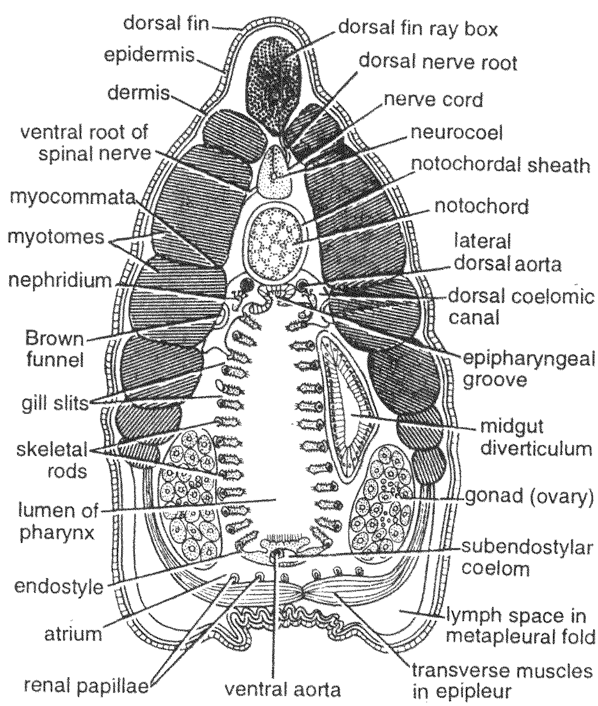


Fig. 17. *Branchiostoma.* T.S. passing through midgut diverticulum and gonads (ovaries).

Cilia covering the endodermal epithelium of anterior and posterior surfaces are long and dense, called *lateral cilia*. Cilia present on a narrow tract of endodermal epithelium on the inner or pharyngeal side are specially long and called *frontal cilia*.

The pharyngeal gill bars are of two types, *primary* and *secondary*, which regularly alternate with each other and also differ in structure and mode of development. The skeletal rod of a *primary gill bar* is called *primary gill rod*. Its lower free end is forked and it encloses a blood vessel and a coelomic canal throughout its length. A *secondary gill bar* develops as a small *tongue bar* which grows downwards from the dorsal wall of a primary gill slit. It finally meets the ventral wall so that the original primary slit is divided into two *secondary gill slits*. The skeletal rod of a secondary gill bar is called *secondary gill rod*. Its terminal ventral end is simple, i.e., unforked and it encloses a blood vessel but no coelomic canal. The primary gill bars are interconnected by a system of *transverse bars* or *synapticula* which impart a basket-like appearance to the pharynx similar to the branchial sac of tunicates. A synapticulum also contains a blood vessel and a skeletal rod.

(b) Endostyle. A hypobranchial tract or an endostyle, similar to that of *Herdmania*, extends mid-ventrally along the entire floor of pharynx. It forms a shallow groove with four longitudinal tracts of mucus-secreting gland cells alternating with five tracts of ciliated cells. The cilia of the median tract are the longest. The endostyle is supported below by two gelatinous skeletal plates under which is present the sub-endostylar coelomic canal containing the ventral aorta. According to Barrington (1968) the endostyle is converted into thyroid gland of vertebrates. Like thyroid, it concentrates radioactive iodine in itself.

(c) Epipharyngeal groove. The hyper-pharyngeal or epipharyngeal groove is a prominent ciliated groove present mid-dorsally along the roof of pharynx. Posteriorly it runs up to the oesophageal opening.

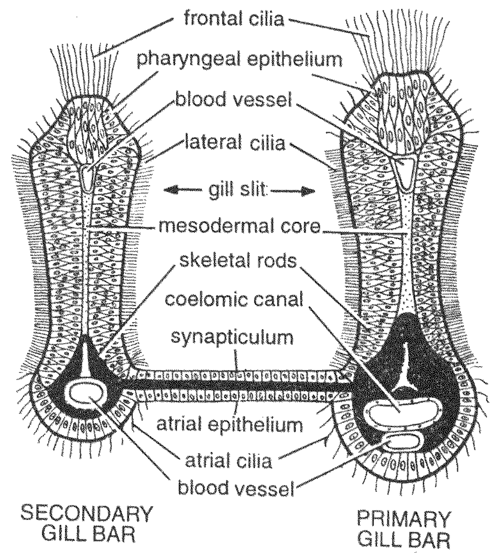


Fig. 18. *Branchiostoma.* Structure of primary and secondary gill bars in T.S.

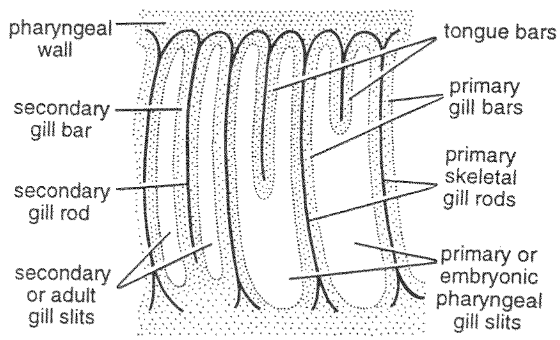


Fig. 19. *Branchiostoma.* Development of secondary gill bars and gill slits.

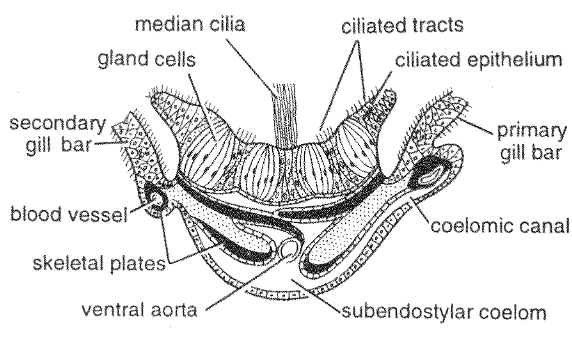


Fig. 20. *Branchiostoma.* Endostyle in T.S.

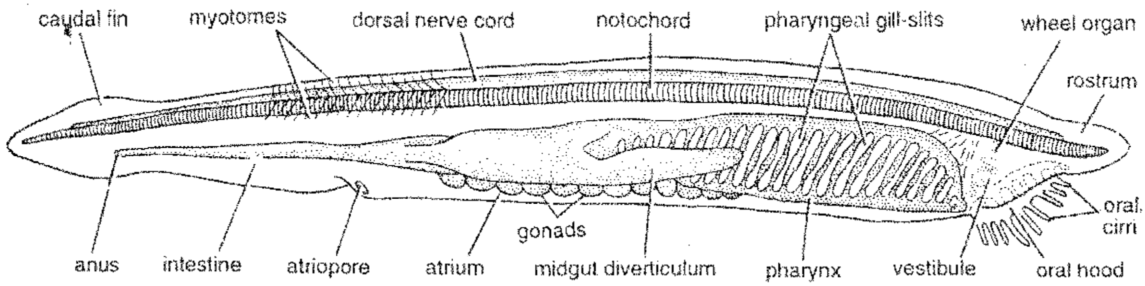


Fig. 21. *Branchiostoma.* Dissection of alimentary canal in left lateral view.

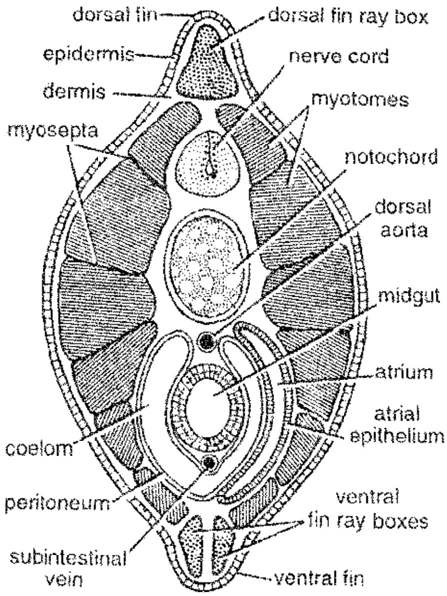


Fig. 22. *Branchiostoma.* T.S. of intestinal region behind atriopore.

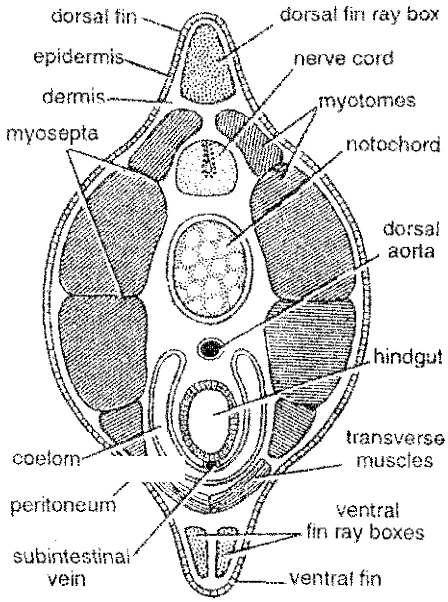


Fig. 23. *Branchiostoma.* T. S. intestine just in front of anus.

(d) Peripharyngeal bands. These are a pair of narrow ciliated tracts arising from the anterior end of endostyle. They run obliquely upwards and backwards, one along either lateral wall of pharynx, to unite dorsally with the anterior end of epipharyngeal groove. These bands demarcate a small, antero-dorsal *prebranchial region* of pharynx devoid of gill slits.

5. Oesophagus. Posteriorly the pharynx opens into a short narrow and tubular oesophagus having ciliated internal lining and leading into the gut or intestine.

6. Intestine. The gut or intestine is as long as the pharynx. It is suspended from the dorsal bodywall by a dorsal mesentery into the atrial cavity. It is covered by a thin layer of smooth muscles and its internal epithelial lining has several ciliated tracts. The intestine can be differentiated into three parts. The anterior, relatively wider part is *midgut.* A large blind pouch or *diverticulum* arises from the junction of oesophagus and midgut towards right side. The lining of midgut on the right lateral side bears a crescentic *lateral ciliary tract.* Its cilia beat downwards directing food into the midgut diverticulum. Midgut is followed by a densely ciliated *ilio-colic ring* whose ciliary action rotates the mucous cord containing food. The *hindgut* that follows in narrower. Its terminal part or *rectum* is heavily ciliated and opens to outside by anus.

7. Anus. It is a small circular aperture controlled by a sphincter. It opens at the base of caudal fin a little left of the mid-ventral line.

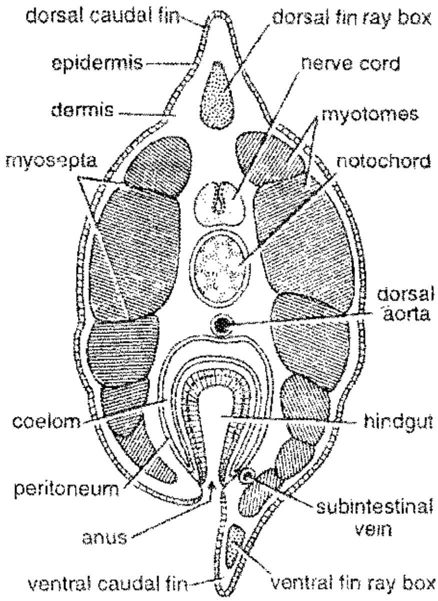


Fig. 24. *Branchiostoma.* T.S. through anal pore.

[II] Digestive glands

The *midgut diverticulum*, often referred to as '*liver*', is the main digestive gland. It arises as a blind pouch from the ventral junction of oesophagus and midgut and extends forward into atrial cavity on the right side of pharynx upto one-third of its length. It is surrounded by a narrow coelomic cavity. Its inner lining has a strong ciliated groove for movement of food. Its zymogen cells secrete a number of digestive enzymes. Besides, the epithelial lining of intestine also contains numerous *gland cells* that secrete digestive enzymes.

[III] Physiology of digestive system

1. Food. *Branchiostoma* is a microphagus animal feeding on diatoms, desmids, protozoans and other pelagic microscopic organisms, suspended in sea water.

2. Feeding mechanism. *Branchiostoma* is a *ciliary* or *filter feeder*, like an ascidian. The animal leads a sedentary life buried in sand and with only the anterior body end protruding out into water. Food particles are filtered from the current of water entering pharynx through mouth

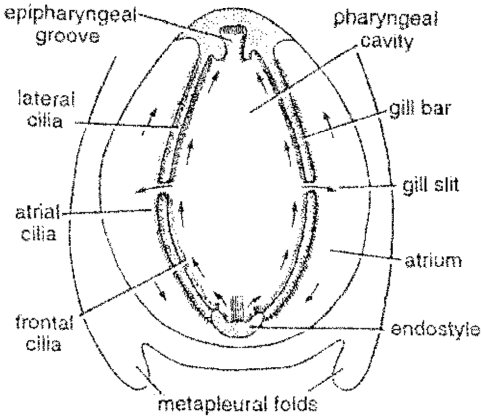


Fig. 25. *Branchiostoma.* Course of feeding current in diagrammatic T.S. of pharynx and atrium.

and finally going out through atriopore. The rotatory movements of cilia of wheel organ cause a whorling current of water into mouth. The buccal cirri fringing the oral hood turn inwards to form a fine mesh or sieve that prevents the entry of larger food and sand particles. While passing through enterostome the water current is further filtered by the velar tentacles so that only very fine food particles enter the pharynx. The chaemoreceptors present on buccal cirri and velar tentacles probably serve to test the nature of water current and food particles. Food particles, that escape the main current, are caught up and concentrated by the mucus secreted by the Hatschek's groove and pit in the oral hood. These food particles are pushed through enterostome into pharynx by the whorling action of wheel organ and join the main current. The ingres of water into pharynx is controlled by the velum (Figs.25 & 26).

Periodically, the atriopore closes and the transverse muscles of the atrial floor undergo sudden contraction. This sets up a reversal of water current or *rejection current* ejecting out forcefully through the enterostome and mouth. As a result the velar tentacles and buccal cirri are able to shed off larger food or sand particles accumulated on them.

Pharynx plays the most important part in food collection. The outward beating of lateral cilia on gill bars and atrial cilia on their outer surface

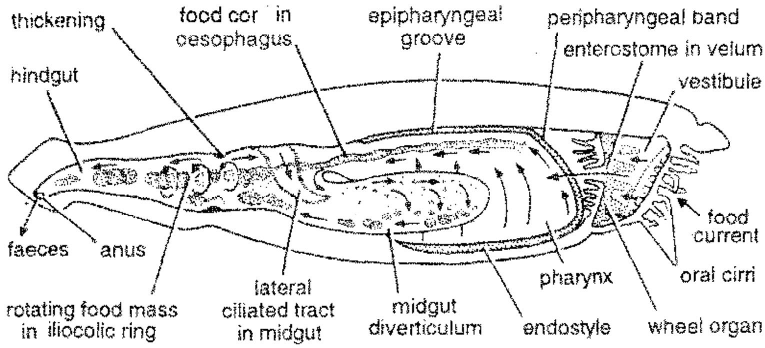


Fig. 26. *Branchiostoma.* Movements of ciliary currents and food in the alimentary canal.

drive the water current through gill slits into atrium and finally passing out through atriopore. This also facilitates the inflow of fresh water current through mouth.

Inside pharynx, the food particles get entrapped in mucus secreted by the glandular tracts of endostyle and by pharyngeal epithelium. The endostylar cilia and the frontal cilia of gill bars beat upwards so that mucous sheets laden with food particles move dorsally to the epipharyngeal groove. The food particles settling down in the prebranchial region of pharynx are also swept up by the cilia of peripharyngeal bands to the mid-dorsal epipharyngeal groove. The cilia of epipharyngeal groove beat backwards moving the food-laden mucus into the oesophagus in the form of a narrow *food cord* or *food cylinder*.

The controlling mechanism of ciliary mode of feeding in *Branchiostoma* is not understood clearly. The afferent and efferent nerve fibres in the atrium possibly play important role in feeding. Moreover, the rate of flow of water inside is also controlled by intensity of beating of cilia and also by degree of contraction and relaxation of inhalant and exhalant apertures. Bone (1960) experimently showed that after ingestion of sufficient food, collection is stopped until food already taken in is digested.

3. Digestion. Digestive enzymes are secreted from two sources, midgut diverticulum and the midgut epithelium. The food cord from pharynx passes through oesophagus into midgut. By lateral tract of cilia it is directed into midgut diverticulum and driven again to midgut by ciliary action. Digestion starts in the midgut and continues in the remaining part of intestine. In the ilio-colic ring, the food cord undergoes rotation due to ciliary activity. This breaks up the food material into still smaller particles, thoroughly mixes up enzymes with food and delays the backward passage of food to allow more time for the action of enzymes. Digestion is mainly *extracellular* but *intracellular* digestion also takes place which is unique as it is unknown in other vertebrates. Intracellular digestion takes place mainly in the phagocytic cells of midgut diverticulum. The digestive enzymes of *Branchiostoma* according to Barrington are amylase, lipase and protease. Pepsin is absent in the digestive enzymes of *Branchiostoma* unlike other vertebrates. Digested food is absorbed partly in midgut but mostly in hindgut and the undigested material is finally thrown out of anus.

Occasionally, some food particles may pass into atrial cavity and eventually engulfed by the phagocytic cells present in renal papillae on the floor of atrial cavity.

Respiratory Mechanism

Special respiratory organs are lacking. The pharyngeal wall of *Branchiostoma* is richly vascular and the water current entering the pharyngeal cavity brings fresh O_2. The blood flows so close to the surface that some exchange between CO_2 of blood and O_2 of water can easily

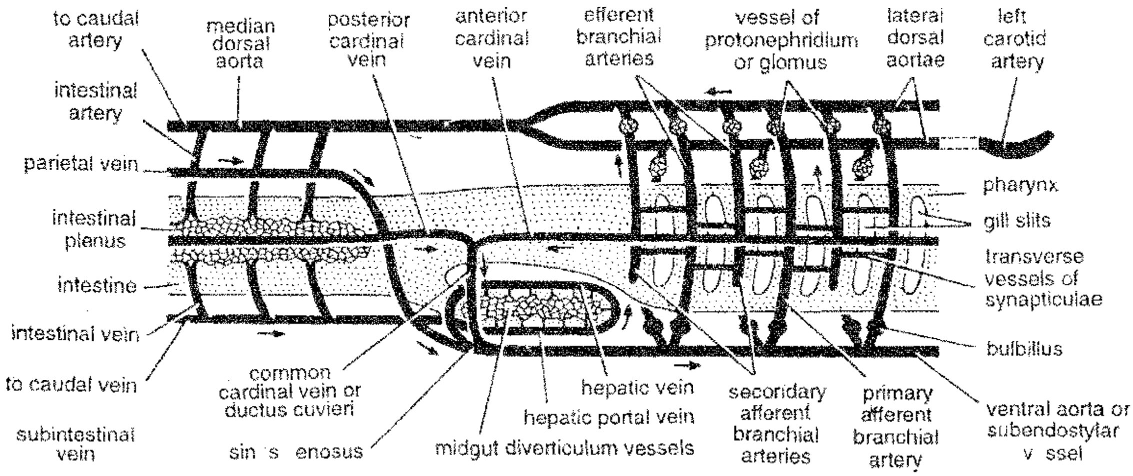


Fig. 27. *Branchiostoma.* Blood vascular system in right lateral view.

occur. But there is no capillary network in gill bars. Further, the blood lacks a respiratory pigment. Therefore, many workers question about the respiratory role of pharynx. It is probable that most gaseous exchange occurs through superficial areas such as fins, metapleural folds and atrial wall containing lymph spaces.

Blood Vascular System

Circulatory system of *Branchiostoma* is of the closed type, well developed and peculiar in many ways. *Blood* is colourless due to lack of any respiratory pigment and corpuscles. Besides blood vessels it also occurs in some lymph spaces such as in metapleural folds and the dorsal and ventral fins. Its main function seems to be the transportation of food and excretory products rather than O_2 and CO_2 for gaseous exchange.

A *heart* is lacking so that all blood vessels are muscular and contractile in nature. Except dorsal aorta, they lack an endothelial lining. There is no structural difference between *arteries* and *veins*, but these names are being given due to their homologies with blood vessels of higher chordates. The principal vessels and their branches are as follows :

1. Sinus venosus. It is a small, thin-walled sac present just below the posterior end of pharynx or midgut diverticulum. Blood from different parts of the body is collected by sinus venosus through a number of veins, and pumped forward into the ventral aorta.

2. Ventral aorta. It is a large median longitudinal artery extending forward from sinus venosus. It runs mid-ventrally in the wall of pharynx below the endostyle in the subendostylar coelom, hence also named as the *subendostylar aorta.* Blood flows in it anteriorly due to rhythmic contractions of its muscular walls. The ventral aorta gives off a series of paired lateral *afferent branchial arteries*, one running through each primary gill bar of pharynx. At the base of gill bar each branchial artery forms a pulsatile tiny bulb called *bulbillus* or *bulbule* (pleural *bulbilli* or *bulbuli*), which helps in circulating blood. Through *transverse vessels* running in synapticulae, the different branchial vessels of primary gill bars are connected to those of secondary gill bars.

The afferent vessels leave the pharynx dorsally as such in the form of *efferent branchial vessels* which open into a *lateral dorsal aorta* of that side. Before doing so, each efferent vessel splits into a small capillary network, the *nephric glomerular sinus* or *glomus*, in relation with a nephridium.

3. Dorsal aorta. Two longitudinal vessels, *right* and *left lateral dorsal aortae*, lie one on either dorso-lateral side of pharynx. They continue anteriorly as *internal carotid arteries* to supply the oral hood region. The right artery is somewhat

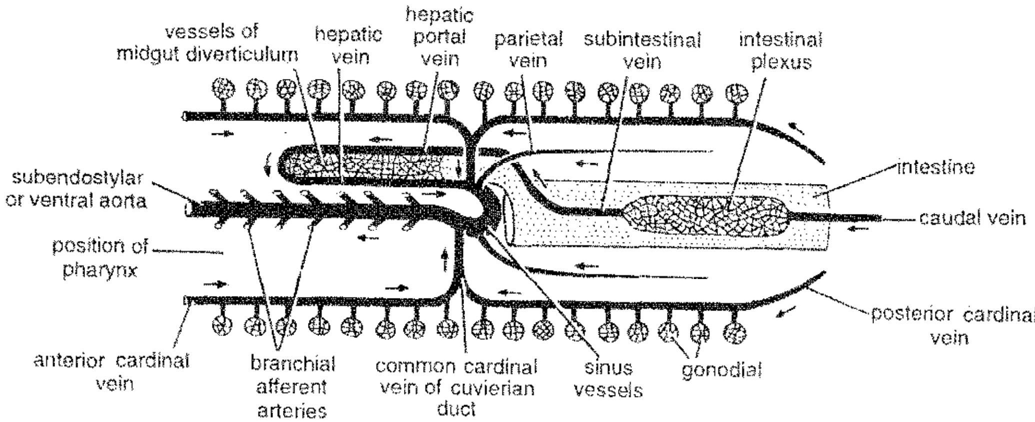


Fig. 28. *Branchiostoma*. Blood vascular system in dorsal view.

dilated. The two lateral aortae unite just behind the pharynx into a single *median dorsal aorta* which runs posteriorly between the notochord and intestine and enters the tail region as the *caudal artery*. Blood flows backwards in the dorsal aortae. From lateral and median dorsal aortae branches lead into myocoel, the lymph space between myotomes and body wall. Besides, the median dorsal aorta supplies blood through several *intestinal arteries* forming a capillary network or *plexus* in the intestinal wall.

4. Sub-intestinal vein. The blood from tail region is collected by a mid-ventral *caudal vein* and from intestine by lateral *intestinal veins*. These join a small median longitudinal *subintestinal vein* lying below the intestine in the form of a plexus. Blood flows in it anteriorly.

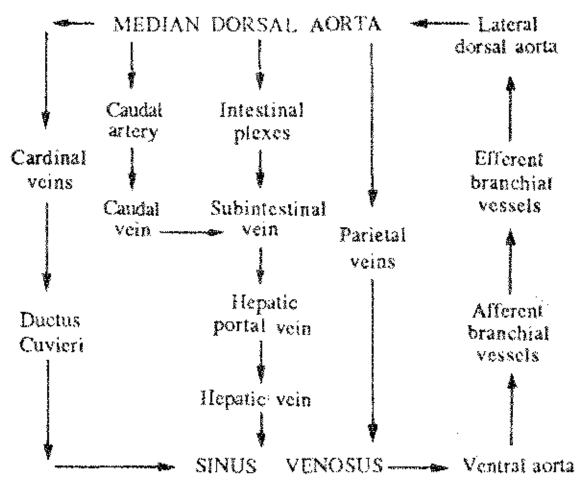
5. Hepatic portal system. The subintestinal vein continues anteriorly as the *hepatic portal vein* running ventrally along the midgut diverticulum into which it breaks up in a capillary network. From midgut diverticulum, blood is collected by a *hepatic vein* running along its dorsal border and bending downwards to join the sinus venosus. Hepatic portal system occurring for the first time in *Branchiostoma* is a precursor of that of higher chordates.

6. Cardinal veins. The blood from ventro-lateral region of body is collected on either side by an *anterior* and a *posterior cardinal vein*. The two unite just behind the pharynx to form a *common cardinal vein* or *ductus Cuvieri*. The two ductus Curieri then run down through the atrium to join the sinus venosus.

7. Parietal veins. Blood from dorsal body wall is collected by a pair of *parietal veins* one on either side. They run above the intestine for some distance and then turn ventrally to join the sinus venosus.

8. Course of circulation. Blood flows anteriorly inside parietal, subintestinal and posterior cardinal veins and ventral aorta. It flows posteriorly inside lateral and median dorsal aortae and anterior cardinal vein. The course of circulation can be graphically represented as shown.

9. Lymphatic system. Lymph as such is lacking. The so-called lymphatic spaces or sinuses present inside fins and metapleural folds, are filled with colourless blood lacking in leucocytes. It is



regarded that most of the oxygen required by the animal is obtained by gaseous exchange between outside water and blood inside these superficial sinuses.

Excretory System

While excretory organs of other chordates are coelomoducts or mesodermal kidneys, those of *Branchiostoma* are entirely different. In *Branchiostoma*, the nephridia developes from the ectodermal cells and have no relation with mesoderm. Thus, they are different from the kidney of vertebrates which are mesodermal in origin. They closely resemble the protonephridia of flatworms or polychaete annelids, thus providing a good example of parallel evolution. Some other organs and cells are also regarded to be excretory.

1. Protonephridia. The protonephridia of amphioxus are simple, closed, ciliated, sac-like and thin-walled ectodermal tubules. 90 to 100 pairs are present segmentally on dorso-lateral pharyngeal wall, one above each gill slit on either side. Each nephridium is bent forming a small upper posterior *horizontal limb* and a long lower anterior *vertical limb*. The vertical limb lies in the coelomic canal of the primary gill bar and terminates blindly. The horizontal limb also lies in the dorsal coelomic canal but opens into the atrium opposite a secondary gill bar by a small ciliated aperture, the *nephridiopore*. The dorsal and anterior surface of nephridium gives out several small branches, each receiving a tuft of flame cells called *solenocytes*. A nephridium bears about 500 solenocytes. Each solenocyte is nearly 50μ long and consists of a tiny rounded nucleated cell body and a long hollow stalk or tubule that opens into the lumen of nephridial branch through a separate aperture. A long vibratile *flagellum* arising from a minute basal body in the cell, extends through the tubule and projects freely into the lumen of nephridium.

The nephridia are richly supplied with blood vessels and the solenocytes freely project into coelomic fluid. Excretion occurs by simple diffusion. Nitrogenous wastes are extracted by solenocytes from blood and coelomic fluid, discharged by nephridiopores into the atrium and

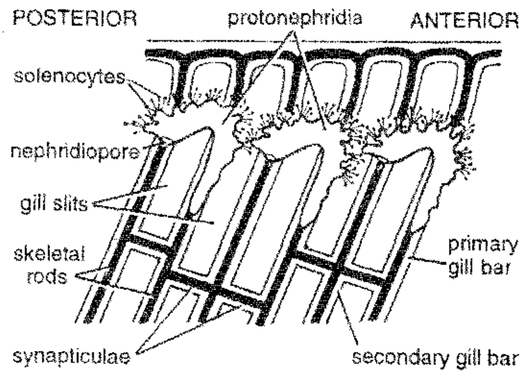


Fig. 29. *Branchiostoma*. Position of nephridia lying on pharyngeal wall.

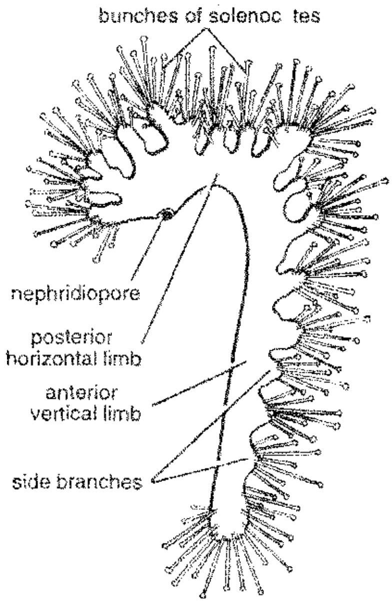


Fig. 30. *Branchiostoma*.. Entire protonephridium.

passed out of body through atriopore with the outgoing water current. As already mentioned, presence of protonephridia in amphioxus is quite peculiar since they do not occur in any other chordate (Figs. 30 & 31).

2. Hatschek's nephridium. A single long and straight tube, called the *nephridium of Hatschek*, lies in the roof of oral hood slightly towards left and ventral to notochord. Its anterior blind end lies somewhat ahead of the Hatschek's pit, but the posterior end opens into the prebranchial sac of pharynx. It is ectodermal in origin and supplied blood by the dorsal aorta. Its structure is basically

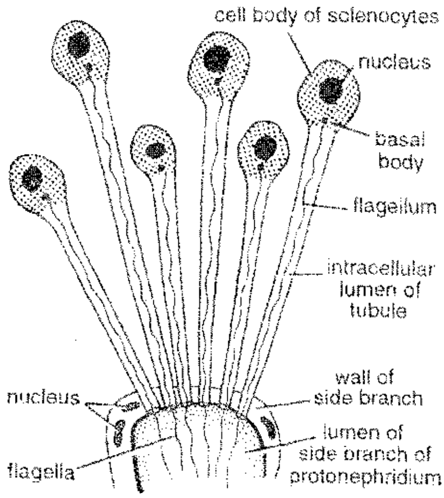


Fig. 31. *Branchiostoma*. An enlarged view of solenocytes.

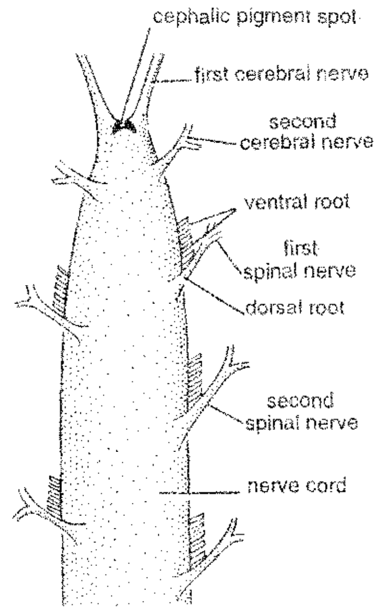


Fig. 32. *Branchiostoma*. Anterior part of nerve cord in dorsal view.

like that of protonephridium already described. Its surface is covered by a number of solenocytes each surrounded by a coelomic sac and extracting nitrogenous wastes.

3. Brown funnels. The two sac-like brown funnels are situated dorsally upon the posterior end of pharynx, one on either side. The narrow anterior end of each funnel opens into the epibranchial or dorsal coelomic canal of its side, while the broad posterior end opens into the atrium. Most workers consider the funnels to be excretory while some regard them to be receptor organs.

4. Renal papillae. Groups of cells present on the floor of atrial cavity, form renal papillae which are probably also excretory in function.

Besides these, group of cells in the atrial wall also serves the excretory function. Moreover, inside the gonads, specially in testes, yellow masses are found containing uric acid which are expelled with gametes also play important role in removal of nitrogenous excretory metabolites.

Nervous System

Nervous system is very much simplified. A well developed brain, as found in higher chordates, is absent (Figs. 32 & 35).

1. Nerve cord. The central nervous system of *Branchiostoma* includes a hollow dorsal *neural tube* or *nerve cord* lying mid-dorsally just above the notochord. It has no ganglia. Its anterior end terminates abruptly in the rostrum just behind the anterior end of notochord. It shows a slight enlargement, the so-called brain or *cerebral vesicle*. The posterior part, called the *spinal cord*, gradually tapers to end, just before the posterior end of notochord. A narrow central canal, called *neurocoel*, runs throughout the length of neural tube and filled with a *cerebro-spinal fluid*. It dilates within the cerebral vesicle forming its *ventricle*. From its roof, arises a pouch-like blind *dorsal diverticulum* the extends behind over the central canal for a short distance. The cerebral vesicle contains two important receptor organs, a *pigment spot* in its anterior wall and an *infundibular organ* on its floor. Histologically, the nerve cord resembles that of other vertebrates. It consists of inner *grey matter* of *nerve cells* surrounding the central canal, and outer *white matter* of *nerve fibres*. As in annelid worms, some *giant neurons* with longitudinal *giant nerve fibres* are present in its dorsal wall. These enable the animal to contract suddenly and violently in case of danger.

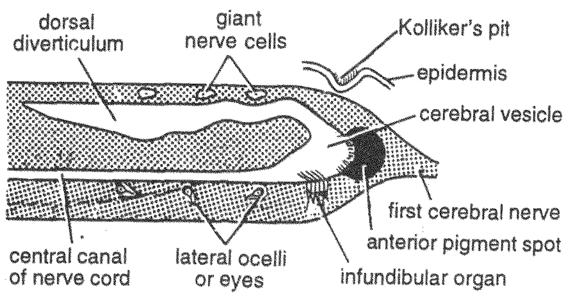


Fig. 33. *Branchiostoma.* V. L. S. anterior part of nerve cord.

2. Nerves. The peripheral nervous system includes *paired nerves* arising from nerve cord. The first two pairs arising from cephalic vesicle are called *cerebral nerves.* They lack ventral roots. These are purely sensory in nature and convey impulses from receptors of snout, oral hood and buccal cirri to the nerve cord.

Nerves arising from nerve cord behind the cerebral vesicle are called *spinal nerves.* One pair of these arises on either side in each segment. Each pair of spinal nerves actually includes separate *dorsal* and *ventral nerve roots* which do not unite to form a single mixed spinal nerve as in vertebrates. Dorsal nerve root is both sensory and motor (mixed) and passes out to skin between myotomes. The ventral nerve root is motor and arises opposite to the myotome which it supplies. Thus, the dorsal and ventral roots of pair do not originate at the same level, but the dorsal root of one side lies opposite the ventral root of the other side. While the dorsal root is single, the ventral root is made of several branches. Nerves of amphioxus are primitive and non-myelinated, i.e., not covered by a sheath of myelin as seen in the nerves of vertebrates.

3. Autonomic nervous system. It consists of two nerve plexes in the gut wall connected to nerve cord by visceral nerves leaving through dorsal roots in each segment. The autonomous system controls the involuntary muscles of the gut wall. Sympathetic ganglia are lacking.

Sense Organs (Receptors)

Amphioxus has simple and various types of receptor organs as follows :

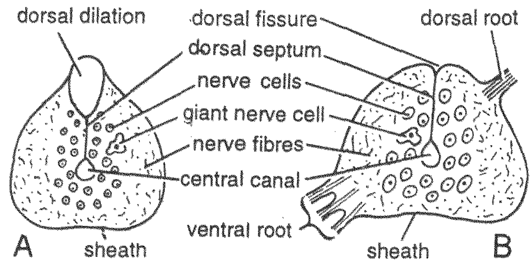


Fig. 34. *Branchiostoma.* T.S. nerve cord. A—through cerebral vesicle. B—Through nerve roots.

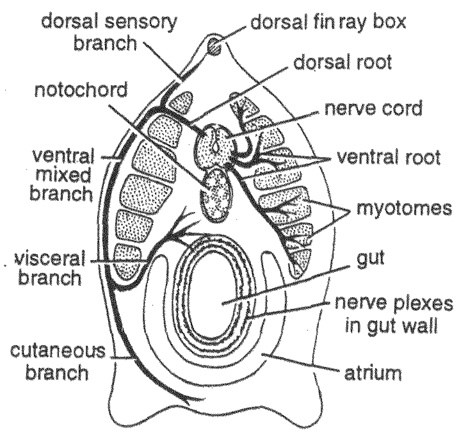


Fig. 35. *Branchiostoma.* Distribution of dorsal and ventral nerve roots.

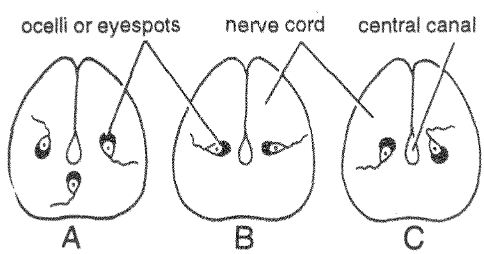


Fig. 36. *Branchiostoma.* Orientation of eyes in different regions of nerve cord.

1. Eye spots or ocelli. These are photoreceptor or light-sensitive organs distributed on the ventro-lateral sides of nerve cord. They are oriented in different directions and help the animal in burrowing in sand or in swimming spirally to perceive light from all directions. An eyespot or ocellus is made up of two cells, an outer *pigment cell* or *melanocyte* and an inner *photosensitive cell* with a striated apical border which serves as a

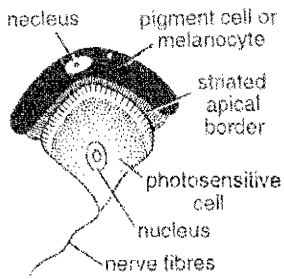


Fig. 37. *Branchiostoma*. An eye.

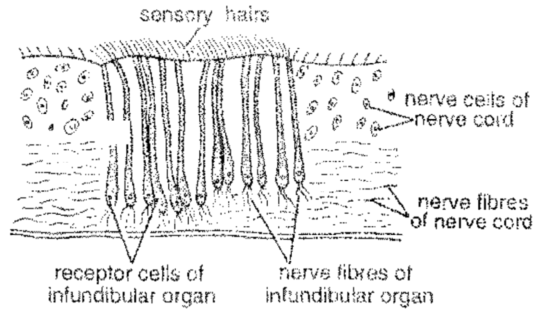


Fig. 38. *Branchiostoma*. V.S. infundibular region.

lens. The photosensitive cell sends a fine nerve fibre to the nerve cord (Figs. 36 & 37).

2. Cephalic pigment spot. It is a large pigmented spot on the anterior wall of cerebral vesicle. It is often referred to as cerebral eye, but it lacks a lens and is also not photosensitive. It is supposed to shield the ocelli from any frontal stimulation by light and probably acts as a thermoreceptor.

3. Infundibular organ. It is located at the floor of cerebral ventricle and so named because of its homology with the infundibulum of vertebrate brain. It consists of a patch of tall, columnar and strongly ciliated epithelial cells. Internally the organ gives out a fine *Reissner's fibre* which extends posteriorly inside the neurocoel. The exact function of infundibular organ is uncertain. The various functions assigned are detection of pressure in the cerebro-spinal fluid (rheo-reception), perceiving the shadow cast by cephalic pigment spot (photoreception), or neurosecretion (Fig. 38).

4. Kollicker's pit. It is a depression of ciliated ectodermal cells on the roof in the anterior region of cerebral vesicle. It marks the area where larval neuropore closes when the adult neural tube is formed. It lacks sensory cells but it is considered an olfactory chaemoreceptor due to its position corresponding with the single nostril of cyclostomes.

5. Hatschek's groove. The pit and groove of Hatschek present in the roof of oral hood are consi ered sensory organs of unknown function.

6. Sensory cells and papillae. Sensory cells are scattered all over the epidermis, especially on the dorsal side. Groups of sensory cells or papillae are present on oral cirri and velar tentacles. These are chaemoreceptors and tactile organs.

7. Free nerve endings. Besides above sensory organs, which are exteroreceptors, there are also present some enteroreceptors in the form of free nerve endings in muscles. These are sensitive to internal stimuli such as contractions of muscles (proprioreceptors).

Reproductive System

In *Amphioxus*, the two *sexes* are separate but there is no *sexual dimorphism* as male and female individuals look identical.

Gonads. The adult has 26 to 27 pairs of similar gonads, arranged metamerically in two rows, one pair in each segment from 25 to 51. The gonads are situated ventro-laterally from middle of pharyngeal region upto the atriopore. They are clearly visible through the transparent bodywall arranged in a linear series on either ventro-lateral side beneath the myotomes. Gonads are simple hollow sacs, mesodermal in origin and bulging conspicuously into the atrial cavity. They

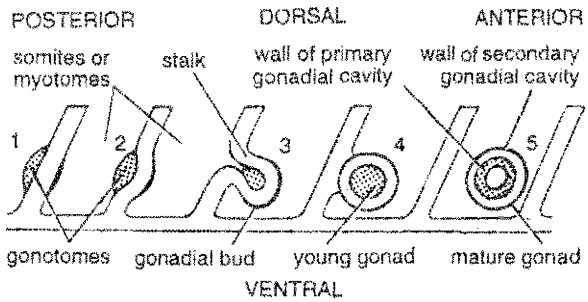


Fig. 39. *Branchiostoma*. Stages of origin and development of a gonad.

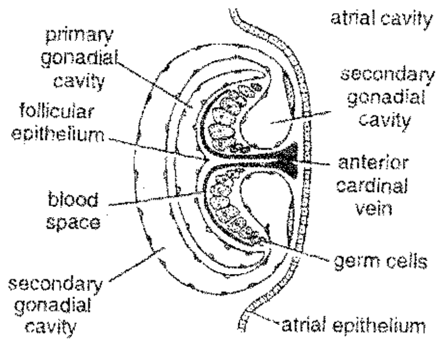


Fig. 40. *Branchiostoma.* V.S. mature gonad.

are covered on the outer side by the bodywall and on the inner side by the atrial epithelium. Each gonad contains an outer *secondary gonadial cavity* or *gonocoel* around and an inner *primary gonadial cavity* surrounding a group of *germ cells* which arise from its wall (Figs. 39 & 40).

Gametes. Mature ovaries or testes can be identified only in sections because of the different structure of spermatozoa and ova they contain. A testis presents a streaky appearance due to presence of spermatozoa. The mature sperm of *Branchiostoma*, one of the smallest among chordates, is about 18 μ in length. It consists of the usual nucleated head with acrosome, a middle piece and long tail. The ovary contains ova which are large and somewhat rounded cells each 0.1

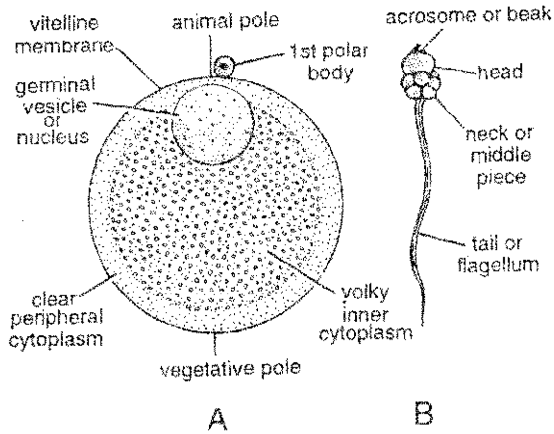


Fig. 41. *Branchiostoma.* Mature gametes. A—Unfertilized ovum. B—Sperm.

mm in diameter and having a large nucleus. They are microlecithal or poor in yolk content (Fig. 41).

Gonoducts are absent. Mature gametes are discharged into the atrium by rupture or dehiscence of gonadial wall along certain weaker spots called *cicatrices* which afterwards close. The gametes so liberated, escape through atriopore with the outgoing water current.

Development. *Fertilization* and *development* take place externally is sea water and have been discussed in chapter 44 in the section of Embryology.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the habitat, habits and external characters of lancelet.
2. Describe the digestive system of *Branchiostoma* and mention its feeding mechanism.
3. Give an account of nervous system and sense organs of *Amphioxus*.
4. Describe the blood vascular system of *Branchiostoma*.
5. Describe the excretory system of *Amphioxus*.

» *Short Answer Type Questions*

1. Draw neat and well labeled diagrams of *Amphioxus*—(i) General anatomy, (ii) T.S. of oral hood, (iii) T. S. through pharyngeal region, (iv) T. S. through intestinal region, (v) T. S. through caudal region.
2. Write short notes on—(i) Atriopore, (ii) Endostyle, (iii) Hatschek's nephridium, (iv) Oral hood, (v) Typical nephridium, (vi) Velum, (vii) Wheel organ.

» *Multiple Choice Questions*

1. Coelom in *Amphioxus* is :
   (a) Enterocoelic in origin (b) Schizocoelic in origin
   (c) Pseudocoelom (d) Absent altogether
2. Atrium in *Branchiostoma* is formed by :
   (a) Folding of endoderm (b) Folding of mesoderm
   (c) Folding of ectoderm (d) A pair of meta pleural folds
3. In *Branchiostoma* gill slits open :
   (a) Into the coelom (b) Directly to the exterior
   (c) Into the atrium (d) Into the pharynx
4. Mouth in *Branchiostoma* is bordered by :
   (a) Oral cirri (b) Oral hood
   (c) Oral frill (d) Oral tentacles
5. Wheel organ is a part of :
   (a) Mouth (b) Oral hood (c) Velum (d) Pharynx
6. Pharyngeal wall between two adjacent gill slits is called :
   (a) Gill clefts (b) Branchial aperture
   (c) Branchial lamellae (d) Gill lamellae
7. The primary gill rod encloses :
   (a) A blood vessel only
   (b) A blood vessel and coelomic canal
   (c) A coelomic canal
   (d) A coelomic canal and a central cavity
8. One of the following is converted into thyroid gland of vertebrates :
   (a) Endostyle (b) Pharyngeal gill slits
   (c) Epipharyngeal groove (d) Peripharyngeal bands
9. Endostyle concentrates one of the following in itself :
   (a) Radioactive fluorine (b) Radioactive chlorine
   (c) Radioactive bromine (d) Radioactive iodine
10. The intestine of *Amphioxus* is divided into :
    (a) Midgut, lateral ciliary tract and diverticulum
    (b) Lateral ciliary tract, diverticulum and rectum
    (c) Midgut, ilio-colic ring and hindgut
    (d) Midgut, hindgut and rectum
11. Liver in *Branchiostoma* is :
    (a) Lateral ciliary tract (b) Ilio-colic ring
    (c) Midgut diverticulum (d) Rectum
12. Hepatic portal system of one of the following is the precursor of that of the higher chordates :
    (a) *Branchiostoma* (b) *Herdmania*
    (c) *Petromyzon*
    (d) *Labeo*
13. Ductus Cuvieri is another name for :
    (a) Sinus venosus (b) Aorta
    (c) Cardinal veins (d) Parietal veins
14. Dorsal nerve root arising from the spinal cord in *Branchiostoma* :
    (a) Is only sensory in function
    (b) Supplies the visceral organs
    (c) Is only motor in function
    (d) Is both sensory and motor in function
15. The thermoreceptor in *Branchiostoma* is :
    (a) Eye spots (b) Cephalic pigments
    (c) Infundibular organ (d) Kollicker's pit
16. In *Branchiostoma* gonads are arranged metamerically one pair in each segment from :
    (a) 25 to 51 (b) 29 to 51 (c) 25 to 58 (d) 29 to 58

ANSWERS

1. (a) 2. (d) 3. (c) 4. (b) 5. (b) 6. (c) 7. (b) 8. (a) 9. (d) 10. (c) 11. (c) 12. (a) 13. (c) 14. (d) 15. (b) 16. (a).

7

Subphylum III. Cephalochordata

General Characters

1. Marine, widely distributed in shallow waters.
2. Mostly sedentary and buried with only anterior body end, projecting above bottom sand.
3. Body small, 5 to 8 cm long, slender, fish-like, metameric and transparent.
4. Head lacking. Body has trunk and tail.
5. Paired appendages lacking. Median fins present.
6. Exoskeleton absent. Epidermis single-layered.
7. Muscles dorso-lateral, segmented into myotomes.
8. Coelom enterocoelous, reduced in the pharyngeal region by development of atrial cavity.
9. Notochord rod-like, persistent, extending from rostrum to tail, hence the name Cephalochordata.
10. Digestive tract complete. Pharynx large, perforated by numerous persistent gill-slits opening into atrium. Filter feeders.
11. Respiration through general surface. No special organs for respiration present.
12. Circulatory system well developed, closed and without heart and respiratory pigment. Hepatic portal system developed.
13. Excretion by protonephridia with solenocytes.
14. Nerve cord dorsal, tubular, without ganglia and brain. Dorsal and ventral nerve roots separate.
15. Sexes separate. Gonads numerous and metamerically repeated. Gonoducts lacking. No asexual reproduction.
16. Fertilization external in sea water.
17. Development indirect, including a free-swimming larva.
18. The Cephalochordata comprise about 30 species mostly of the genus *Branchiostoma* and all put in the class Leptocardii.

Primitive, Degenerate & Specialized Characters of *Branchiostoma* (Cephalochordata)

1. Primitive characters. *Branchiostoma* is regarded to be a primitive chordate. It differs from vertebrates because it retains several primitive chordate characters in most typical or unmodified form, as relics from its ancestors. The most prominent of these primitive characters are as enumerated below :

(1) Asymmetrical body as in echinoderms, which are regarded to have common ancestry with chordates.

(2) Absence of a specialized head or cephalization.

(3) Absence of paired limbs or fins.

(4) Epidermis one-cell thick. Dermis absent.

(5) Coelom enterocoelous, arising as lateral pouches of larval archenteron.

(6) Metamerically arranged muscles or myotomes.

(7) Notochord persistent throughout life. Vertebral column or any other endoskeleton not developed.
(8) Jaws absent. Alimentary canal straight.
(9) Pharynx large, perforated by persistent gill slits and specialized for ciliary mode of feeding by drawing a water-food current. Endostyle present without modification.
(10) Liver represented by a midgut diverticulum.
(11) Blood vascular system is simple, without a heart and any distinction between arteries and veins. Hepatic portal system is primitive.
(12) No special respiratory organs and respiratory pigment.
(13) Excretion by segmentally arranged protonephridia which are not coelomoducts.
(14) Neural tube hollow and lying dorsally above notochord. Specialized brain lacking. Dorsal and ventral roots of spinal nerves separate. Dorsal roots without ganglia so that impulses pass directly from skin to neural tube.
(15) Sensory organs simple and paired.
(16) Gonads several pairs, alike, segmentally arranged and without gonoducts.
(17) Eggs are small, almost yolkless. Blastula is spherical, hollow and one-layered. Gastrulation embolic.

2. Degenerate characters. Workers like Gregory consider that *Branchiostoma* was once more developed but underwent specialization and degeneration during later course of evolution due to semisedentary mode of life. The degenerated characters include :

(1) Poorly developed brain (cerebral vesicle) and simple sensory organs.
(2) Lack of any cartilaginous or bony endoskeleton.
(3) Lack of gonoducts.

3. Specialized, peculiar or secondary characters. These changes developed perhaps due to their special mode of life and also probably prevented their further evolution. Because of their degenerate and special characters, they are not considered in direct line of evolution of chordates but as a side offshoot.

(1) Peculiar asymmetry of adult and early stages of development.
(2) Anterior projection of notochord into rostrum making it stronger for burrowing. Over-development of notochord may be responsible for the lack of brain.
(3) Mouth surrounded by oral hood, with sensory oral cirri, meant for filtering and concentrating food particles from water.
(4) Elaborate velum with sensory tentacles to permit only small food particles to enter pharynx.
(5) Large, spacious and elaborate pharynx, with ciliated gill clefts which are more numerous than actual body segments, to enable sufficient food collection.
(6) Wheel organ and Hatschek's groove and pit developed to help in ciliary feeding.
(7) Delicate pharynx surrounded by a protective atrial cavity opening to outside through atriopore.
(8) Coelom displaced and reduced due to development of atrium.

Classification

Subphylum Cephalochordata includes a single class *Leptocardii*, a single family *Branchiostomidae*, and only two genera, *Branchiostoma* with 8 species and *Asymmetron* with 7 species. *Asymmetron* differs from *Branchiostoma* in having unpaired gonads on the right side of body and asymmetrical metapleural folds.

Affinities and Systematic Position

Cephalochordates (*Branchiostoma*) are unique in showing affinities with chordates as well as non-chordates.

[I] Non-chordate affinities

Cephalochordates have been regarded to be phylogenetically related to several non-chordate groups at one time or other. Only those with more important groups are being summarized below. But these can be overlooked in favour of the more chordate-like characteristics of cephalochordates.

1. Affinities with Annelida. Some of the common features are : (i) Body bilaterally symmetrical and metamerically segmented, (ii) metamerically arranged protonephridia with solenocytes (as in some polychaetes), (iii) well developed coelom, (iv) closed and similarly disposed blood vascular system, and (v) filter feeding method in some polychaetes.

Objections. In cephalochordates, unlike annelids, metamerism is restricted only to myotomes and gonads. Coelom is enterocoelic and not schizocoelic as in annelids. The flow of blood in main blood vessels is in opposite directions in the two groups. Above all, the three basic chordate characters of Cephalochordata are not present in Annelida.

2. Affinities with Mollusca. It was Pallas (1778) who first described and named amphioxus as *Limax lanceolatus* considering it to be a slug. But the ciliary mode of feeding and respiratory mechanism through water current which are common features of the two groups may be due to similar mode of life. Their anatomy is completely different. Moreover, molluscs are unsegmented and their locomotory podium is also unknown in cephalochordates.

3. Affinities with Echinodermata. Echinoderms have asymmetrical body, enterocoelic coelom and similarly formed mesoderm. Perforations in the calyx of some fossil echinoderms look similar to gill-slits of amphioxus. As in *Branchiostoma*, ophiuroids have similar phosphagens (creatine phosphate). But all these similar features may be because of a very remote common ancestry of the two groups.

[II] Chordate affinities

Cephalochordata (*Branchiostoma*) shows the three basic chordate features, viz. the notochord, dorsal tubular nerve cord and pharyngeal gill-slits, in the most typical manner and there is no doubt about its chordate nature. However, it shows relationships with all the major groups of phylum Chordata, and its real status in the phylum remains uncertain.

1. Affinities with Hemichordata. Hemichordata and Cephalochordata resemble in having similar (i) pharyngeal apparatus with numerous gill slits and gill bars, (ii) filter feeding mechanism, (iii) respiratory mechanism, (iv) enterocoelic coelom, and (v) numerous gonads without gonoducts.

Objections. But, muscles in Hemichordata are unsegmented, nervous system distinctly of nonchordate type, gill-slits dorsal in position instead of lateral, and a postanal tail is lacking. Moreover, inclusion of Hemichordata under Chordata is also uncertain because of doubtful nature of notochord. As such, Hemichordata, without question, are more primitive than Cephalochordata.

2. Affinities with Urochordata. *Branchiostoma* (Cephalochordata) and *Herdmania* (Urochordata) are regarded to be very closely related because of (i) primitive ciliary feeding and respiratory mechanisms, (ii) large pharynx bearing numerous lateral gill slits, epipharyngeal groove, endostyle and peripharyngeal bands, (iii) an ectoderm-lined atrial cavity opening to outside through atriopore (atrial siphon), (iv) identical early stages, (holoblastic cleavage, gastrulation by invagination) of development, and (v) the ascidian larva having a continuous notochord, above it a dorsal hollow nerve cord, and a post-anal tail with median caudal fin without fin rays.

Objections. But the adult urochordates are extremely degenerate and sedentary animals having several features unrepresented in cephalochordates, such as (i) body unsegmented, (ii) covered by a test made of cellulose, (iii) with enterocoelic coelom, (iv) without notochord, and hollow nerve cord, (v) with a liver, (vi) a well-developed muscular heart covered by peritoneum, (vii) without nephridia, (viii) sexes united with hermaphrodite gonads and (ix) larva undergoing retrogressive metamorphosis to become the adult. These differences show that inspite of close similarities reflecting upon a probable common ancestry, the cephalochordates are better evolved than the urochordates.

3. Affinities with Cyclostomata. The *Ammocoete larva* of lamprey (Cyclostomata) and *Branchiostoma* show a striking similarity in many characters, such as : (i) elongated, slender fish-like body, (ii) continuous dorsal median fin, (iii) mouth surrounded by an oral hood and (iv) guarded by a velum, and (v) pharynx having endostyle and gill slits. Besides these fundamental chordate characters, their adults show metameric myotomes, persistent gill slits, velum and a postanal tail.

4. Affinities with other vertebrates. Besides cyclostomes, *Branchiostoma* also resembles other vertebrates in several ways, such as (i) metamerically arranged myotomes, (ii) true coelom lined by mesodermal epithelium, (iii) postanal tail, (iv) midgut diverticulum comparable with liver, (v) well-formed hepatic portal system and (vi) similar arrangement of main longitudinal vessels with forward flow of blood in ventral and backward flow in dorsal blood vessel.

Objections. Cephalochordates differ from cyclostomes and other vertebrates in most of their primitive features already described, such as (i) lack of head, paired limbs, skull, vertebral column, muscular heart, red blood corpuslces, brain, specialized sense organs, gonoducts, etc., and (ii) in possessing nephridia, atrium, numerous gonads, asymmetry etc.

[III] Systematic position

Cephalochordates (*Branchiostoma*) possess all the important chordate characters so that their inclusion in the phylum Chordata is beyond doubt and conclusive. However, their true systematic place in the phylum remains controversial. They are definitely more evolved than the hemichordates.

Wiley (1894) stated that *Amphioxus* (=*Branchiostoma*) is a prototype chordate which can be placed along the main line of chordate evolution. According to Garstang (1928) and Berrill (1958), cephalochordates and vertebrates both evolved from a neotenic ascidian larva which failed to metamorphose. But this view is no longer upheld. The specialized characters of *Branchiostoma* indicate that it is not on the direct line of evolution of chordates.

Costa (1834) and Yarrel (1836) and more recently Gregory (1936) consider *Branchiostoma* to be a modified and degenerate form of some jawless vertebrates (cyclostomes or Agnatha). Some workers even considered *Branchiostoma* to be a permanent paedogenetic larval form of some species of cyclostomes. But the absence of craniate or vertebrate characters (head, cranium, skull, vertebral column, special sense organs, etc.) and the presence of protonephridia unknown in chordates, show that it has a very primitive character.

Conclusion. *Branchiostoma* possesses a peculiar admixture of primitive, degenerate as well as specialized or secondary characters. As such, it can not be placed in the direct line of evolution of chordates. It is regarded to be a generalized and primitive type of chordate very close to the ancestral vertebrates. But, because of its many differences, it is not included in the vertebrates. Instead it is placed in an independent subphylum Cephalochordata.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Enlist the primitive, degenerate and specialized characters of Cephalochordata.
2. Discuss the affinities and systematic position of Cephalochordata.

» ***Short Answer Type Questions***

1. Enumerate general characters of Cephalochordata.

» *Multiple Choice Questions*

1. Members of subphylum Cephalochordata live in :
   (a) Marine and shallow waters
   (b) Marine and deep waters
   (c) Swamps
   (d) Freshwater lakes
2. Cephalochordates are mostly sedentary and are buried :
   (a) Completely under the bottom sand
   (b) With only anterior end projecting above bottom sand
   (c) With only posterior and projecting above bottom sand
   (d) Under the bottom sand laterally
3. Cephalochordates are small and slender animal with :
   (a) Snake like and unsegmented body
   (d) Metameric and opaque body
   (c) Fish like, metameric and segmented body
   (d) Transparent, snake like body
4. Body of a Lancelet is divided into :
   (a) Head and tail (b) Head, trunk and tail
   (c) Head, neck, trunk and tail (d) Trunk and tail
5. Lancelets possess :
   (a) Median fins, but paired appendages are absent
   (b) Paired appendages
   (c) Paired appendages and operculum
   (d) Paired appendages but median fins are absent
6. Exoskeleton in cephalochordates is :
   (a) Well developed (b) Bony
   (c) Cartilaginous (d) Absent
7. Muscles in cephalochordates are :
   (a) Dorso-ventral (b) Dorso-lateral
   (c) Ventro-lateral (d) Antero-posterior
8. Notochord in cephalochordates :
   (a) Extends from pharynx to tail
   (b) Extends from rostrum to pharynx
   (c) Extends from rostrum to tail
   (d) Completely absent
9. In cephalochordates, gill slits open into :
   (a) Pharynx (b) Atrium (c) Coelom (d) Heart
10. In cephalochordates respiration takes place :
    (a) Through gills
    (b) Through nostrils
    (c) Through general body surface
    (d) Through lungs
11. Circulatory system in cephalochordates is :
    (a) Well developed, closed, with a heart and lacks a respiratory pigment
    (b) Poorly developed, open, with a heart and lacks a respiratory pigment
    (c) Well developed, open, with a heart and lacks a respiratory pigment
    (d) Well developed, closed, without a heart and lacks a respiratory pigment
12. In cephalochordates, excretion takes place by :
    (a) Protonephredia with solenocytes
    (b) Mesonephredia with solenocytes
    (c) Protonephredia without solenocytes
    (d) Mesonephredia without solenocytes
13. Nerve chord in cephalochordates is :
    (a) Dorsal, tubular with ganglia and brain
    (b) Dorsal, tubular without ganglia and brain
    (c) Ventral, tubular with ganglia and brain
    (d) Ventral, tubular without ganglia and brain
14. In cephalochordates :
    (a) Sexes are separate
    (b) Organisms are hermaphrodite
    (c) One pair of gonads are present
    (d) Organisms are hermaphrodite, with metamerically arranged gonads
15. Development in Cephalochordata is :
    (a) Indirect including a parasitic larva
    (b) Direct including a parasitic larva
    (c) Indirect including a free swimming larva
    (d) Indirect including a free swimming larva

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (d) 7. (b) 8. (c) 9. (b) 10. (c) 11. (d) 12. (a) 13. (b) 14. (a) 15. (c).

8

Protochordata : General & Comparative

What are Protochordates ?

As already described in chapter one, the lower primitive chordates are collectively known as the 'protochordates' or *Protochordata* (Gr., *protos*, first; *chorde*, cord). They comprise three major subdivisions ranked as subphyla: Hemichordata, Urochordata and Cephalochordata. This division is chiefly based on the *notochord* found in the three subphyla. In *Hemichordata*, the notochord is of doubtful existence. It is represented by a short stomodaeal diverticulum or stomochord to the proboscis. For this reason, the Hemichordata is now-a-days treated as an independent invertebrate phylum. The *Urochordata* have notochord only in the tail of the tadpole larva. Only *Cephalochordata* have a persistent notochord extending along the whole length of their body throughout life.

At one time, Protochordata was considered to be a distinct phylum, but it has no such official sanction now. Even then, the term Protochordata has been retained, for the convenience of study.

Significance of Protochordates

The protochordates are of little economic importance. But they have great phylogenetic significance to the zoologists. They show great affinities and perhaps, common origin with the living vertebrates. They retain the three basic chordate features (notochord, hollow dorsal nerve cord and pharyngeal gill-slits) throughout life. As such, they are considered most primitive and borderline chordates closer to the ancestor which probably gave rise to the final and the largest group of chordates, the vertebrates.

Comparison of Three Protochordate Subphyla

The earlier arrangement of recognizing the taxonomic status of *phylum Protochordata* has been given up now-a-days because the three subphyla do not show any intimate relationship. No doubt they all possess the three fundamental or primitive chordate characteristics (notochord, dorsal hollow nerve cord and pharyngeal gill slits) but they differ from one another in several ways. Their chief contrasting characters have been summarized in Table 1.

Table I. **General Comparison of Three Protochordate Subphyla.**

	Characters	Subphylum I Hemichordata (*Balanoglossus*)	Subphylum II Urochordata (*Herdmania*)	Subphylum III Cephalochordata (*Branchiostoma*)
1.	**Distribution**	Marine, worldwide	Marine, worldwide	Marine, worldwide
2.	**Habits and habitat**	Solitary or colonial. Mostly tubicolous	Solitary or colonial. Fixed or free-swimming	Solitary, burrowing and free swimming
3.	**Shape**	Elongated, cylindrical, wormlike	Degenerate, bag-like	Fish-like, laterally compressed
4.	**Body divisions**	Head, neck, trunk	Unsegmented without head and tail	Segmented without distinct head
5.	**Postanal tail**	Absent	Absent	Present
6.	**Fins**	Absent	Absent	Median fins
7.	**Test**	Absent	Present	Absent
8.	**Coelom**	Enterocoelous, divisible into three body regions	Absent, replaced by atrial cavity	Reduced by atrial cavity
9.	**Atrial cavity**	Absent	Greatly developed	Well developed
10.	**Notochord**	Absent, instead stomochord present	Only in larval tail, absent in adult	Persistent, throughout life, rod-like
11.	**Muscles**	Unsegmented	Unsegmented	Metamerically segmented as myotomes
12.	**Digestive tube**	Complete, straight or coiled	Complete, coiled	Complete, straight
13.	**Oral hood**	Absent	Absent	Present
14.	**Pharyngeal apparatus**	Large, simple with two dorsal linear rows of gill slits	Large, complex, with 2 to several pairs of lateral gill slits	Large, complex with several pairs of lateral gill slits
15.	**Feeding mechanism**	Ciliary or filter	Ciliary	Ciliary
16.	**Respiratory organs**	Absent, Respiration through general surface.	Absent. Respiration through body surface	Absent. Respiration through body surface
17.	**Heart**	A dorsal heart present	Well developed muscular heart	Heart absent
18.	**Excretory organs**	Glomerulus in proboscis	Neural gland, pyloric gland & nephrocytes	Protonephridia
19.	**Nervous system**	Intraepidermal	—	—
20.	**Sexes**	Separate	United	Separate
21.	**Gonads**	One to several pairs	One pair	Numerous pairs metamerically arranged
22.	**Gonoducts**	Absent	Present	Absent
23.	**Development**	Direct or indirect, with or without metamorphosis	Indirect with retrogressive metamorphosis	Indirect with metamorphosis

Table 2. **Comparison of Habits and Habitat.**

	Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1.	**Occurrence**	Marine	Marine	Marine
2.	**Distribution**	Worldwide, all seas	Worldwide, Indian, Pacific & Carribean seas	Worldwide all seas
3.	**Habitat**	Marine, shallow coastal waters of intertidal zones.	Marine, shallow waters with rocky bottom.	Marine, shallow waters with sandy bottoms.
4.	**Mode of life**	Solitary, burrowing, nocturnal and sluggish.	Solitary, attached to sub-stratum by broad base, diurnal and sluggish	Solitary, burrows in sand or free swimming, nocturnal, active.
5.	**Burrow**	U-shaped, having at least two openings, lined by sand particles cemented together by mucus.	Does not form burrows.	Mostly remains burried in sand with anterior body end projecting above sand.
6.	**Food**	Micro-organisms and organic particles in sand and water.	Planktonic microorganisms.	Planktonic microorganisms.
7.	**Feeding habit**	Microphagus	Microphagus	Microphagus
8.	**Mode of feeding**	Ciliary filter feeding as well as swallowing with mud.	Ciliary filter feeding by food-cum- respiratory water current passing through perforated pharyngeal sac	Ciliary filter feeding by passing food-laden water current through perforated pharyngeal sac.
9.	**Water current**	Enters branchial sac through mouth and goes outside directly through gill pores.	Enters branchial sac through mouth and goes out through atriopore.	Enters branchial sac through mouth, reaches atrial cavity through gill slits and outside through atriopore.
10.	**Protective device**	Secretion of a foul smelling iodoform-like substance. One species is phosphorescent.	Body surrounded by a gelatinous test containing spicules.	Swims actively when disturbed
11.	**Reproduction**	Only sexual. Sexes separate. Also great power of regeneration.	Only sexual. Sexes united. Some reproduce asexually by budding.	Only sexual. Sexes separate. No asexual reproduction.

Table 3. **Comparison of Alimentary Canal and Associated Glands.**

Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1. **Alimentary canal**	Complete, straight narrow canal from mouth to anus.	Complete, curved canal with intestinal loop.	Complete, straight canal from mouth to anus.
2. **Mouth opening**	Wide, circular, permanently open, situated mid-ventrally between proboscis and collar.	Four-sided branchial opening, bordered by four lips, situated on branchial siphon.	Wide, antero-ventral opening, bordered by free margin of oral hood and buccal cirri.
3. **Buccal cavity**	Short, without tentacles	It is cavity of branchial siphon, with a circlet of branchial tentacles.	It is spacious vestibule of oral hood containing wheel organ.
4. **Pharynx**	Divided by lateral parabranchial ridges into a dorsal branchial portion with gill-slits and a ventral digestive portion.	Divided by two ciliated peribranchial ridges into an anterior small prebranchial region and a large posterior branchial sac with gill slits.	Lateral oblique ciliated peripharyngeal bands demarcate a small antero-dorsal prebranchial region from large posterior branchial sac.
5. **Velum**	Absent	Absent	Present between vestibule and pharynx with velar tentacles.
6. **Endostyle**	Absent	Extends mid-ventrally along floor of pharynx.	Same as in *Herdmania*.
7. **Hyperpharyngeal groove or band**	Absent	Dorsal lamina present with tongue-like processes or languets.	Ciliated groove present without processes.
8. **Gill slits**	Dorso-lateral U-shaped gill-slits open into branchial sacs which open externally through gill pores.	About 2,00,000 gill-slits open into atrial cavity.	150 to 200 pairs of gill slits open into atrial cavity.
9. **Stomach**	Not demarcated clearly from intestine.	Demarcated from intestine and sphinctered at both the ends.	Stomach or midgut not demarcated from intestine.
10. **Intestine**	Straight tube. Anterior or hepatic region sacculated, forming hepatic caeca.	Forms a looped or U-shaped tube enclosing the left gonad. Ilio-colic ring is absent.	Forms a straight tube internally ciliated containing lateral ciliary tract and ilio-colic ring.
11. **Rectum**	Not differentiated.	Differentiated and internally ciliated.	Demarcated and heavily ciliated.
12. **Anus**	Intestine opens at the tip of trunk by a sphinctered circular anal opening.	Rectum curves dorsally to open into cloaca by anus bordered by four lips.	It is a small, circular, sphinctered aperture opening at the base of caudal fin to outside.
13. **Atrial cavity**	Absent	Gill slits & anus open into atrial cavity leading to exterior through atrial opening bordered by four lips and situated on atrial siphon.	Gill slits open into atrial cavity leading outside through atriopore. Anus does not open into atrial cavity.
14. **Digestive glands**	Definite glands unknown.	Liver is composed of two lobes. Besides a branching pyloric gland in wall of stomach and intestine is supposed to be digestive as well as excretory.	A midgut diverticulum is said to function as liver. Pyloric gland is absent.

***Table 4.* Comparison of Pharynx.**

Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1. **Position of pharynx**	Present inside anterior one-third part or branchiogenital region of trunk.	Occupies the major part of body cavity.	Occupies nearly one half anterior part of body.
2. **Shape**	Elongated	Large, sac-like	Large, spacious, cylindrical and laterally compressed chamber.
3. **Attachment**	Attached with the bodywall by dorsal and ventral mesenteries.	Attached only mid-ventrally to mantle.	Attached dorsally to bodywall.
4. **Atrium**	Absent	Pharynx surrounded dorso-laterally by the atrium or peribranchial cavity which opens to the outside through atrial aperture.	The peribranchial cavity or atrium surrounds pharynx on all sides except the dorsal. Its atriopore lies posteriorly.
5. **Relation with mouth**	Large mid-ventral mouth leads into a short buccal cavity which in turn leads into pharynx.	Small, 4-rayed terminal mouth or branchial siphon. Its opening into pharynx is guarded by branched branchial tentacles.	Large oval mouth bordered by oral hood with buccal cirri and guarded by velar tentacles leads into pharynx through a circular aperture, the enterostome.
6. **Pharyngeal cavity**	Simple and uniformly lined by cilia and mucous cells.	Internal wall complicated and longitudinally folded with cilia and glands restricted into definite tracts.	Cavity very much complicated with definite ciliary and glandular tracts.
7. **Division**	Two lateral parabranchial ridges incompletely divide pharynx into a dorsal respiratory or branchial chamber and a ventral digestive chamber.	Differentiated into a small anterior prebranchial zone and a much larger, posterior branchial sac, by two pairs of ciliated peripharyngeal bands.	Divided into a small anterior prebranchial zone and the pharynx proper by a pair of ciliated peripharyngeal bands.
8. **Gill-slits**	Branchial portion of pharynx is perforated by numerous U-shaped gill-slits leading into branchial sacs. Each sac leads to exterior by a single gillpore.	Branchial sac of pharynx is perforated by about 200,000 elongated gill-slits or stigmata leading into atrial cavity.	Lateral walls of pharynx are perforated by 150 to 200 pairs of vertically oblique narrow gill-slits openings into the atrial cavity.
9. **Endostyle**	Absent.	Endostyle is a shallow longitudinal midventral groove on floor of branchial sac. It consists of 5 ciliary tracts alternating with 4 glandular tracts.	A hypobranchial tract or an endostyle similar to that of *Herdmania* is present. It is made of ciliary and alternating mucus-secreting cells.
10. **Dorsal lamina**	Absent.	A ciliated hyperpharyngeal band or dorsal lamina hangs mid-dorsally bearing tongue-like languets into the branchial sac.	A prominent ciliated epipharyngeal or hyperpharyngeal groove is present mid-dorsally opposite endostyle. Languets are absent.
11. **Peripharyngeal bands**	Absent.	Dorsal lamina and endostyle are connected on either lateral side by a pair of ciliated peripharyngeal bands.	Epipharyngeal groove and endostyle are connected anteriorly by a pair of lateral peripharyngeal ciliated bands.
12. **Relation with intestine**	Pharynx opens directly into intestine.	Leads into intestine via oesophagus and stomach.	Opens into intestine via short oesophagus and midgut.

Table 5. **Comparison of Food and Feeding.**

	Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1.	**Food**	Microorganisms and organic particles in sand and water.	Planktonic microorganisms.	Planktonic microorganisms.
2.	**Feeding habit**	Microphagus.	Microphagus.	Microphagus.
3.	**Mode of feeding**	Ciliary filter feeding as well as swallowing mud.	Ciliary filter feeding.	Ciliary filter feeding.
4.	**Trapping or collection of food particles**	External. Minute food particles trapped outside body by mucus secreted by proboscis.	Internal. Food particles collected inside pharynx by mucus secreted by glandular tracts of endostyle.	Internal. By sticky secretion of mucous cells of endostyle on the floor of pharynx.
5.	**Water current production**	By lashing of lateral cilia on gill slits of pharynx, a constant feeding water current enters through mouth.	Beating of lateral cilia lining stigmata drives a continuous water current into mouth.	Wheel organ on roof of oral hood causes a constant flow of sea water through mouth.
6.	**Course of feeding current**	Mouth → buccal cavity → pharynx → pharyngeal gill slits → branchial sacs → exterior gill pores	Mouth → pharynx → stigmata → atrium → atriopore → exterior	Same as in *Herdmania*
7.	**Regulation of feeding current rejection of larger food particles**	Chemo-receptor cells of pre-oral ciliary organ at the base of proboscis test the quality of food and water entering mouth. Muscular ventral part of collar regulates feeding current by closing mouth under nervous control	Branchial tentacles act as chemoreceptors and also as strainers to prevent entry of impurities and larger food particles. Ciliary beating is under nervous control.	Buccal cirri and velar tentacles serve as sieves as well as chemoreceptors preventing entry of larger food and sand particles. Ciliary beating is under nervous control.
8.	**Formation & passage of food string**	Endostyle and epipharyngeal groove absent. Food particles move backwards by ciliary action via ventral digestive part of pharynx into oesophagus.	Mucous-entangled food particles from ventral endostyle are shifted dorsally along pharyngeal wall to dorsal lamina and driven backwards into oesophagus by ciliary action.	Sheets of food particles entrapped by mucus secreted by endostyle move dorsally to epipharyngeal groove and passed as a narrow food cord into oesophagus by ciliary action.
9.	**Reverse current**	Not known.	Unwanted current and larger particles thrown out of mouth by producing a strong reverse current by muscular contraction.	Periodically, the atriopore closes and atrial flood suddenly contracts regurgitating water current and large food particles forcefully through mouth.
10.	**Egestion**	Undigested food and sand pass out through anus as castings.	Undigested food expelled out forcefully, through atrial aperture, by sudden contraction of body musculature.	Undigested food is thrown out directly to outside through anus.

Table 6. **Comparison of Excretory System.**

	Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1.	**Main excretory organ**	Excretory organ is the proboscis gland or glomerulus projecting into proboscis coelom.	Excretory organ is the neural gland lying mid-dorsally embedded in mantle above the nerve ganglion.	Main organs are 90 to 100 pairs of protonephridia present segmentally one above each gill slit.
2.	**Structure**	Glomerulus consists of tubular projections lined by peritoneum and containing blood.	Neural gland consists of peripheral and central tubules leading into a small duct opening anteriorly by a large ciliated funnel at the base of dorsal tubercle.	Each nephridium consists of lower vertical limb terminating blindly, and an upper horizontal limb opening by a small nephridiopore into atrium.
3.	**Solenocytes**	There are no solenocytes.	There are no solenocytes.	Both limbs give out several small branches each receiving a tuft of flame cells or solenocytes.
4.	**Physiology of excretion**	The peritoneal cells of glomerulus extract from blood the excretory particles, discharge them into proboscis coelom and finally to the exterior through proboscis pore.	The excretory cells or nephrocytes collect waste products, and discharge through aperture of the duct into prebranchial zone of pharynx.	Nitrogenous wastes diffuse from surrounding blood and coelomic fluid into solenocytes, discharge into atrium through nephridiopores and pass out of body through atriopore with the outgoing water current.
5.	**Secretion of hormones**	Unknown.	Unknown.	Neural gland secretes a hormone controlling oviposition, development and metamorphosis, and is considered homologous to vertebrate pituitary gland.
6.	**Hatschek's nephridium**	Not found.	Not found.	A nephridium of Hatschek lies in roof of oral hood. Its structure and function are similar to those of a protonephridium.
7.	**Brown funnel**	Not found.	Not found.	Two sac-like brown funnels situated dorsally upon pharynx are also considered to be excretory.
8.	**Renal papillae**	Not found.	Not found.	Groups of cells or renal papillae present on atrial floor are also considered to be excretory.

Table 7. **Comparison of Nervous System.**

	Characters	Hemichordata (*Balanoglossus*)	Urochordata (*Herdmania*)	Cephalochordata (*Branchiostoma*)
1.	**Grade of nervous system**	Primitive, resembling that of coelenterates or echinoderms.	Adult nervous system simple and degenerate.	Simple but better developed than in *Balanoglossus* and *Herdmania*.
2.	**Structure**	Consists of subepidermal plexus of nerve fibres and cells, forming two definite strands or nerve cords, one mid-dorsal and other mid-ventral.	Consists of a solid nerve ganglion lying just below the nerural gland mid-dorsally in the mantle between the two siphons. A nerve cord is also present in the larva.	Consists of a hollow tube or nerve cord lying mid-dorsally above the notochord.
3.	**Brain**	Brain is lacking.	Nerve ganglion is the so-called brain or cerebral ganglion.	Anterior end of nerve cord slightly dilates, forming the so-called brain or cerebral vesicle.
4.	**Nerves**	Definite nerves lacking.	Nerve ganglion sends 3 nerves to branchial siphon and 2 nerves to atrial siphon. No spinal nerves present.	There are 2 pairs of sensory cerebral nerves, followed by several pairs of spinal nerves, each with separate dorsal and ventral nerve roots.
5.	**Autonomic system**	Lacking.	Lacking.	Present.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Differentiate between the habits and habitats of *Balanoglossus, Herdmania* and *Branchiostoma.*
2. Compare the circulatory, excretory and nervous systems of *Balanoglossus* with that of an ascidian and a lancelet.
3. Describe the alimentary canal and associated glands of *Branchiostoma* and compare it with that of a hemichordate and a urochordate.
4. Describe the structure and function of pharynx in *Herdmania* and compare it with that of *Balanoglossus* and *Branchiostoma.*
5. Compare the food and feeding of the three Protochordate subphyla.

» *Short Answer Type Questions*

1. List the three common chordate characters.
2. What are Protochordates? Discuss their significance.
3. Give a general comparison of the three Protochordate subphyla.

» *Multiple Choice Questions*

1. The post-anal tail is present in :
   (a) Hemichordates (b) Urochordates
   (c) Cephalochordates (d) All Protochordates
2. Test is present in :
   (a) All protochordates (b) Hemichordate
   (c) Urochordates (d) Cephalochordates
3. Metamerically segmented muscles are present in :
   (a) All protochordates (b) Hemichordates
   (c) Urochordates (d) Cephalochordates
4. Development in Urochordata is :
   (a) Direct
   (b) Indirect with retrogressive metamorphosis
   (c) Indirect without metamorphosis
   (d) Indirect with metamorphosis
5. In *Amphioxus* rectum is :
   (a) Not differentiated
   (b) Differentiated and sparsely ciliated
   (c) Differentiated but not ciliated
   (d) Differentiated and heavily ciliated
6. In Urochordata, the pyloric gland is :
   (a) Digestive as well as excretory
   (b) Only digestive
   (c) Only respiratory (d) Only excretory
7. In *Balanoglossus* each branchial sac opens to the exterior :
   (a) Directly (b) By a single gill pore
   (c) By a single gill slit (d) Through the pharynx
8. In *Herdmania* the opening of branchial siphon into the pharynx is guarded by :
   (a) Branched branchial tentacles
   (b) Branched and ciliated tentacles
   (c) Unbranched tentacles
   (d) Unbranched pharyngeal tentacles
9. In *Amphioxus* reverse current is caused by the closing of :
   (a) Atriopore (b) Anus (c) Oral hood (d) Mouth
10. In Urochordata and Cephalochordata the course of feeding current is :
    (a) Mouth → stigmata → atrium → atriopore →exterior
    (b) Mouth → pharynx →atrium →exterior
    (c) Mouth →pharynx →atrium →atriopore → exterior
    (d) Mouth →pharynx →stigmata → atrium → atriopore → exterior
11. In Hemichordata the function of excretion is chiefly performed by :
    (a) Pyloric gland (b) Liver
    (c) Proboscis gland (d) Neural gland
12. In cephalochordates the brown funnels situated near pharynx are :
    (a) Respiratory (b) Excretory
    (c) Circulatory (d) Sensory
13. Autonomic nervous system is present in :
    (a) All Protochordates (b) Urochordata
    (c) Hemichordata (d) Cephalochordata
14. In Cephalochordates :
    (a) Only cerebral nerves are present
    (b) Only spinal nerves are present
    (c) Nerves are absent
    (d) Both cerebral and spinal nerve are present

ANSWERS

1. (c) 2. (c) 3. (d) 4. (b) 5. (d) 6. (a) 7. (b) 8. (a) 9. (a) 10. (d) 11. (c) 12. (b) 13. (d) 14. (d).

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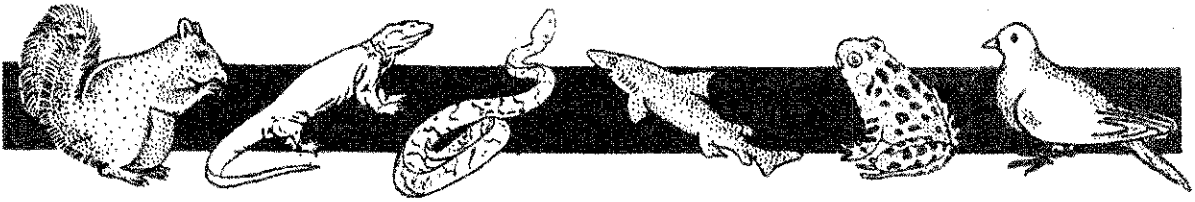

Subphylum IV. Vertebrata

What are Vertebrates ?

Vertebrates belong to the subphylum Vertebrata of the phylum Chordata. Their names is derived from the presence of serially arranged '*Vertebrae*' (L., *vertebratus*, jointed), which comprise a major part of their axial endoskeleton, the vertebral column or the backbone. Another feature, that all vertebrates share as a common diagnostic character, is the elaboration of anterior skeletal elements into a '*cranium*' or '*skull*' which houses various sense organs and a complex brain. This gives another name, the 'Craniata', which is sometimes used for the group. There is reason to believe that the distinctive vertebrate cranium and brain evolved even before the vertebral column and are, therefore, more fundamentally characteristic of vertebrates than the backbone.

A vertebrate may be defined as a special kind of chordate animal that has a cartilaginous or bony endoskeleton consisting of a cranium, housing a brain and a vertebral column through which the nerve cord passes. No other group of animals possesses these two fundamental and related characters which have existed in vertebrates since the late Cambrian and Ordovician.

Chordates versus Vertebrates

Many persons usually think of the chordates as synonymous with the vertebrates. By now it must be obvious that the terms 'chordate' and 'vertebrate' are not synonymous. Further, all the vertebrates are included in the subphylum Vertebrata. No doubt, they make up the vast majority of the animals in the phylum Chordata. But they share the big three characteristics (dorsal hollow nervous system, notochord, and pharyngeal gill-slits) with some inconspicuous and primitive chordates belonging to the subphyla Urochordata and Cephalochordata, and doubtfully the Hemichordata. Hence, the vertebrates plus the protochordates together comprise the chordates. The terms 'Euchordata' and 'Craniata' can be regarded equivalent to 'Vertebrata.'

General Characters of Subphylum Vertebrata

As already defined, one of the most important characteristics, that gives the subphylum its name, is the presence of *vertebrae*. Another important diagnostic feature is the presence of a skull or *cranium* from which is derived the other name *Craniata* for the subphylum. Besides, they also possess the three fundamental or chief diagnostic chordate characteristics, also found in the protochordates; namely, the *notochord, pharyngeal gill-slits* and *dorsal hollow nerve cord*. These are the 'big five' diagnostic vertebrate characteristics. The others are only 'satellite characteristics' not necessarily unique among vertebrates.

(1) Lower vertebrates aquatic, higher vertebrates predominantly terrestrial.

(2) Body medium to large, bilaterally symmetrical and metamerically segmented.

(3) Body typically made of head, trunk and a postanal tail. A neck may also be present, especially in the terrestrial forms.

(4) Trunk bears typically two pairs of jointed, lateral appendages; may be reduced or absent in some; serve for support, locomotion and other special functions.

(5) Body covering or integument is a stratified epithelium made of an outer epidermis and an inner dermis; with many mucous glands in aquatic species.

(6) Skin covered by a protective exoskeleton comprising scales, feathers, hairs, claws, nails, horns, etc.

(7) Coelom large, nearly always developed as a schizocoel, and largely filled with the visceral systems.

(8) Notochord stops short beneath the forebrain, invested by cartilage or bone or replaced by a vertebral column.

(9) A living jointed endoskeleton of bone or cartilage or both, including skull, vertebral column, girdles and limb bones.

(10) Many muscles are attached to the endoskeleton for motion and locomotion.

(11) Digestive canal more or less convoluted. Liver massive not tubular. Pharyngeal gill-slits not more than 7 pairs except in some cyclostomes.

(12) Respiration in lower aquatic forms by paired gills; in terrestrial forms by lungs.

(13) Blood vascular system closed. Heart ventral, muscular contractile and consists of 2, 3 or 4 chambers. Blood plasma contains both white and red corpuscles, the latter containing the respiratory pigment, haemoglobin.

(14) Excretion by paired kidneys, mesonephric or metanephric, segmental or non-segmental, and discharging through ducts into cloacal or anal region.

(15) Anterior end of dorsal nerve cord enlarges into a complex brain, protected by skull. Remaining nerve cord forming the spinal cord surrounded and protected by vertebrae. 10 to 12 pairs of cranial nerves in the head. Except in the cyclostomes, the spinal nerves formed by the union of dorsal and ventral roots, which are given out in each segment. The dorsal and ventral nerve roots are separate in lower vertebrates, like cyclostomes. In higher vertebrates the two nerve roots are united to form a common spinal nerve. The ventral nerve is efferent or motor in nature, it carries nerve impulse from the central nervous system to the effeector organ. While, the dorsal nerve is mixed. It bears a swelling called spinal ganglion.

(16) Special sensory organs include a pair of eyes and a pair of auditory organs, derived in part from brain.

(17) An endocrine system of ductless glands scattered through body, regulating body processes, growth and reproduction.

(18) Sexes separate. Gonads paired discharging sex cells through ducts opening into or near the anus.

(19) Development direct or indirect. There is never a typical invaginate gastrula. Mesoderm arises as paired longitudinal bands, which subsequently become segmented.

Diversity of Vertebrates

In many respects, vertebrates are by far the most important and most progressive of all groups of organisms. They are a highly diverse group exhibiting many interesting features, and play important ecological roles.

Numerical strength. Subphylum Vertebrata is the largest of all chordate groups. About 49,000 species of animals exhibit vertebral columns. Of these 40,000 species are living, the rest extinct.

Kinds of vertebrates. What are the different kinds of vertebrates? Besides the familiar backboned animals such as fishes, amphibians, reptiles, birds and mammals, they also include man, who is the supreme animal and the most potent force on earth today.

Categories of vertebrates. The vertebrates may be grouped in various ways. Table 1 shows the general categories of vertebrates. Commonly 9 classes of vertebrates are recognized, including two

***Table 1.* General Categories of Vertebrates.**

Groups	Superclasses		Classes with examples
I. Agnatha		1.	Ostracodermi-extinct armoured fishes
		2.	Cyclostomata-lampreys and hagfishes
II. Gnathostomata	(a) Pisces	3.	Placodermi-extinct fishes with primitive jaws
		4.	Chondrichthyes-Cartilaginous sharks, rays and skates
		5.	Osteichthyes-bony fishes
	(b) Tetrapoda	6.	Amphibia-frogs, toads, salamanders
		7.	Reptilia-turtles, lizards and snakes
		8.	Aves-birds
		9.	Mammalia-mice, whales, men

***Table 2.* Selected characterstics of Living Vertebrate Classes**

<table>
<tr><th rowspan="2">closses</th><th rowspan="2">Jaws</th><th rowspan="2">Endoskeleton</th><th rowspan="2">Locomotory appendages</th><th rowspan="2">Respiratory surface</th><th rowspan="2">Extra embryonic membranes</th><th rowspan="2">Body temperature energetics</th><th colspan="2">Integument</th></tr>
<tr><th>Glands</th><th>Exoskeleton</th></tr>
<tr><td>Cyclostometa</td><td>AGNATHA (jawless)</td><td rowspan="2">CARTILAGE</td><td rowspan="3">FINS (Fishes)</td><td rowspan="2">GILLS</td><td rowspan="4">ANAMNIOTA (Yolk sac & chorion)</td><td rowspan="5">ECTOTHERMAL</td><td rowspan="4">GLANDULAR mucous secretions</td><td>naked</td></tr>
<tr><td>Chondischthyes</td><td rowspan="6">GNATHOSTOMATA (jawed)</td><td>placoid scales</td></tr>
<tr><td>Osteichthyes</td><td rowspan="5">BONE</td><td>primarily gills</td><td>dermal scales</td></tr>
<tr><td>Amphinbia</td><td rowspan="4">LIMBS (Tetrapode)</td><td>primarily lungs</td><td>naked</td></tr>
<tr><td>Reptilia</td><td rowspan="3">LUNGS</td><td rowspan="3">AMNIOTA (Yolk sac chorion, allantois & amnion)</td><td rowspan="2">AGLANDULAR dry</td><td>epidermal scales</td></tr>
<tr><td>Aves</td><td rowspan="2">ENDOTHERMAL</td><td>feathers & epidermal scales</td></tr>
<tr><td>Mammalia</td><td>SECONDARY GLANDULAR oily & watery scretions</td><td>hair</td></tr>
</table>

(Ostracodermi and Placodermi) that are extinct. The first two classes (Ostracodermi and Cyclostomata) lack jaws and are placed in the group *Agnatha*. The remaining classes have jaws and form the group *Gnathostomata*. The gnathostomes are further arranged into two superclasses : *Pisces* (fishes) and *Tetrapoda* (four-legged land vertebrates). The first five classes are aquatic, hence their popular name *fishes*. The last four classes are mainly nonaquatic or terrestrial.

Selected characters of classes. All the nine vertebrate classes share the common chordate-vertebrate characters. Nevertheless, each of these classes differs from the others in some fundamental ways, showing a progressive series of changes from the primitive jawless fishes to the highly complex mammals. Table 2 depicts some of the selected characteristics of the seven living classes of vertebrates.

Phylogeny or Evolutionary History of Vertebrates

The evolutionary history of a group of organisms is termed *phylogeny*. It is derived from greek roots which mean "to beget a race" : (Gr. *phylon*, race or tribe + *gennao*, to bring forth). The concept of phylogeny is used to place animal groups in proper evolutionary sequence. Thus, in phylogenetic order, fishes came before reptiles, and reptiles before birds and mammals.

A phylogenetic tree (Fig. 1) makes a good model to record the evolutionary history of vertebrates. The vertical dimension or height of the tree represent geological time. The diversification into group is represented by branches. The width of each branch indicates the relative abundance of each group in time. Various diagrams representing a phylogenetic tree have been presented, reflecting different ideas of interrelationships of animal groups (Fig. 2).

Cambrian and Ordovician periods. The first fossils of vertebrates were found in the rocks of the Ordovician period in the form of the *Ostracoderms*. These were small jawless, bony, fish-like forms related to the cyclostomes, that lived some 480 million years ago. This shows that their chordate ancestors must have existed much before, in the late Cambrian. The scarcity of early vertebrate fossils is probably due to the fact that they evolved mainly in freshwater and did not have as much chance to become fossilized as marine forms did. The *Ostracodermi* became extinct but some *Cyclostomata* (modern lampreys and hagfishes) are still with us.

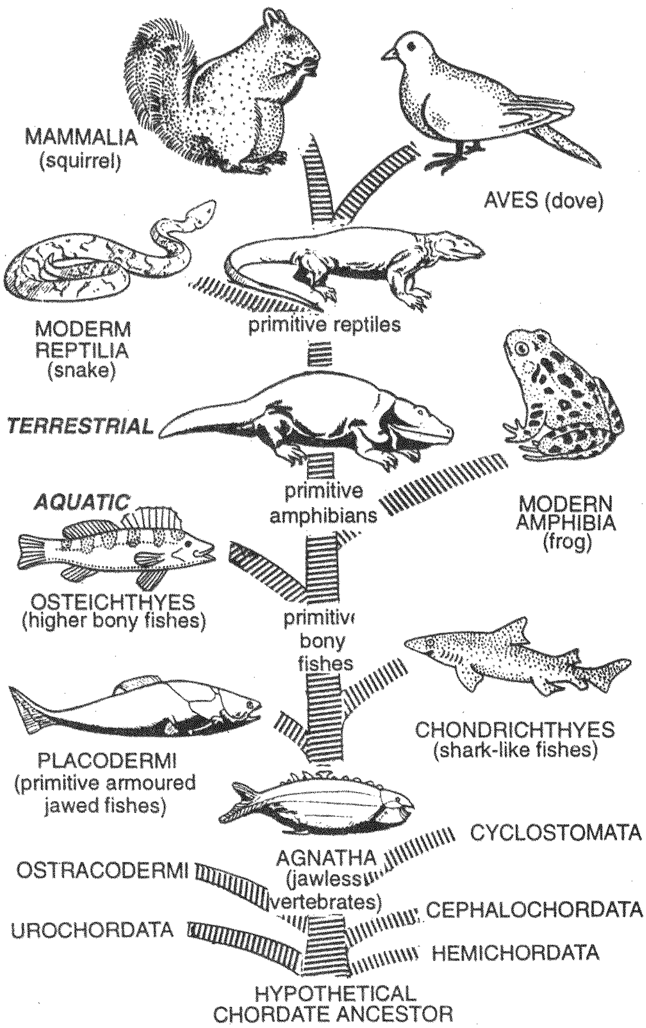

Fig. 1. A simple phylogenetic tree of vertebrates showing classes.

Silurian and Devonian periods. Some fossil fish are found in the Silurian period, but far more are present in the succeeding Devonian period

Table 3. **Comparison of Lower Vertebrata and Higher Vertebrata.**

Lower Vertebrata (*Anamniota*)	**Higher Vertebrata** (*Amniota*)
1. Lower vertebrates comprise the classes Cyclostomata, Chondrichthyes, Osteichthyes & Amphibia, forming the group Anamniota.	1. Higher vertebrates include the classes Reptilia, Aves & Mammalia forming the group Amniota.
2. Predominantly aquatic.	2. Predominantly terrestrial.
3. Body typically consists of three parts : head, trunk & tail. Neck usually absent.	3. Neck usually present so that body typically includes four divisions.
4. Appendages are 2 pairs of fins or limbs.	4. Fins never present. Usually 2 pairs of pentadactyle limbs.
5. Exoskeleton absent or dermal scales present.	5. Exoskeleton includes epidermal scales, feathers, hairs, claws, horns, etc.
6. Pharyngeal gill clefts mostly persist throghout life.	6. Gill clefts disappear in the adult.
7. Notochord usually persists, becomes in vested by cartilage and segmented.	7. Notochord disappears in the adult, replaced by a series of bony vertebrata forming the vertebral column.
8. Endoskeleton mostly cartilaginous.	8. Endoskeleton mostly bony.
9. Heart made of 2 or 3 chambers.	9. Heart of 4 chambers except in most reptiles.
10. Poikilothermous or cold-blooded with variable body temperature.	10. Homoiothermous or warm-blooded expect most reptiles, with constant body temperature.
11. Respiration usually by gills.	11. Respiration by lungs.
12. Kidneys are mesonephric.	12. Kindneys are meso-or metanephric.
13. Cranial nerves are 10 pairs.	13. Cranial nerves are 12 pairs.
14. Male without copulatory organ.	14. Male with a copulatory organ except in most birds.
15. Fertilization is external.	15. Fetilization is internal.
16. Development includes metamorphosis.	16. Development is direct, without metamorphosis.
17. Amnion does not appear during development, hence the group name Amniota.	17. A special membrane called amnion present during development, hence the name Anamniota of the group.

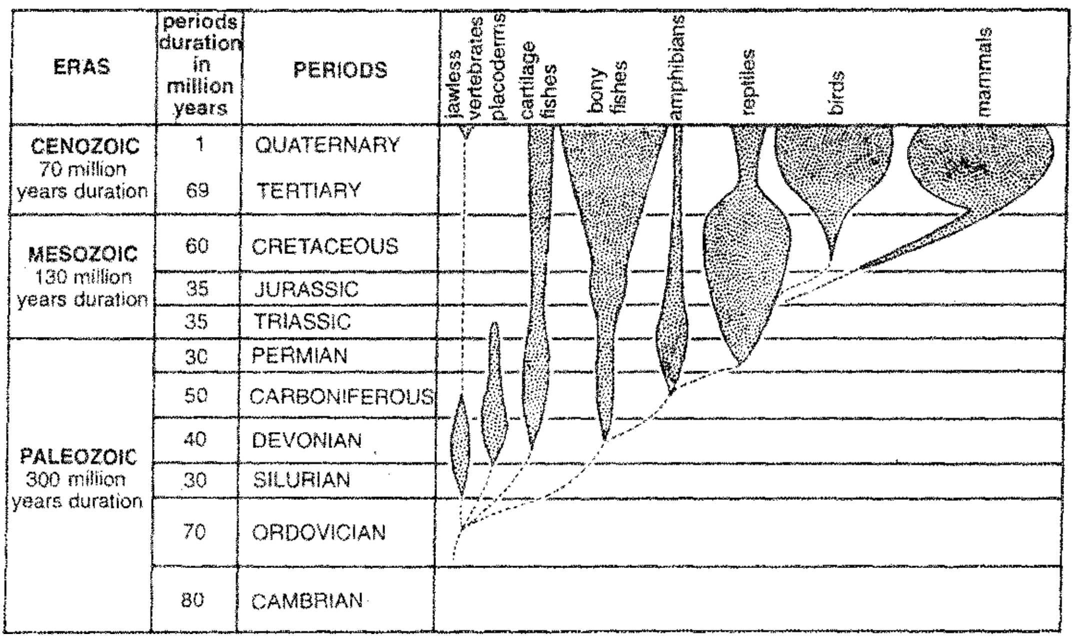

Fig. 2. Geological chart with a simple family tree of vertebrate classes showing their relative abundance through time.

which is known as the *Age of Fishes.* Ostracoderms were jawless fish, but during Devonian the first jawed fish, the *placoderms*, arose. The *Placodermi* became extinct without leaving living representatives. It is likely that early placoderms were ancestors of cartilaginous and bony fishes, both of which have true jaws, but we do not have any direct evidence. Contrary to the former belief, cartilaginous fishes (*Chondrichthyes*) did not give rise to bony fishes (*Osteichthyes*).

Carboniferous period. In late Devonian or early Carboniferous period, the lobe-finned bony fishes (*Crossopterygii*) gave rise to *labyrinthodonts* or primitive *stem Amphibia.* They were the first vertebrates to walk on land. The Amphibia became abundant and mutated in many directions during Carboniferous usually known as the *Age of Amphibians.*

Mesozoic era. In the early Carboniferous, the very primitive amphibians also gave rise to the *primitive reptiles.* They reached their peak and great abundance during Mesozoic era which is aptly known as the *Age of Reptiles.* They included among others the famed dinosaurs, the ichthyosaurs, and the pterodactyls or flying reptiles. They dominated the world for nearly 130 million years, until the end of the Mesozoic when most of them suddenly became extinct. While only 4 orders of reptiles are living today, as many as 10 orders are represented by their numerous fossil remains.

The *ancestral mammals* were derived from the primitive reptiles during Triassic period. The *first birds* also appeared in the late Jurassic period and one of their fossils, the *Archaeopteryx*, had both reptilian as well as avian characteristics.

Cenozoic era. Following the decline of the reptiles during the late Mesozoic, both birds and mammals started flourishing. The mammals became the most diversified of all animals during Cenozoic era which is also called the *Age of Mammals.* This era started nearly 70 million years ago and is divided into two periods : Tertiary and Quaternary. After reaching their peaks in Tertiary, the mammals are steadily declining in numbers of species even though man, a member of this group, is considered to be the dominant form of life on earth today.

Origin and Ancestry of Vertebrates (Chordates)

Man being a vertebrate himself, it is not surprising that the problem of searching into the origin and ancestry of vertebrates has long been of particular interest to zoologists. But, like that of most of the animal phyla, the origin of vertebrates also remains obscure. Over the years, several hypotheses have been proposed to explain the origin of vertebrates, but none could stand the test of close scrutiny.

Time of origin. The earliest known truly vertebrate animals were freshwater forms, abundant during the late Silurian and middle Devonian periods. Their fossils are collectively known as *ostracoderms.* They are placed with living cyclostomes (lampreys, hagfishes), in the jawless group called *Agnatha.* As their name refers to, their body was covered by a dermal bony armour forming an elaborate rounded solid shield on the head. Like cyclostomes, they had presumably a persistent notochord and no vertebrae. The mouth was anterior, ventral and lacked jaws and teeth. They had no paired appendages homologous with those of vertebrates. Paired eyes, median nostrial and pineal eye were present. A variable number of pharyngeal gill pouches opened by lateral common or separate gill openings. They were adapted for filter feeding.

The oldest fragmentary fossils belonging to ostracoderms occur in the late Cambrian and middle Ordovician. Absence of any vertebrate fossils in rocks older than the Cambrian, permits only speculation about the earlier history of the vertebrates. Which group was ancestral to the first true vertebrates (ostracoderms)? In fact there have been no fossils intermediate between the ostracoderms, which are already vertebrates, and any other earlier group of animals. As a result, there has been a great deal of speculation about the time of origin and the early progenitors of the

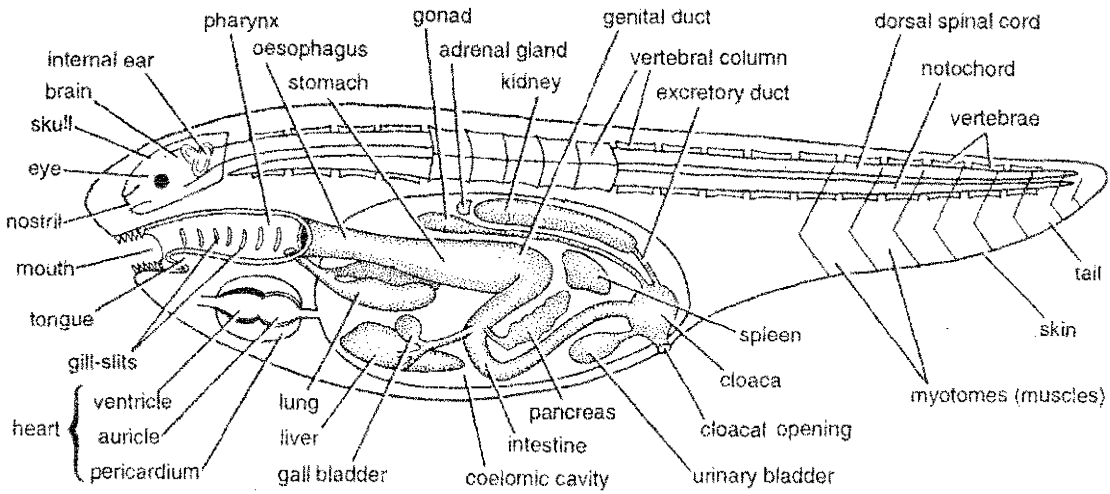

Fig. 3. Hypothetical body plan of ancestral vertebrate.

vertebrates (chordates). Probably the vertebrate organisation had been evolving for several millions of years before the appearance of the first, late Cambrian fossils.

Place of origin. The American geologist Chamberlain gave the idea of *freshwater origin* of vertebrates, in 1900. It was also supported by Romer and Homer Smith. They argued that dilute body fluids, compared to sea water, and the glomerular kidney to get rid of excess water evolved as adaptations to freshwater conditions.

However, evidence for a *marine origin* of vertebrates is also overwhelming. The protochordates and deuterostome invertebrate phyla are exclusively marine forms. All known Cambrian and Ordovician vertebrates also occur as marine fossils. Further, a glomerular kidney is found in hagfishes (Myxiniformes), which are exclusively marine and have body fluids similar to sea water in salt concentration. As Professor James Robertson argues, the primary function of a glomerular kidney is excretory and not osmoregulatory, and it is valuable to an active and mobile vertebrate irrespective of whether it is adapted to sea, to freshwater, or to life on land.

Hypothetical vertebrate ancestor (Prevertebrate). Whatever this *ancestral vertebrate* or *prevertebrate* may have been, there are no fossil records to show. There is reason to believe that it was soft bodied, without any hard exo-or endoskeleton, which could be fossilized (Fig. 3).

The simplest chordates living today are the invertebrate chordates or protochordates belonging to the subphyla Hemichordata, Urochordata and Cephalochordata. They possess the notochord, dorsal nerve cord, pharyngeal gill-slits and postanal tail, fundamentally associated with the vertebrate body plan. They lack the vertebrae and some other features of the earliest as well as the living vertebrates, but they show closest affinities and certainly a common origin with the vertebrates. Therefore, it seems most reasonable and logical to draw inferences about the imaginary, generalized or ancestral vertebrate among them. The ancestor of vertebrates (chordates) can be reconstructed from our present knowledge of existing protochordates.

The American geologist Chamberlain, who proposed the theory of freshwater origin of vertebrates in 1900, also gave the plan of a hypothetical protovertebrate (Fig. 3). It was an aquatic, motile, actively swimming, fish-like animal having a bilaterally symmetrical body with definite head and tail ends. As in higher invertebrates and chordates, the basic internal organization would be some sort of modified tube-within-a-tube arrangement with the major internal organs present inside a large body cavity or coelom. It would also possess all the diagnostic chordate-vertebrate features. It had an internal skeleton in the form of a mid-dorsal longitudinal flexible rod, the notochord, surrounded by the vertebrae. There were internal supports in fins, bony plates in the skin and a rigid cranium or skull housing the tripartite brain and associated sense organs. Muscles were V-shaped and segmentally arranged along the sides of the body, particularly the tail, forming myotomes used in locomotion. Mouth was a simple anteroventral opening without jaws. It probably fed on microorganisms, filtered from the water or from bottom detritus. The water taken in through the mouth passed outwards through paired, lateral pharyngeal gill-slits, bathing the internal gills for aquatic respiration. A liver and primitive kidneys were present. Whether the prevertebrate possessed a circulatory system with a single differentiated heart, is uncertain. The nervous system included a tripartite brain and a hollow nerve cord, dorsal to notochord. Sense organs were well developed including the lateral-line organs. The endocrine system was probably already well developed in the prevertebrate. Finally, the gonads were paired. The female laid eggs and the fertilization was external.

It was from such beginnings that the whole array of vertebrates evolved.

Origin of Chordata. We shall now consider the origin of the earlier chordate ancestors of vertebrates. That the chordates have originated from the invertebrates is not doubted by most zoologists now-a-days. Since the earlier chordate ancestors were all soft bodied forms, they left no fossil remains to give us clues as to their origin. Therefore, the only basis for judging the origin of the group comes from the resemblances between the lower chordates (protochordates and the invertebrates. Some structural features shared by them, such as bilateral symmetry, anteroposterior body axis, triploblastic coelomate condition, metameric segmentation, etc., may be because of their common ancestry.

Theories of invertebrate ancestry of chordates. Several theories have been advanced to explain the origin of chordates either directly from some invertebrate group or through the intervention of some protochordate. Almost every invertebrate phylum—Coelenterata, Nemertean, Phoronida, Annelida, Arthropoda and Echinodermata—has been suggested. But these theories are far from being satisfactory and convincing and have only a historical value. Only the *echinoderm theory* has received some acceptance and shall be considered and evaluated under deuterostome line of chordate ancestry.

Division of Bilateria. The greatest group of metazoan phyla, the *Bilateria,* is divided into two major divisions—*Protostomia* and *Deuterostomia.* The basis of division is the basic difference in embryonic and larval developments. The divisions probably represent two main lines of evolution within the Animal Kingdom. Their main differences are summarized in the Table 4.

Deuterostome line of chordate evolution. A mere glance at the Table 4, showing common features of all Deuterostomia, suggests strong

Table 4. **Basic Difference between Protostomia and Deuterostomia.**

	Character	Protostomia	Deuterostomia
1.	Cleavage	Spiral and determinate	Mostly radial and indeterminate
2.	Blastopore	Forms mouth	Forms anus
3.	Mesoderm formation	By cell cleavage between ectoderm and endoderm	By outpocketing from dorsolateral, endodermal wall of archenteron.
4.	Coelom formation	Schizocoelous, by a split of mesoderm	Enterocoelous, by fusion of gut pouches (except vertebrates)
5.	Type of larva	Trochophore	Tornaria or Bipinnaria (except vertebrates)
6.	Phosphagen	Arginine	Creatine
7.	Major phyla included	Annelida, Mollusca and Arthropoda	Echinodermata, Pogonophora, Hemichordata, and Chordata

evidence of embryological and biochemical nature of a closer evolutionary relationship between the thr-- -rinci-al deuterostome phyla—Echinodermata, Hemichordata and Chordata. For example :

(1) Early cleavages of zygote are indeterminate, i.e. in, each early blastomere is capable of developing into a whole adult if separated.

(2) Blastopore of gastrula forms the anus, while mouth is formed as a secondary opening.

(3) Pockets or folds arise from the endoderm of developing archenteron of the embryo. The fusion of spaces in the pockets forms the *coelom* enterocoelous, except in verte rates and their walls become the *mesoderm*.

(4) The pelagic *larvae* of echinoderms and hemichordates bear a close structural resemblance. The vertebrates, however, do not have floating larvae, having been lost in the course of evolution.

(5) Biochemically, all deuterostomes use an identical phosphagen, the *creatine*, in the energy cycle of their muscular contraction. The phosphagen of invertebrates is *arginine*. However, certain hemichordates as well as echinoids use both arginine phosphate as well as creatine phosphate. These facts are interpreted to show that the hemichordates are connecting link between chordates and nonchordates.

(6) Serological tests demonstrate that the proteins of the three deuterostome phyla are more closely related to one another than to those of any other phyla.

The precise relationship of the three deuterostome phyla remains unknown, but there is little doubt that they share a common evolutionary history. Several workers have attempted to explain the deuterostome line of chordate evolution. Some of the proposals are as follows :

1. Echinoderm ancestry. On the basis of anatomical, embryological, palaeontological, biochemical and serological evidences, various workers had tried to establish that the chordates probably had originated directly from some primitive echinoderm or some echinoderm larva.

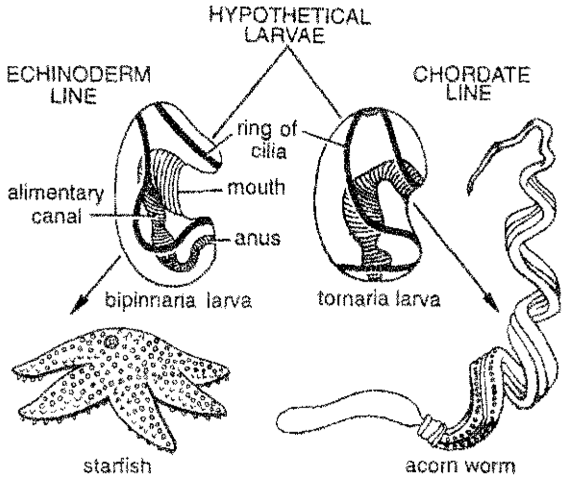

Fig. 4. Similarity of larval forms of echinoderms and hemichordates has lent support to the idea that both came from a common ancestor.

The hemichordata larva (tornaria) is strikingly similar to the larva (bipinnaria or dipleurula) of echinoderms (Fig. 4). It was, in fact, mistaken for an echinoderm when first discovered. Both are small, transparent, free swimming and bilaterally symmetrical. Both have similar ciliated bands in loops, a dorsal pore, sensory cilia at the anterior end and a complete digestive system of ventral mouth and posterior anus. This striking larval resemblance led Johannes Muller and Bateson to suggest a common ancestry for the echinoderms and the hemichordates. But presence of apical plate with eyespots in tornaria larva raises doubts about the common ancestry of echinodermates and hemichordates. Garstang and de Beer proposed the *Neotenous Larva theory* suggesting that probably the auricularia larva of echinoderms became sexually mature and later this neotenic larva gave rise to the chordates.

Garstrong (1894) imagined that if ciliated bands together with underlying nervous tissue of auricularia larva of echinodermates, concentrates to form ridges leaving a groove between them and if lips of the groove fuses subsequently, it will give rise tube. It will resamble with the nervous system of chordates.

Cambrian and ordovician fossil records of Carpoid echinoderms lead Torsten and Gislen to assume that Carapoid echinoderms might have evolved from tornaria like creatures which have begun to sattle down to lead sedentary life. The water vascular system might have developed out of ciliated grooves of these creatures. Besides this, it was also claimed that in the lower silurian period, one carapoid echinoderm had the calyx perforated by a series of 16 small apertures. These apertures can be compared with the gill-slits of *Branchiostoma.*

Moreover, some isolated biochemical studies (Needham, 1932 and Wihelmi, 1942) also put some weight on the concept of diversion of chordates from echinodermates. Most of the nonchordates use arginine phosphate for the transfer of energy but ophiuroides, cephalochordates, ascidians and vertebrates use creatine phosphate. On the other hand hemichordates and echinodermates use both arginine and creatine phosphates as phosphate carrier.

The descent of Chordata from the Echinodermata by the direct transformation of any echinoderm or its neotenous larva into a chordate is no longer accepted now-a-days. The view most widely accepted at present is that the living echinoderms and the living chordates had in common an immediate ancestor.

2. Hemichordate ancestry. There is a strong suggestive evidence that the early evolutionary stage of Deuterostomia group was sessile or sedentary. The pharynx perforated by gill-slits, a characteristic feature of chordates, is also a likely adaptation to sedentary habit. No doubt, hemichordates are sedentary and have pharyngeal gill slits and a hollow dorsal nerve cord. But the presence of a true notochord is doubtful and their adult body plan is quite different from vertebrates. Therefore the prospects of some hemichordate as a likely ancestor of vertebrates seems to be impossible so that they are put under a separate phylum of their own.

3. Urochordate ancestry. The *urochordate* or *ascidian theory* of vertebrate origin was advocated by W. Garstang in 1928 and later elaborated by

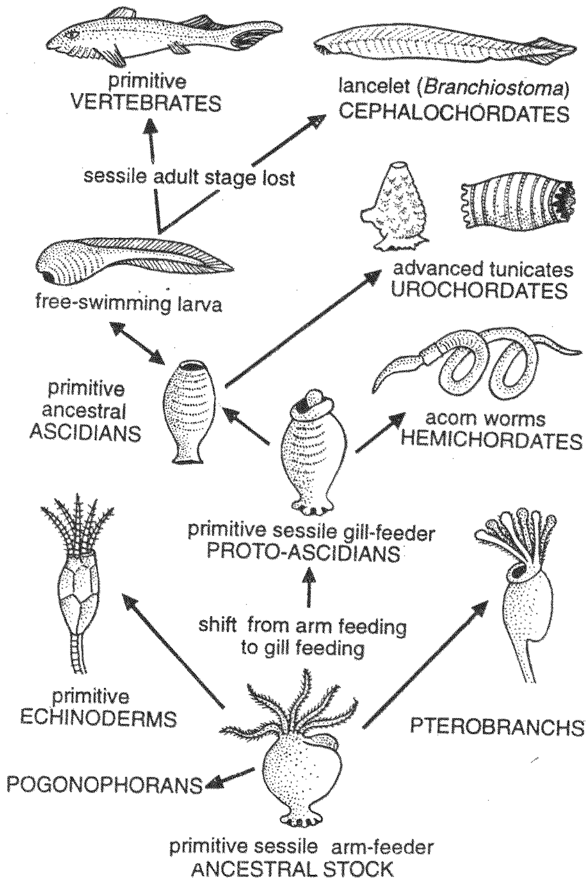

Fig. 5. Diagrammatic representation of chordate evolution based on the hypotheses of Berrill and Barrington.

N.J. Berrill (1955) in his book, "*Origin of Vertebrates*", Romer (1959) and others. The adult tunicates or ascidians reflect the primitive sessile marine and filter feeding condition of the ancestral chordates. But their body plans are so divergent that it is impossible to imagine a direct evolutionary transformation of an adult ascidian into a vertebrate. On the other hand, the ascidian larvae are tadpole-like, elongated, bilaterally symmetrical and free-swimming creatures with pharyngeal gill-slits, notochord, dorsal hollow nerve tube, and a muscular postanal tail. They represent only slightly modified living caricature of the ancestral chordate that gave rise to the vertebrate line of evolution. According to this theory, certain of these larvae failed to metamorphose into adults, but became *neotenous**, that is, sexually mature by developing gonads precociously, and later evolved into the cephalochordates and vertebrates. The sessile nature of life of the primitive chordate ancestory, pterobranch hemichordates and primitive echinoderms by the workers is considered resulting from common ancestry.

However, the ascidian theory of chordate origin does not seem to be perfect. The principal drawback is that the theory considers sessile urochordates to be ancestral to chordates. Whereas, they are highly specialized because sessility is a specialized condition wherever it occurs in the Animal Kingdom.

4. Cephalochordate ancestry. The cephalochordates, particularly the lancelets (*Branchiostoma lanceolatum*) are an interesting group of animals. They possess the three basic chordate features in diagrammatic form. According to Colbert, the living *Amphioxus* (=*Branchiostoma*) answers the logical structure of a model prevertebrate. Homer Smith's reconstruction of the hypothetical protovertebrate in his book, *From Fish to Philosopher* (1953), also greatly resembles *Amphioxus*. But, the excretory system of cephalochordates consisting of flame cells called *solenocytes*, is altogether different from that of vertebrates. The solenocytes are ectodermal and therefore not homologous with the mesodermal vertebrate kidneys. Further, lack of strong cephalization and sense organs, and the unique forward extention of notochord indicate that the cephalochordates may hint about the likely ancestral body plan of vertebrates, but they are not themselves ancestral. Both may represent divergent paths of evolution from a common remote ancestor.

5. Barrington's hypothesis. The most plausible hypothesis by E.J.W. Barrington (1965) is based on the deuterostome line of chordate evolution. The common echinoderm—chordate ancestor was in all probability a small, sessile or semisessile, lophophorate or *arm feeding creature*. It fed by ciliary method by trapping food particles in a set of waving tentacles. From this ancestral stalk were derived early stalked echinoderms and pogonophores. The next logical step was the derivation of a sessile *filter feeder* or *stem chordate*. The cumbersome external tentacles were replaced by an internal filtering apparatus in which food is entrapped inside pharynx which develops external gill-slits and a mucus-secreting endostyle. *Cephalodiscus*, a living pterobranch hemichordate, shows the transitional stage between the two modes of feeding because it has a single pair of gill-slits besides the crown of tentacles. *Pharyngotremy*, that is, perforated pharynx with internal food-trapping mechanism, resulted in the evolution of free-living hemichordates on one hand and the sessile ancestral urochordates (tunicates) on the other. Some ancestral tunicates, instead of producing ciliated larvae common to the earliest groups, formed tadpole larvae with all the typical somatic features of the chordates. According to Garstang, the larva became elongated and increased in size, the longitudinal ciliary bands shifted mid-dorsally and changed to the hollow nerve cord, the adoral cilia developed into the endostyle, and muscle fibres evolved in the tail. This typical chordate larva by paedogenesis suppressed the sessile adult stage, developed gonads precociously and became the ancestor of cephalochordates (*Branchiostoma*), vertebrates and the larvaceans probably representing three cases of parallel evolution.

* N.B. The development of gonads in the ascidian larva is wrongly called *neoteny*. It must be correctly termed *paedogenesis* or *paedomorphosis*. Neoteny properly refers to the retention of an embryonic or larval trait in the adult body. Examples of neoteny are retention of embryonic cartilaginous endoskeleton in adult elasmobranch fishes and the external gills in adult aquatic salamanders. In contrast, paedogenesis emphasizes the premature development of gonads in the larval body, which never undergoes metamorphosis.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. What are vertebrates ? Describe their general characters.
2. Differentiate between—(i) Chordates and vertebrates, (ii) Lower vertebrates and higher vertebrates, (iii) Protostomia and Deuterostomia.
3. Write an essay on the origin and ancestry of vertebrates.
4. Give the outline of evolutionary history of vertebrates.

» *Short Answer Type Questions*

3. Enlist the 'big five' diagnostic vertebrate characteristics.

» *Multiple Choice Questions*

1. The term vertebrata is synonymous to :
(a) Craniata (b) Chordata
(c) Urochordata (d) Protochordata
2. In vertebrates, the pharyngeal gill slits are not more than :
(a) 6 pairs (b) 7 pairs (c) 8 pairs (d) 9 pairs
3. Heart in vertebrates is :
(a) Dorsal, muscular (b) Ventral, skeletal
(c) Ventral, muscular (d) Dorsal, skeletal
4. Respiratory pigment in vertebrates is :
(a) Chlorophyll (b) Haemocyanin
(c) Heparin (d) Haemoglobin
5. Excretion in vertebrates takes place by :
(a) Unpaired kidney (b) Unpaired pronephron
(c) Paired mesonephric kidneys
(d) Paired mesonephric and metanephric kidneys
6. Brain in vertebrates, is the enlarged :
(a) Anterior end of dorsal nerve cord
(b) Posterior end of dorsal nerve cord
(c) Anterior end of ventral nerve cord
(d) Posterior end of dorsal nerve cord
7. Spinal nerves in vertebrates are formed by the union of :
(a) A pair of dorsal roots (b) A pair of ventral roots
(c) A dorsal and a ventral nerve root
(d) Two dorsal and one ventral nerve root
8. Which period is known as the age of fishes :
(a) Cambrian (b) Ordovician (c) Silurian (d) Devonian
9. The first fossil records of vertebrates were found in the rocks of :
(a) Ordovician (b) Cambrian (c) Jurassic (d) Devonian
10. The first jawed vertebrates (Placoderms), arose in :
(a) Cambrian (b) Ordovician (c) Devonian (d) Silurian
11. The first tetra pods arose in :
(a) Ordovician period (b) Devonian period
(c) Silurian (d) Carboniferous
12. The 'age of amphibians' is used for :
(a) Ordovician period (b) Devonian period
(c) Silurian (d) Carboniferous
13. Which era is known as 'the age of reptiles' :
(a) Archaeozoic (b) Proterozoic
(c) Paleozoic (d) Mesozoic
14. Mammals arose during the :
(a) Cretaceous period (b) Triassic period
(c) Jurassic period (d) Permian period
15. The connecting link between reptiles and birds :
(a) *Apteryx* (b) *Struthio*
(c) *Archaeopteryx* (d) *Crocodilus*
16. Which era is known as the age of mammals :
(a) Archaeozoic (b) Paleozoic
(c) Mesozoic (d) Cenozoic
17. In deuterostomes, blastopore forms :
(a) The mouth (b) The anus (c) Brain (d) Kidney
18. Which phosphagen is utilized by vertebrates in energy cycles of muscle contraction :
(a) Creatine (b) Arginine (c) Guanine (d) Cysteine

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (d) 6. (a) 7. (c) 8. (d) 9. (a) 10. (c) 11. (d) 12. (d) 13. (d) 14. (b) 15. (c) 16. (d) 17. (b) 18. (a).

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Class 1. Ostracodermi (Extinct)

The earliest known vertebrates to appear in fossil record were jawless primitive fishlike animals collectively known as the *ostracoderms*, and placed under the class *Ostracodermi*. They resembled the present day cyclostomes (lampreys and hagfishes) in many respects and together with them, constitute a special group of jawless vertebrates, the *Agnatha*.

Occurrence

Ostracoderms were encountered first as fragmented fossils occurring in the rocks of late Cambrian and middle Ordovician periods, dating back approximately 500 million years. They were quite abundant during the upper Silurian and Devonian periods. Most of their fossils were preserved in the bottom sediments of freshwater streams. However, opinion is sharply divided as to whether their habitat was freshwater or marine.

Important Features

These primitive vertebrates were small to medium sized. Their body form was fishlike, usually flattened dorso-ventrally, with a huge head and gill region, a tapering but muscular trunk and some sort of tail fin. They had no jaws and no pectoral or pelvic fins but had only median fins. Remarkably these earliest vertebrates were very bony and heavily armoured. The head was encased in a solid shield made of broad bony dermal plates, while the rest of the body surrounded by a series of smaller plates often called dermal scales. This has led to their names 'ostracoderms', 'armoured fishes' or 'bony skin' (Gr., *ostrakon*, shell + *derma*, skin). Why were they so heavily armoured ? It has been suggested that the heavy exoskeleton served as a protection against the giant scorpion-like arthropods, the eurypterids, which were dominant predators of Cambrian, Ordovician and Silurian periods. Later, when these enemies disappeared, the jawed descendants of ostracoderms also lost their heavy armour which only hindered rapid progress.

The ostracoderm head was rather unusual. Most kinds had a pair of large lateral eyes and a median pineal eye on top of head. A single median nostril was located anterior to pineal eye. Very little is known about ostracoderm internal anatomy. They had no axial endoskeleton or vertebrae. Mouth was anteroventral small and without jaws or teeth. Sensory fields on head were probably a part of the lateral line system. Judging by their flattened body and feeble fins, they were probably sluggish bottom dwellers and filter feeders, like most of the present day lower chordates. An internal ear with 2 semicircular canals was present.

Classification

All ostracoderm fossils have been generally put under a single class *Ostracodermi*. It is divided into 2 sub-classes and 5 orders, as follows :

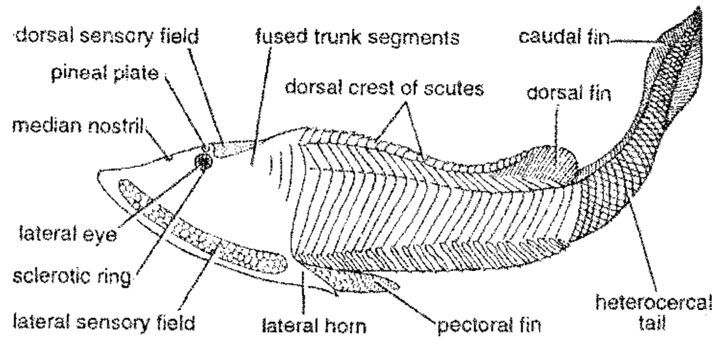

Fig. 1. Restoration of *Cephalaspis*.

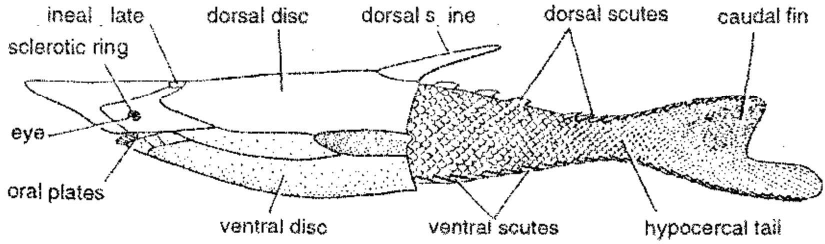

Fig. 2. Restoration of *Pteraspis rostrata*.

Subclass I. Monorhina

A single, large, slit-like median nostril on top of head between eyes.

Order 1. Euphanerida. Silurian. Represented by a single genus and species, *Jamoytius kerwoodi*, previously placed under order Anaspida by Stensio and Ritche (1960). Newth regarded it as ammococt larva of ostracoderms, discovered in the silurian strata of England. About 18 cm long, fusiform, blunt-head and naked. Indications of two lateral and a median dorsal fin folds, notochord, and muscle myotomes like those of *Branchiostoma*. No gill-slits. Regarded as an ancestor of ostracoderms.

Order 2. Anaspida. Silurian-Devonian. Body small about 15 cm long. Head naked or covered by a complex of small plates. Arrangement of scales was complicated. In the trunk region, scales were oriented in longitudinal rows. Mouth was terminal. Eyes laterally placed. Nostril, single median. Paired appendages were represented by a pair of pectoral spines. A series of spines was found in the mid-dorsal line of the trunk. An anal spine might have also been present. About 8 gill-slits were present in front of the pectoral spine in slanting fashion. Tail hypocercal (lower lobe larger). They were active swimmers. *Birkenia, Lasanius, Pteroleps, Rhyncholepis* and *Pharyngolepis*.

Order 3. Osteostraci (Cephalaspida). Silurian-Devonian. A single piece head shield or carapace without sutures. Tail heterocercal (upper lobe larger). A pair of palps behind the gills served like pectoral fins. Several pairs of gill slits. Sensory fields on head. Lateral eyes close together. Lampreys (Petromyzontiformes) probably were derived from Osteostraci. Tail, heterocercal. *Cephalaspis, Hemicyclaspis, Tremataspis, Kiaeraspis, Didymaspis, Benneviaspis* etc. (Fig. 1).

Subclass II. Diplorhina

Two separate nasal openings, where known.

Order 1. Heterostraci (Pteraspida). Ordovician-Devonian, Body large, Head encased in a shield. Tail was laterally compressed, covered with small scales hypocercal. Mouth slit like aperture. Anterior portion of the snout is prolonged into rostrum. Lateral eyes widely separated. A single large gill-slit on each side. No signs of sensory organs. Lateral line was distinct. A backwardly directed dorsal spine projected upwards from the posterior part of cephalic shield. Entire trunk was found covered with ractangular scales. Hagfishes (Myxiniformes) were probably derived from Heterostraci. *Pteraspis, Drepanaspis* (Fig. 2).

Order 2. Coelolepida. Ordovician-Devonian. Body small (10 to 12 cm long) and fusiform or torpedo-like, Surface covered by numerous minute placoid-scale like denticles. Tail hypocercal or heterocercal. Lateral eyes widely apart. Broad flanges project antero-laterally from body. *Phlebolepis, Lanarkia, Coelolepis*.

Biological Significance of Ostracoderms

(1) Ostracoderms are especially interesting because they represent the oldest known vertebrate fossils in the late Cambrian and Ordovician rocks dating back to nearly 500 million years. They are the remote ancestors of all the vertebrates including man.

(2) Microscopic examination of their fossilized bony tissues reveals a great complexity of structure, thereby implying that these vertebrates were far advanced and had undergone a considerable period of evolution before becoming fossilized.

(3) Lack of earlier vertebrate fossils shows that they had perhaps evolved in a habitat (fres-hwater?) which was inimical to fossilization. It is also likely that the earliest ancestors lacked hard skeletal materials, i.e., bone.

(4) They developed heavy bony armours perhaps for survival against the attacks of contemporary giant arachnid predators, the eurypterids. As these enemies disappeared, the descendants of ostracodermis, the cyclostomes, also lost the unwanted heavy armour which was a hinderance in rapid progression.

(5) The cartilage of cyclostomes and sharks and skates (Chondrichthyes) was previously considered a precursor to bone and more primitive. Since the ostracoderms had bony skeletons, the bone is now considered more primitive and the cartilage is interpreted as a degenerate condition.

Interrelationship and Affinities

The affinities of the ostracoderm fossils with each other have been much disputed. There is evidence to believe that ostracoderms were not all equally related and at least two district major groups are recognized : the *cephalaspids* and the *pteraspids*. According to Lankester pteraspids were related to cephalaspids because both are jawless, have a large cephalic shield and occur in the same beds. On the other hand Prof. Eric Stensio (1927) believes that the pteraspids have given rise to myxinoids and the cephalaspids to lampreys. There is indeed little in common among the ostracoderm fossils except for the absence of jaws. Differences in the shape of their tails are especially baffling. As White suggests, the earliest vertebrates had straight or diphycercal tails. From these evolved pteraspids with hypocercal tails, as well as cephalaspids with heterocercal tails. The modern cyclostomes have been probably evolved from the cephalaspids. But which ostracoderm group gave rise to the earliest gnathostomes is unknown.

The ostracoderms closely resemble the modern cyclostomes in : (i) absence of biting jaws, (ii) structure of brain and cranial nerves, (iii) similar auditory capsules, (iv) unpaired olfactory organs, and (v) pouch-like branchial sacs. Stensio (1927) believes that cyclostomes have descended from ostracoderms by the evolution of a sucking mouth, loss of bony exoskeleton and paired limbs and development of cartilage.

The fossil ostracoderms, as we find them, were specialized and products of a long evolutionary past. They probably evolved from unarmoured ancestors such as *Jamoytius*. They could not compete with the jawed fish that evolved in such diversity during Devonian and became extinct. Before extinction the ostracoderms gave rise to the first bony fishes, the placoderms, and the cartilaginous Chondrichthyes.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Write an account of the characters, classification, biological importance and affinities of ostracoderms.

» *Short Answer Type Questions*

1. Write short notes on—(i) *Cephalaspis*, (ii) *Ostracoderms*, (iii) *Pteraspis*.

» *Multiple Choice Questions*

1. The earliest known vertebrates to appear in fossil records :
   (a) Ostracoderms (b) Placoderms
   (c) Tetrapods (d) Mammals
2. The ostracoderms are grouped into :
   (a) Pisces (b) Agnatha
   (c) Gnathostomata (d) Tetrapoda
3. Ostracoderms date back almost :
   (a) 300 million years (b) 400 million years
   (c) 500 million years (d) 600 million years
4. The fossils of ostracoderms were preserved in :
   (a) Bottom sediments of oceans
   (b) Bottom sediments of large lakes
   (c) Gondvana land
   (d) Bottom sediments of freshwater streams
5. The ostracoderms lack :
   (a) Jaws and median fins (b) Jaws
   (c) Median fins (d) Jaws and paired fins
6. Body of the first vertebrates was surrounded by :
   (a) Dermal scales
   (b) Placoid scales
   (c) Ctenoid
   (d) Cycloid scales
7. The sense organs in ostracoderms include :
   (a) A pair of nostrils
   (b) A pair of large lateral eyes, a median peneal eye and a median nostril
   (c) A single lateral and a median eye
   (d) Three nostrils

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (d) 6. (a) 7. (b).

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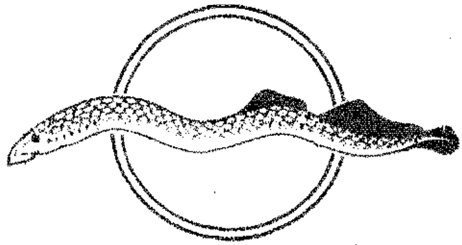

Type 4. *Petromyzon* : The Lamprey

The lowest or most primitive of all vertebrates belong to the group *Agnatha* without jaws. Besides ancient fossil ostracoderms, they include only one class of living vertebrates, the *Cyclostomata*. They derive their name from their circular mouth (Gr. *cyklos*, circular + *stoma*, mouth). The cyclostomes include lampreys, hagfishes and slime eels. They are commonly known as round mouthed eels as they superficially look like eels. However, they are not to be confused with true eels which are highly developed bony fishes.

Lampreys are both marine and freshwater forms. *Petromyzon marinus* is the destructive marine lamprey, while brook lampreys *Lampetra fluviatilis* is the common freshwater lamprey. They are usually used for laboratory studies because of their large size.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Group	Agnatha
Class	Cyclostomata
Order	Petromyzontiformes
Family	Petromyzonidae
Type	*Petromyzon* (Lamprey)

Distribution and Habitat

Lampreys are worldwide in distribution and found in both salt and fresh water. Three species are common in temperate zones of Northern Hemisphere. *Petromyzon marinus*, commonly called the sea lamprey, inhabits the waters of the Great Lakes between U.S.A. and Canada as well

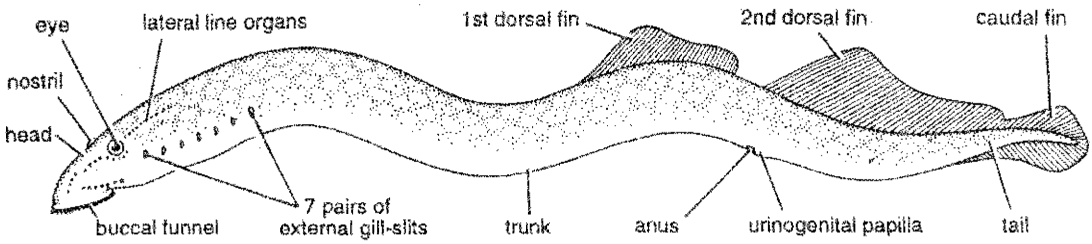

Fig. 1. Sea lamprey *Petromyzon marinus.*

as along the Atlantic coasts of North America, Europe and Africa.

Habits

Petromyzon is a rather unpleasent animal. Its life cycle includes two quite different phases. The larval phase, called *ammocoete* is a freshwater, sedentary, filter feeding and microphagus creature reminiscent of the lancelet or *Branchiostoma*. The fish-like adult lives in the sea and is parasitic on fishes. It clings to fishes, turtles, etc., with its powerful suctorial mouth and then removes small bits of tissue with its rasping tongue, thus becoming a formidable foe of fish populations. They are often referred as quasi-parasitic, which is not true biologically. The sea lamprey swims about near the bottom of salt or fresh water by undulations of its body. When moving upward in a strong current, it darts suddenly forward and clings to rocks. In autumn, all adult lamprys usually ascend rivers to spawn in the spring, after which they die.

While, in the river system, lampreys do not eat any thing, but utilize accumulated subcutaneous fat that provides nourishment. They migrate to the rivers during autumn after attaining maturity in winter. However, breeding takes place in spring. Some lampreys (*Lampetra*) have peculiar habit of nest building, at the bottom of the river, where sand and stone both are present.

External Features

Shape, size and colour. The adult lamprey has an elongated eel-like body made of three regions : *head, trunk* and *tail*, which are not clearly demarcated. Head and trunk are cylindrical, where as the tail is laterally compressed. Body surface or skin is mottled greenish-brown in colour. Upper body surface is usually dark and lower surface is light. It is without exoskeleton, soft and made slimy by secretions from epidermal glands. Sea lamprey (*Petromyzon marinus*) attains a length of one metre, common freshwater lamprey (*Lampetra fluviatilis*) reaches 90 cm, while brook lamprey (*L. planeri*) does not exceed 45 cm. (Fig. 1).

Fins. Paired appendages are absent. Two unequal median *dorsal fins*, first and second, are located near the posterior end. Around the tail there is a *caudal fin*, the upper lobe of which is continuous with the second dorsal fin. The fins are supported by thin cartilaginous rods, the *fin rays*. These rays are fused together at their bases to the membranous sheath that surrounds the notochord and neural tube and help to strengthen the latter. In some lampreys (*Lampetra planeri*), the female possesses an anal fin, but in males, it is reduced to a copulatory papilla.

Buccal funnel. The anterior body end or head bears a ventrally directed large cup-like depression, the *sucker* or *buccal funnel*. It is surrounded by a *marginal membrane*, beset with numerous soft small projections, the *oral fimbriae* or *papillae* which help in attachment to a fish. In between the papillae project out longer sensory processes, the *cirri*. The inside of buccal funnel is beset with radiating rows of conical yellow, horny, epidermal *teeth* which have a very definite arrangement. The teeth in the upper and lower sides of the mouth fuse to form large tooth plates called *supra oral* and *infra oral tooth plates* respectively. Teeth are not homologous with true vertebrate teeth. At the apex of the buccal funnel is a small circular

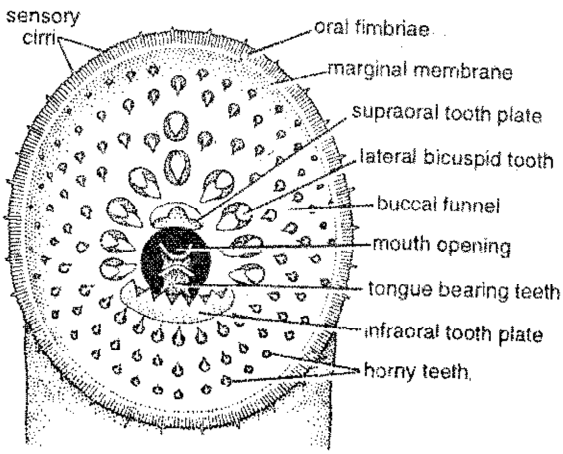

Fig. 2. *Petromyzon.* Buccal funnel in ventral view.

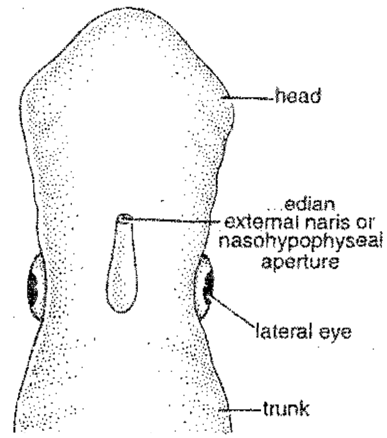

Fig. 3. *Petromyzon.* Head in dorsal view.

mouth opening. The mouth is surrounded by the concentric rows of *lateral teeth* each having two cusps, thus referred as *bicuspid*. Immediately below and behind the mouth projects the so-called *tongue*. It also bears large horny teeth.

Eyes. On each lateral side of the head is a large prominent eye. The two eyes lack eyelids and are covered by a transparent area of skin.

Apertures. As already mentioned (i) *Mouth* is a narrow aperture lying at the apex of the buccal funnel and held open by a ring of cartilage. (ii) Between the eyes and on the head is a single small mid-dorsal *nostril* or *nasohypophyseal aperture*. But Stensio (1968) disagreed with the presence of single olfactory organ and external nasal aperture. According to him, the nasal capsule of both sides of olfactory organ in Petromyzontia is a paired organ. He further pointed out that, all recent cyclostomes evolved from agnathan forms, having paired olfactory organs, similar to gnathostomes. The secondarily unpaired nasal capsule has paired external nasal opening, seperated by internasal septum of soft tissues. Immediately behind the nostril, a transparent area of skin indicates the position of the *pineal organ*. (iii) Seven small rounded openings of *external gill slits* form a longitudinal row on each lateral side of the head, just behind each eye. (iv) On the ventral side, at the junction of trunk and tail, is a slit-like depression, the *cloaca*. A *urinogenital papilla* bearing on its tip a minute urinogenital aperture protrudes through the cloaca. Just in front of it, lies the small *anus* within the cloacal depression (v) Numerous small *sensory pores* of the lateral line system extend along each lateral side of the body and below the head.

Internal Anatomy and Physiology

Skin. Skin is soft smooth, slimy and consists of many layers of cells. *Epidermis* has many unicellular mucous glands producing slime. Besides typical gland cells, two other special types of glands have also been reported from the skin viz., granular cells of unknown function and club cell, *kobenzelle* characterized by having elongated cell body and hyaline cytoplasm. The outermost cells have a striated cuticular border. *Dermis* is composed of collagen and elastin fibres, running mostly in a circular direction. Star-shaped chromatophores are able to migrate, changing the skin colour dark or pale. A layer of subcutaneous tissue contains blood vessels, fat and connective tissue and chromatophores are found between dermis and bodywall musculature. Pigment cells are present in dermis.

Musculature and locomotion. Locomotion is by means of powerful short segmental muscles of trunk and tail arranged in E-shaped *myotomes* separated by *myocommas*, similar to that of fishes. Myotomes are further divided with the help of horizontal septum into dorsal and ventral pairs.

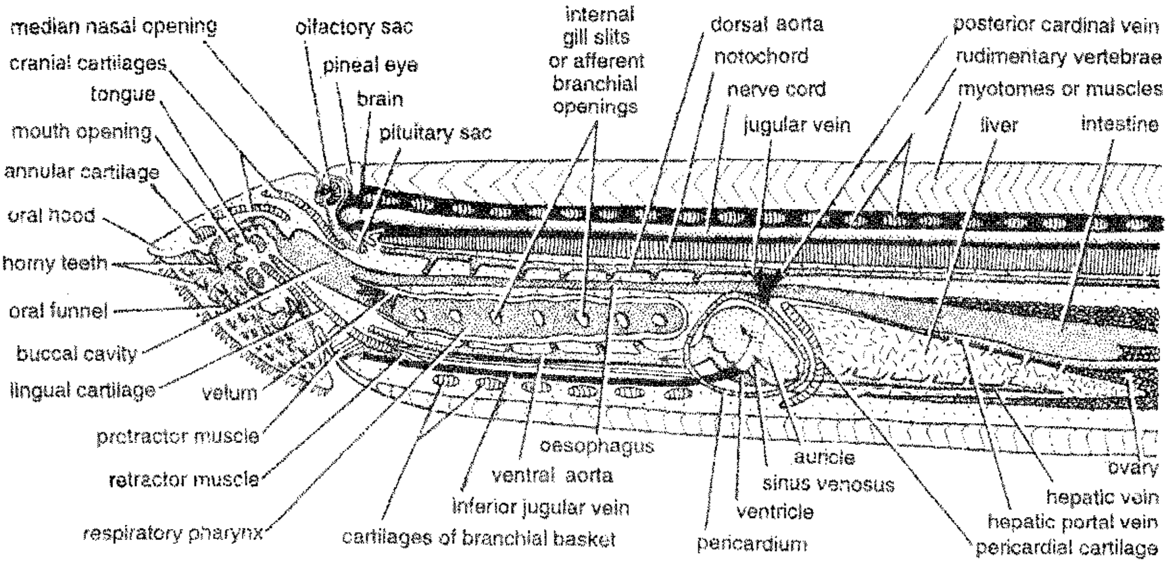

Fig. 4. *Petromyzon.* M.L.S. of anterior end of female to show internal strucutre.

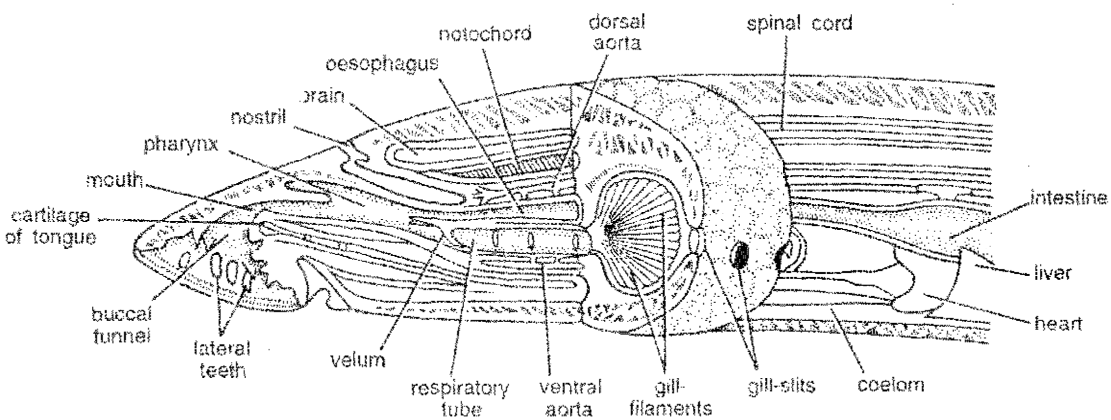

Fig. 5. *Petromyzon.* Longitudinal sectional view of the anterior portion showing the internal structures. A portion of the body is kept intact to show the position of a gill-slit (after Storer and Usinger).

Muscle fibres are striated. Contraction of myotomes on one side results in bending the entire body in that direction. Sucking action of the buccal funnel is operated by radial muscles. The rasping tongue is moved by small protractor and large retractor muscles (Figs. 4 & 5).

Skeleton. It contains no true bone but includes notochord and cartilage. A rod-like gelatinous *notochord*, sheathed in tough connective tissue, persists throughout life as axial skeleton. It resembles the notochord of amphioxus in both structure and function. Rest of the skeleton is formed by *cartilage* and includes : (i) small rod-like *neural arches* of prevertebrae on either side of nerve cord; (ii) Cranium and sense capsules (*skull*) enclosing the brain and organs of special sense; (iii) an elaborate *branchial basket* supporting the gill region; (iv) a stout *lingual cartilage* in the tongue; (v) a ring of *annular cartilage* surrounding the *buccal funnel*; and (vi) a cartilaginous structure enclosing the heart and pericardium.

Digestive system and feeding. The small *mouth opening* at the end of the buccal funnel leads into a large *buccal cavity*. Mouth can be closed or opened by the forward and backward piston-like movement of the *tongue*. Buccal cavity communicates behind with two tubes, a dorsal

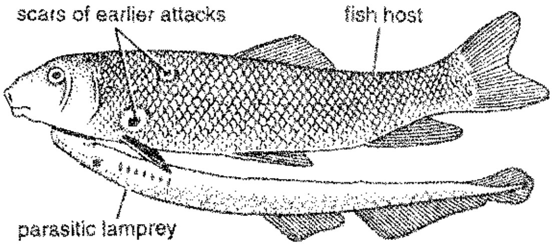

Fig. 6. *Petromyzon* attached to a bony fish, for feeding.

oesophagus and a ventral *respiratory pharynx*. The latter is a blind pouch, which bears 7 internal gill slits on each side. A valve like structure, the *velum*, prevents the passage of food into the respiratory tube. There is no distinct stomach. Anterior part of intestine is dialated, representing the stomach. Posteriorly, the oesophagus opens by a valve into the straight *intestine* which terminates at the small *anus* in the cloaca. Inside the intestine is a spiral longitudinal fold, the *spiral valve* or *typhlosole*.

Digestive glands are well developed. A pair of *buccal* or *salivary glands* opening below the tongue secrete an anticoagulant. A bilobed voluminous *liver* surrounds the anterior part of intestine. A gall bladder and a bile duct although present in the ammocoete larva, are absent in the adult. It is uncertain whether a pancreas or a spleen is present. Besides this, patches of secretory cells are found in the epithelium of anterior part of intestine. The secretory cells are of two types— *zymogen cells*, secrete pancreatic enzymes, which are tryptic in nature. And *cells of the follicles of the Langerhans*. The endocrine function of the follicle cells of Langerhans has been established. It is that if these cells are distructed, a sharp increase in the blood glucose level takes place. Moreover if glucose is administered in the body, these cells develop vacuoles.

Petromyzon is a predator feeding mainly on bony fishes. It attaches itself by means of its powerful sucker-like buccal funnel to the body of the fish. By fore-and-aft piston-like movements, the tongue with its sharp horny teeth rasps off small bits of flesh from the body of the victim. Lamprey then injects an anticoagulant in saliva into the wound and sucks blood and body fluids of the prey (sanguivorous habit). Such wounds often prove fatal to host fish, especially if they are made in the abdominal region of the body. Lampreys do not enter the prey's body.

Respiratory system. There are seven *gills* in spherical *gill pouches* on either side between the respiratory pharynx and the body wall. They are separated from one another by membranous *inter-branchial septa*. Each gill pouch has an appearance of a biconvex lens. The inner wall is folded to form numerous *gill lamellae*, and the outer wall is highly muscular. Blood in gill capillaries takes in O_2 and releases out CO_2 in water in gill pouches. Each gill pouch communicates to the exterior by an *external gill slit*, and with the respiratory pharynx by an *internal gill slit*. In larval lamprey, respiratory water current enters through the mouth and passes out through the gill-slits, as in true fishes. But in the adult lamprey, water for respiration passes into as well as out of the gill pouches through the seven rounded external gill-slits on either side. This method is necessary because when attached to another fish by buccal funnel for feeding, water cannot enter through mouth. Velum prevents water of pharynx from entering the buccal cavity.

Circulatory system. Circulatory system is similar to that of amphioxus. The *heart* is located ventrally just behind the last pair of gill pouches, enclosed in a thick-walled *pericardium* supported by a cartilaginous plate. The heart is 'S' shaped. It develops in the larva as a straight tube, which elongates further but due to paucity of space, it twists to give 'S' shape. It is made up of four chambers– one *sinus venosus*, one *auricle*, one *ventricle* and one *conus arteriosus*. Blood from various parts of body returns to a small *sinus venosus*, from where it first goes into a thin-walled *auricle* and then into a thick-walled *ventricle*. Ventricle pumps blood into a *ventral aorta* which gives off 7 pairs of *afferent branchial arteries* to gills. Here, blood gives off CO_2 and takes a fresh supply of O_2. From gills, blood is collected through 7 pairs of *efferent branchial*

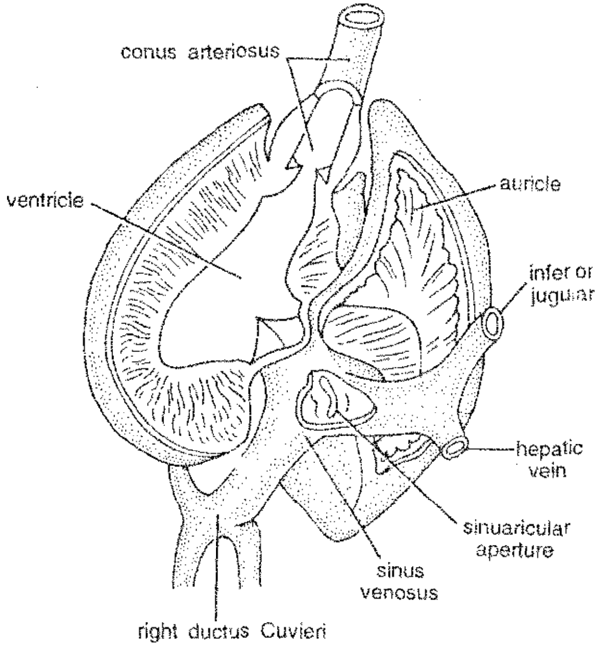

Fig. 7. Diagrammatic longitudinal section of the heart of *Petromyzon*. The chambers are exposed showing the internal details (after Jollie).

arteries in median *dorsal aorta* and distributed to various parts of the body. A *hepatic portal vein* is present but a renal portal system is lacking. A lymphatic system is also present. *Blood* contains both red blood corpuscles with haemoglobin and white blood corpuscles. Red blood corpuscles are nucleated and circular in outline. But white blood corpuscles are similar to lymphocytes and polymorphs of higher vertebrates. Blood forming tissues are present in the spiral valve, kidney and spinal cord. The *median dorsal aorta* gives rise to *segmental arteries* to the myotomes. Diffused *chromaffin cells* are present in segmental arteries (also in segmental veins), which represent the adrenal medulla, and its secretion resembles with mammalian adrenalin. Most of the arteries except efferent branchial and renal arteries are provided with valves at the point of their origin in order to reduce the pressure of blood in the arteries (Fig. 7).

Excretion. *Kidneys* are of the *mesonephric* type. They are a pair of long strap-like structures suspended mid-dorsally by mesenteries. As blood circulates through *glomeruli* inside *Bowman's capsules* or capillary network, nitrogenous wastes are extracted by the *uriniferous tubules* and poured into a mesonephric duct or *ureter*. A tubular ureter runs along the free ventral edge of each kidney, conveying urine to the *urinogenital sinus* which empties to the exterior throu_h the *urino_enital papilla*.

Nervous system. The *brain* of the adult lamprey is very primitive. In forebrain two large *olfactory lobes* are followed by smaller *cerebral hemispheres* attached to *diencephalon* which carries dorsally a *pineal organ* and ventrall_ a broad *infundibulum*. Midbrain has a pair of large *optic lobes*. Hindbrain includes a small transverse rudimentary *cere'ellum* an' a fairly well-'evelope' *medulla oblongata*. Within the brain are 4 *ventricles*, as in other vertebrates, 10 pairs of *cranial nerves* are present. *Spinal cord* is a flat, ribbon-like structure. The spinal cord of lampreys is peculiar as no blood vessel is present within it. The dorsal and ventral roots of *spinal nerves* remain separate, as in *Branchiostoma*, and are not bound together as in other vertebrates. Sympathetic nervous system is poorly defined. All the nerve fibers of lampreys are non-myelinated, because of which, rate of conduction of nerve impulses is very slow (Fig. 8).

Sense organs. The single mid-dorsal external nostril leads into a small *olfactory sac* (organ of smell) receiving two separate olfactory nerves indicating its bilateral origin. The olfactory sac gives off ventrally a long tube of unknown function, called *pituitary pouch*. The two lateral *eyes* are primitive and lack the suspensory ligament and ciliary apparatus. The median *pineal eye*, with clear lens and pigmented retina can probably distinguish light from dark. Each *internal ear* has only two vertical semicircular canals each with an ampulla. Utriculus and sacculus are not distinct. There are *taste buds* in the pharynx. *Lateral line* sense organs on sides of body and beneath head probably detect water movements. In salt water, lampreys can produce electric fields to detect the prey. *Integumentary photoreceptors* showing photosensitivity are also found in the

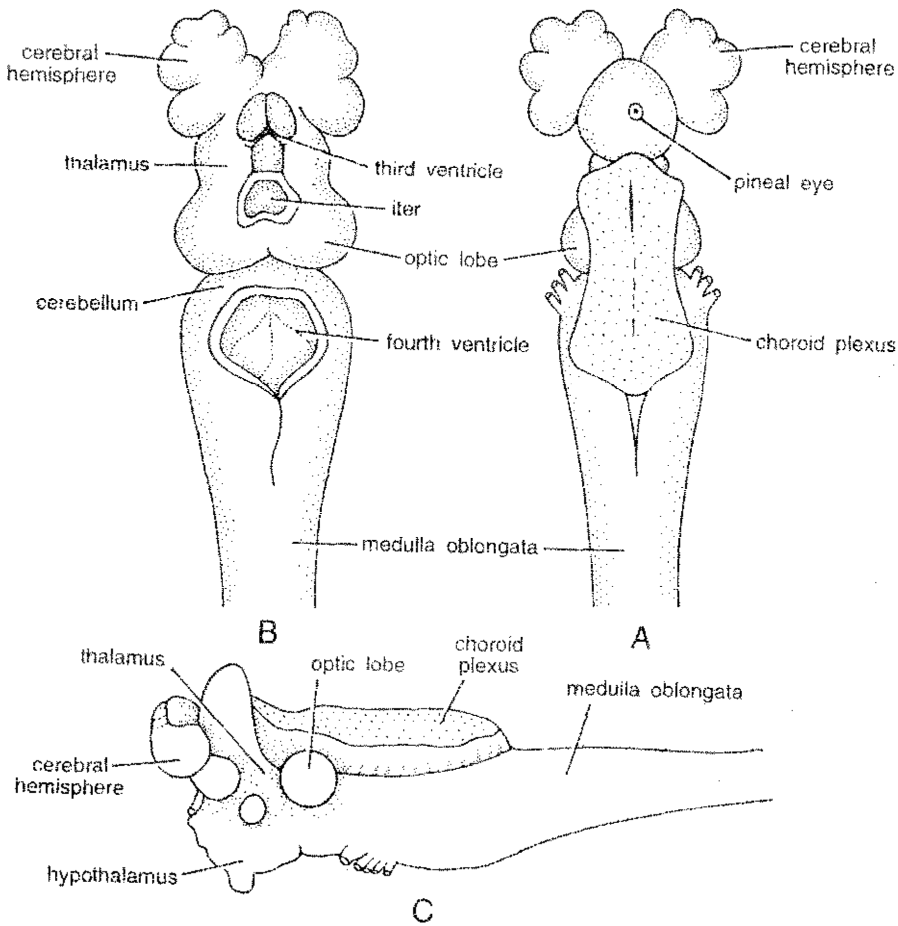

Fig. 8. Brain of *Petromyzon*. A. Dorsal view having the choroid plexus intact. B. Dorsal view after removing the choroid plexus. C. Lateral view (after Young).

integument of lampreys. These cells are found in abundance in tail region of the animals.

Reproduction. Sexes are separate (dioecious). The differentiation of gonads takes place quite lately. In ammocoetes larva *hermaphroditic* gonad is present containing both oocyte and spermatocytes. At sexual maturity a single large *gonad* fills most of the abdominal cavity. There is no *genital duct*. Mature eggs or sperm escape from gonad into coelom, pass through *genital pores* into the urinogenital sinus, and leave the body through the urinogenital opening into water.

In spring or early summer, lampreys become sexually mature and migrate into a neighbouring freshwater stream or river for breeding. With their buccal funnels, the males move pebbles from a sandy bottom and form a *nest* in the form of a shallow rounded depression or pit. When a female attaches to a stone in the nest, a male winds his tail around her and eggs and sperm are discharged. More than one pair may spawn in the same nest. The adults die after spawning. *Fertilization* is external, taking place in water. A large female sea lamprey lays upto 236,000 eggs.

Development. The eggs are *telolecithal types* having a good quantity of yolk. Cleavage is *holoblastic*, unequal. Gastrulation takes place by *invagination*, blastopore takes postero-dorsal position, and it is finally converted into anus. Development of central nervous system is quite

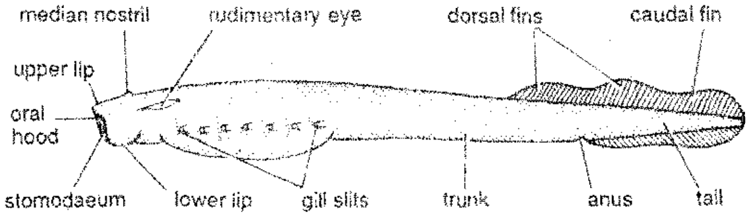

Fig. 9. Ammocoete larva. External features in lateral view.

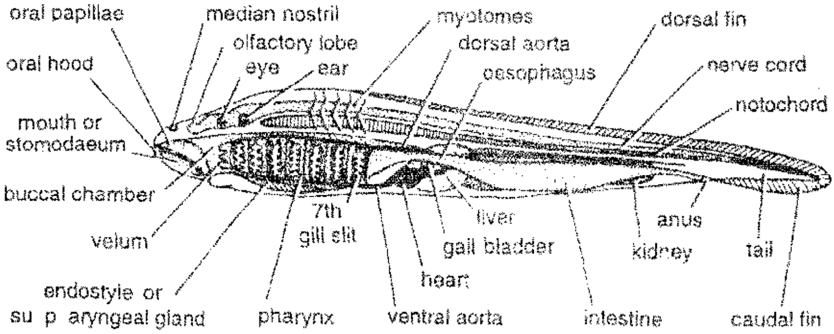

Fig. 10. Ammocoete larva showing general internal structure.

peculiar in lampreys. It develops in the form of a solid cord or keel, which subsequently hollows to form the lumen of nerve cord. This type of formation of central nervous system is called *thickened keel method.*

Ammocoete larva. The eggs hatch in about 3 weeks into minute transparent larvae called *ammocoetes.* They are so radically different from their parents that they were originally described as a distinct genus, *Ammocoetes.* At first, they are about 7 mm in length and stay in the nest. When about 15 mm long, they quit the nest and burrow in mud and sand in quiet water. Each larva constructs and inhabits a V or U-shaped tunnel. The larval period lasts from 3 to 7 years, according to species during which they grow to about 170 mm in length and become opaque.

The ammocoete larva is of great importance as it probably represents the most primitive and generalized vertebrate form intermediate between cephalochordates and vertebrates. Its body is eel-like but it differs from the adult in several respects. It has a continuous single median *dorsal fin.* It is a blind, toothless and non-parasitic filter feeder. Feeding and respiration are like those of *Branchiostoma.* It has no suctorial buccal funnel but a semicircular upper lip or *oral hood* around the mouth, similar to that of *Branchiostoma.* Mouth also has a transverse lower lip. It emerges at night, from its burrow to feed on the bottom organic ooze, containing unicellular algae and bacteria, which are caught on the floor of pharynx in mucous strings secreted by a tubular *endostyle.* A *velum* made of a pair of muscular flaps, regulates the entry of water current into the pharynx which is continued posteriorly into the oesophagus. 7 pairs of *gill pouches* are present, each with its internal gill slit into pharynx and external gill slit to the exterior. *Branchial basket* supporting the pharyngeal wall alternately expands and contracts, drawing water through mouth into pharynx and pumping out through external gill slits. Thus, water circulation is by muscular activity and not by ciliary activity, as in *Branchiostoma.* This is probably a necessary evolutionary development for engulfing larger pieces of food. Liver, bile duct, gall bladder and protonephros (kidney) are present. Pericardial cavity enclosing heart connects with coelom. Paired eyes remain hidden under thick skin and muscles. Unpaired median pineal eye is well-developed but hypophysial and nasal sacs are poorly developed.

Metamorphosis. After a prolonged larval life of 3 to 7 years, ammocoetes undergo several radical structural changes to metamorphose into the semiparasitic adult form : (i) Oral hood is replaced by a suctorial *buccal funnel* with strong and sharp teeth, tongue, rounded mouth and complex musculature. (ii) Endostyle changes into a *thyroid gland* below pharynx. (iii) *Velum* becomes reduced to guard the opening of respiratory pharynx only. (iv) Oesophagus separates from *respiratory pharynx* which becomes a blind sac. (v) *Gall bladder* and *bile duct* disappear. (vi) *Gills* develop into gill pouches. (vii) Pronephros is replaced by a *mesonephros*. (viii) Paired *eyes* become uncovered and functional (ix) Single median *nostril* shifts to the top of head. (x) *Naso-hypophyseal sac* grows backwards. (xi) *Nasal sac* becomes folded internally. (xii) Continuous dorsal fin becomes divided into two. (xiii) Pericardial cavity becomes completely cut off from coelom. (xiv) *Spinal cord* becomes dorso-ventrally flattened. (xv) Skin colour changes from yellow-brown to mottled greenish-brown.

After metamorphosis, the young lampreys swim down to the sea where they remain for 3 or 4 years before reaching maturity, when they once again migrate to streams or rivers to spawn and die. Gonads become mature at that time when adults return river for spawning.

Economic Importance

Lampreys have posed a great economic problem to the fisheries in some regions. They destroy valuable fish by feeding on their blood and body fluids. Fishes so attacked die or become so debiliated as to fall a prey to disease or predators. The scars left on the body of fishes render them unfit for the market. Flesh of lampreys is used for food in Europe and America to some extent. Larval lampreys are sometimes used for bait. In general, sea lampreys are very detrimental.

Control methods such as trapping and preventing them from spawning have been only partially successful. Control devices such as poison and electric barriers, have not been wholly effective.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give an illustrated account of external morphology of *Petromyzon*.
2. Describe the digestive system and feeding in *Petromyzon*.
3. Discuss the structure of Ammocoete larva.

» *Short Answer Type Questions*

1. Describe the metamorphosis of Ammocoete larva.
2. Write short notes on — (i) Musculature and locomotion in lampreys, (ii) Digestive system in lampreys, (iii) Respiratory system in lampreys. (iv) Excretion in lampreys, (v) Circulatory system in lampreys.

» *Multiple Choice Questions*

1. Lampreys belong to the group :
   (a) Agnatha (b) Gnathostomata
   (c) Pisces (d) Tetrapoda
2. The *Petromyzon* larva is called :
   (a) Tornaria (b) Ammocoete
   (c) Crinoid (d) Nauplius
3. Exoskeleton in lampreys is :
   (a) Bony (b) Cartilagenous
   (c) Scaly (d) Absent
4. In Lampreys paired appendages are :
   (a) 2 pairs (b) 3 pairs (c) absent (d) 3 pairs
5. The teeth in upper and lower side of mouth lampreys are grouped into :
   (a) Preoral and supraoral tooth plates
   (b) Supraoral and infraoral tooth plates
   (c) Preoral and postoral tooth plates
   (d) Suboral and supraoral tooth plates

6. The marginal membrane in *Petromyzon* is beset with :
   (a) Oral fimbrae (b) Oral cirri
   (c) Buccal fimbrae (d) Buccal cirri
7. The pineal organ is :
   (a) Present immediately behind the eye
   (b) Present immediately behind the eye
   (c) Present between the eye and the nostril
   (d) Absent
8. A urinogenital papilla is present :
   (a) Near the anus (b) Near the caudal fin
   (c) Protrudes through the cloaca
   (d) Absent
9. The outermost layer of cutaneous epidermis :
   (a) Have a ciliated cuticular border
   (b) Have a glandular cuticular border
   (c) Have a squamous cuticular border
   (d) Have a striated cuticular border
10. In *Petromyzon* dermis is composed of :
   (a) Collagen and elastin fibres
   (b) Only collagen fibres
   (c) Only elastin fibres
   (d) Longitudinal muscles
11. Muscles of trunk and tail in *Petromyzon* are arranged in :
   (a) D shaped myotomes (b) E shaped myotomes
   (c) F shaped myotomes (d) C shaped myotomes
12. Sucking action of the buccal funnel is operated by :
   (a) Circular muscles (b) Longitudinal muscles
   (c) Radial muscles (d) Skeletal muscles
13. The cartilage surrounding the buccal funnel in *Petromyzon* is :
   (a) Branchial basket (b) Lingual cartilage
   (c) Pericardium (d) Annular cartilage
14. Two tubes are given from the buccal cavity in *Petromyzon* :
   (a) Oesophagus and respiratory pharynx
   (b) Oesophagus and eustachian tube
   (c) Eustachian tube and intestine
   (d) Nasopharynx and intestine
15. Passage of tube in the respiratory tube in *Petromyzon* is prevented by :
   (a) Oral hood (b) Velum
   (c) Sphincter muscles (d) Scroll valve
16. Anticoagulant in *Petromyzon* is secreted by :
   (a) Mucous glands (b) Goblet cells
   (c) Salivary glands (d) Zymogen cells
17. Each gill pouch in *Petromyzon* communicates with the respiratory pharynx by :
   (a) Gill lamella (b) Gill arches
   (c) External gill slits (d) Internal gill slits
18. In *Petromyzon* water of pharynx is prevented from entering the buccal cavity by :
   (a) Velum (b) Endostyle
   (c) Typhlosole (d) Spiral valve
19. Blood from various parts of body in :
   (a) Aorta (b) Sinus venosus
   (c) Auricle (d) Ventricle
20. In *Petromyzon* ventral aorta gives off seven pairs of afferent branchial arteries to :
   (a) Brain (b) Kidney (c) Gills (d) Liver
21. Kidneys in lampreys are :
   (a) Glomerular (b) Pronephric
   (c) Mesonephric (d) Metanephric
22. In *Petromyzon* optic lobes are present in :
   (a) Forebrain (b) Midbrain
   (c) Hindbrain (d) Medulla oblongata
23. The eggs of lampreys are :
   (a) Alecithal (b) Mesolecithal
   (c) Telolecithal (d) Oligolecithal
24. Intermediates between Cephalochordates and vertebrates :
   (a) Ostracoderms (b) Placoderms
   (c) *Branchiostoma* (d) Ammocoete larva

ANSWERS

1. (a) 2. (b) 3. (d) 4. (c) 5. (b) 6. (a) 7. (b) 8. (c) 9. (d) 10. (a) 11. (b) 12. (c) 13. (d) 14. (a) 15. (b) 16. (c) 17. (d) 18. (a) 19. (b) 20. (c) 21. (c) 22. (b) 23. (c) 24. (d).

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Class 2. Cyclostomata

General Characters

1. Body elongated, eel-like.
2. Median fins with cartilaginous fin rays, but no paired appendages. Tail diphycercal.
3. Skin soft, smooth, containing unicellular mucous glands but no scales.
4. Trunk and tail muscles segmented into myotomes separated by myocommata.
5. Endoskeleton fibrous and cartilaginous. Notochord persists throughout life. Imperfect neural arches (arcualia) over notochord represent rudimentary vertebrae.
6. Jaws absent (group Agnatha).
7. Mouth ventral, suctorial and circular, hence the class name Cyclostomata (Gr. *cyklos*, circular + *stoma* mouth).
8. Digestive system lacks a stomach. Intestine with a fold, typhlosole.
9. Gills 5 to 16 pairs in lateral sac-like pouches of pharynx, hence another name of class, *Marsipobranchii*. Gill-slits 1 to 16 pairs.
10. Heart 2-chambered with 1 auricle and 1 ventricle, with a conus arteriosus anteriorly. Many aortic arches in gill region. No renal portal system. Hepatic portal system present. Blood with leucocytes and nucleated circular erythrocytes. Body temperature variable (poikilothermous).
11. Two mesonephric kidneys with ducts to urinogenital papilla.
12. Dorsal nerve cord with differentiated brain. 8 to 10 pairs of cranial nerves.
13. Single median olfactory sac and single median nostril. Auditory organ with 1 or 2 semicircular canals.
14. Sexes separate or united. Gonad single, large, without gonoduct.
15. Fertilization external. Development direct or with a prolonged larval stage.

Classification

About 50 species of the living jawless fishes are recognized. They belong to two major divisions (*Petromyzontiformes* and *Myxiniformes*) termed variously as subclasses, orders or families. Because they possess a round jawless mouth, they are combined in the class Cyclostomata. The similarity of these two groups is probably the result of convergent evolution. However, they show important and basic morphological differences which can be attributed to their long phylogenetic separation and different habits and habitats. Their differences have been enumerated in the Table 1.

Order 1. Petromyzontiformes

(Gr., *petros*, stone + *myzon*, suck)

Members of this order are called lampreys or lamper eels or lamperns or sand pride etc.

1. Mouth ventral, within a suctorial buccal funnel beset with many horny teeth.

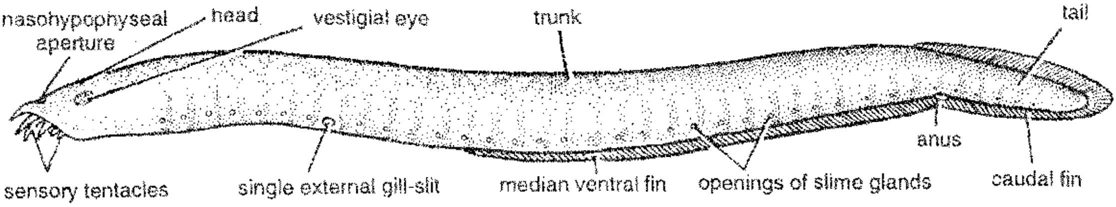

Fig. 1. *Myxine.*

2. Nostril dorsal. Nasohypophyseal sac closed behind, not connected to pharynx.
3. Gill pouches and gill slits 7 pairs each, opening in a separate respiratory pharynx.
4. Dorsal fin well developed.
5. Branchial basket complete.
6. Dorsal and ventral roots of spinal nerves remain separate.
7. Ear with 2 semicircular canals.
8. Eggs numerous, small. Development indirect with a long larval stage and metamorphosis.
9. Both marine and freshwater forms.

Examples : Lampreys. Over 30 species. *Petromyzon, Lampetra, Entospherus, Ichthyomyzon.*

Order 2. Myxiniformes
(Gr., *myxa*, slime + *oidea*, type of)

Representatives of this class are called hagfishes. They are exclusively marine.

1. Mouth terminal with 4 pairs of tentacles and few teeth. No buccal funnel.
2. Nostril terminal. Nasohypophyseal duct opens behind into pharynx.
3. Gill pouches 6 to 15 pairs. Gill slits 1 to 15 pairs.
4. Dorsal fin feeble or absent.
5. Branchial basket poorly developed.
6. Dorsal and ventral roots of spinal nerves united.
7. Ear with only 1 semicircular duct.
8. Eggs few, large. Development direct.
9. Hagfishes are all marine 15 species.

Example : *Myxine, Eptatretus* (=*Bdellostoma*), *Paramyxine*.

Other Cyclostomes

1. *Myxine*. Members belonging to the order Myxiniformes are commonly known as *hagfishes*. They are exclusively marine- *Myxine* is found of the coasts of Europe, America, Africa and Japan. It lives in colonies on the sea bottom, each individual in a mud burrow feeding on polychaete worms. Soft, scaleless, pinkish, elongated, eel-like or worm-like body reaches a length of 50-60 cm and differentiated into head, trunk and tail. It differs from lamprey (*Petromyzon*) in several ways. Suctorial mouth is terminal with soft wrinkled lips like those of an old ugly woman or hag, hence the common name *hagfish*. Eyes are degenerate and covered with a thick skin. Six cartilage-supported cirri or tentacles around mouth compensate for the sightless degenerate eyes. The protrusible tongue, bordered by two multitoothed horny plates, serves as a powerful rasping tongue. The single median nostril lies close to the mouth. 6 pairs of gill pouches are located far behind the head region and their efferent ducts join into a single pair of external gill slits, probably an adaptation to burrowing. Large mucous glands open along the sides of body and secrete enormous quantity of slime, hence another common name, the *slime eel*. A feebly developed mid-ventral fin and a caudal fin are present. Myxine attacks injured or dead fishes and burrows into their body for flesh consumption, hence also called a *borer*. It is really an internal parasite. It may pose a serious threat to fisheries in some regions. Unlike lampreys, the hagfishes do not migrate to fresh water to spawn. The eggs hatch directly into miniature adults without passing through a larval stage (Fig. 1).

2. *Eptatretus (Bdellostoma)*. It is also a common hagfish of the Pacific coasts of America, Newzealand and South Africa. Its structure and habits are similar to those of *Myxine* with few differences. It reaches a length of 1 metre. In different species, 6 to 15 very small external gill

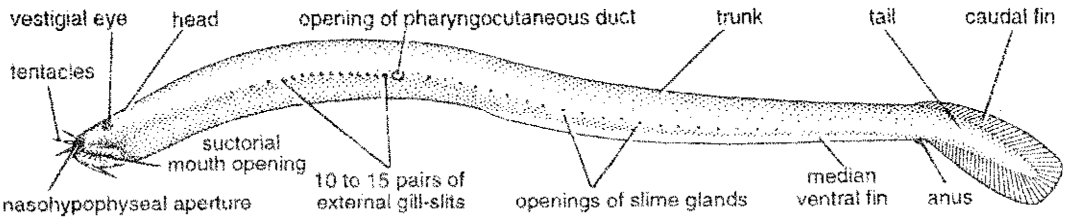

Fig. 2. *Eptatretus* (=*Bdellostoma*).

slits are found, each connected to pharynx through a gill pouch. Behind the last external gill slit of left side is the opening of the *pahryngocutaneous duct* which opens directly into pharynx (Fig. 2).

Affinities of Cyclostomata

The chordate characteristic of cyclostomes are clear-cut. They represent the most primitive members among living vertebrates. The similarity of several features of ammocoete larva of lamprey with Cephalochordata (*Branchiostoma*) indicates primitive relationship. But the adult cyclostomes have certain specialized as well as degenerate features as adaptations to a parasitic habit. Thus, the affinities of cyclostomes may be best described by discussing their (i) *primitive*, (ii) *advanced*, (iii) *specialized* and (iv) *degenerate* characters, as under.

[I] Primitive characters

1. Resemblances with Cephalochordata (*Branchiostoma*). The adult cyclostomes and *Branchiostoma* have many characters in common, such as : (i) Lack of jaws, exoskeleton, paired fins and gonoducts. (ii) Persistent and continuous notochord. (iii) Segmental muscle blocks or myotomes. (iv) Numerous gill slits, (v) Straight and simple alimentary canal. (vi) Dorsal and ventral roots of spinal nerves separate in lamprey. Besides these, the ammocoete larva of lampreys further resembles *Branchiostoma* in : (i) Fish-shaped body, (ii) Vestibule (oral hood) anterior to mouth, (iii) Continuous median dorsal and caudal fins, (iv) Ciliated gut, (v) Microphagus filter feeder, (vi) Endostyle functions in feeding.

2. Differences from fishes (vertebrates). Both cyclostomes and fishes are aquatic vertebrates, but

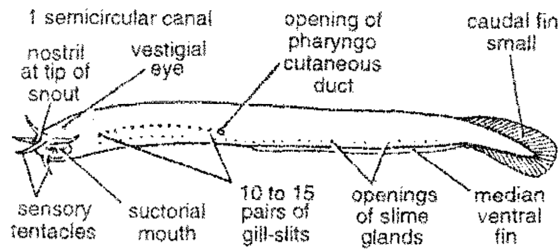

Fig. 3. *Eptatretus* (=*Bdellostoma*).

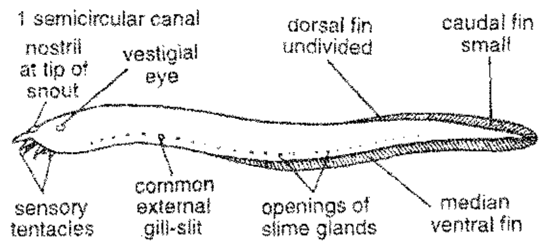

Fig. 4. *Myxine* (hagfish).

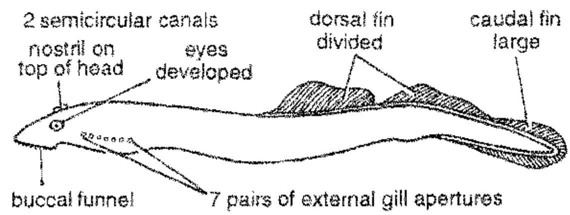

Fig. 5. *Petromyzon* (lamprey).

cyclostomes present many primitive characters in which they differ from fishes, such as : (i) Absence of biting jaws, scales, true teeth, paired appendages, true fin rays, girdles, ribs, stomach, spleen and gonoducts, (ii) Diphycercal caudal fin, (iii) Continuous median dorsal fin, (iv) Single median nostril rather than paired, (v) Incomplete or poorly developed cranium, vertebral column, intestinal spiral valve, pancreas, brain, sympathetic

Table 1. **Difference between Lampreys and Hagfishes.**

	Characters	Lampreys (*Petromyzon*)	Hagfishes (*Myxine*)
1.	Habitat	Marine as well as freshwater	Exclusively marine, burrowing in sand
2.	Parasitism	Externally parasitic or nonparasitic species	Behave as internal parasites
3.	Feeding	Rasp away flesh and suck out blood of host fishes.	Primarily scavengers, burrowing into dead or morbid fish for flesh consumption
4.	Breeding	Anadromous, i.e., ascend fresh water rivers and streams for spawning	Spawn on ocean floor
5.	Knot tying activity	Not found	For feeding and defense body draws a knot and squeezes out
6.	Body	Stout	Feeble
7.	Size	Species reach upto 1 metre	Remain under 1 metre
8.	Fins	Well formed. Dorsal fin notched	Poorly developed. Dorsal fin single or absent
9.	Skin	Less slimy	Exceedingly slimy
10.	Nostril	High on head	Terminal
11.	Paired eyes	Large and functional	Degenerate, covered by thick skin
12.	Pineal eye	Present	Absent
13.	Mouth	Ventral	Terminal
14.	Buccal funnel	Present	Absent
15.	Sensory oral tentacles	Absent	3 or 4 pairs
16.	Tongue	Less developed with larger teeth	Strongly developed with smaller teeth.
17.	Salivary glands	Present secreting an anticoagulant	Absent
18.	Pharynx	Ends blindly as a respiratory tube	Continued into oesophagus
19.	Gill pouches	7 pairs	6 pairs in *Myxine* to 15 pairs in *Eptatretus*
20.	External gill slits	7 pairs	1 pair in *Myxine*, 15 pairs in *Eptatretus*
21.	Intestine	With a spiral fold or typhlosole	With longitudinal folds
22.	Branchial region and basket	Large and well developed	Small and poorly developed
23.	Skull	Imperfectly roofed	Without roof
24.	Neural arches	Present	Absent
25.	Cartilaginous oral ring	Present	Absent
26.	Lingual cartilage	Poorly developed	Well developed
27.	Pericardial sac	Thick-walled, supported by a cartilage	Thin walled, not supported by cartilage
28.	Ductus Cuvieri	Single of right side	Two of both sides
29.	Aortic arches	Each supplies hemibranchs of adjacent gill pouches	Each supplies hemibranchs of same gill pouch
30.	Kidneys	Advanced mesonephros	Primitive pronephros as well as mesonephros
31.	Brain	Better developed	Poorly developed
32.	Cranial nerves	10 pairs present	8 pairs present
33.	Spinal nerve roots	Dorsal and Ventral roots separate	Roots united
34.	Nasohypophyseal duct	Ends blindly	Opens into pharynx
35	Semicircular canals	Two	Single
36.	Urinogenital sinus	Present	Absent
37.	Sexes	Separate	United. Gonad hermaphroditic
38.	Eggs	Small, naked, without shell	Large, enclosed in a horny shell
39.	Segmentation	Holoblastic	Meroblastic
40.	Development	Indirect with a larval stage (ammocoete) and metamorphosis	Direct, without larva and metamorphosis

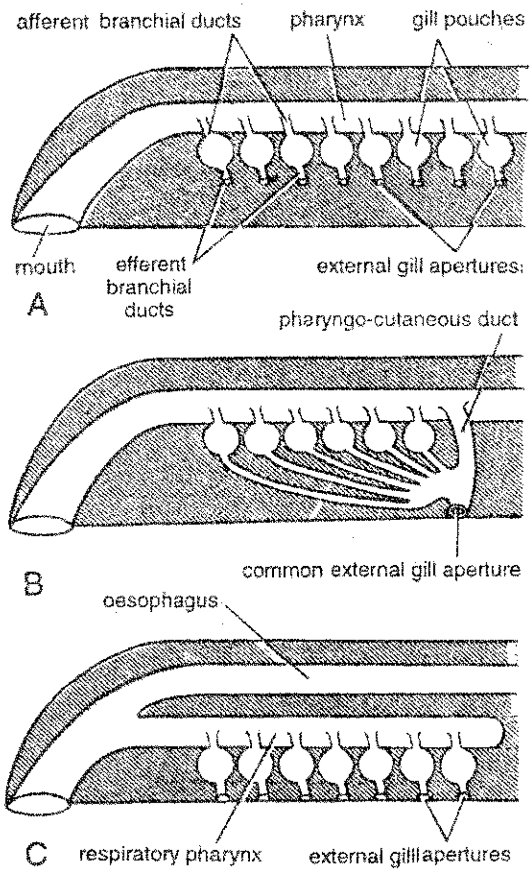

Fig. 6. Types of gill systems in cyclostomes. A—Primitive hagfish type (*Eptatretus*). B—Advanced hagfish type (*Myxine*). C—Lamprey type (*Petromyzon*).

nervous system and lateral line organs, (vi) Heart S-shaped tube, (vii) 9th and 10th cranial nerves not enclosed by cranium, (viii) Non-myleinated nerves, (ix) 1 to 2 semicircular canals in ear instead of 3 of advanced vertebrates, (x) Poorly developed lateral line sense organs.

3. Affinities with ostracoderms. The oldest fossils of vertebrates are fragments of ostracoderms belonging to Ordovician. They become abundant in Silurian but died out in Devonian. Palaeontologists believe that they were the forerunners of higher fish. The fossil ostracoderms and living cyclostomes are grouped together under Agnatha because of the following structural similarities : (i) Absence of biting jaws. (ii) Single nasal opening. (iii) Pineal eye. (iv) No paired limbs. (v) Pouch-like branchial sacs. (vi) Internal ear with 2 semicircular canals. (vii) Lateral line system.

[II] Advanced or vertebrate characters

Cyclostomes are undoubtedly vertebrates as they have many advanced though simple features similar to those of fishes and higher vertebrates. These are : (i) Formation of a distinct head bearing paired eyes and internal ears. (ii) Differentiated brain like embryonic vertebrates with several pairs of cranial nerves. (iii) Cranium for housing brain. (iv) Beginning of segmental vertebrae. (v) Stratified or multilayered epidermis. (vi) Dorsal root ganglia on spinal nerves. (vii) Sympathetic nervous system. (viii) Lateral line organs. (ix) Gills primarily used for respiration and not for food collection as in *Branchiostoma*. (x) Water enters into pharynx by muscular activity and not by ciliary activity as in *Branchiostoma*. (xi) E-shaped myotomes as in fishes. (xii) Presence of liver, gall bladder, bile duct, pineal and parietal eyes, pancreatic cells in midgut wall and thyroid and pituitary glands. (xiii) Well developed circulatory system with a muscular, contractile heart. (xiv) Blood with erythrocytes and leucocytes. (xv) Hepatic portal system. (xvi) Lymphatic system, and (xvii) Mesonephric kidneys.

[III] Specialized characters

Adult cyclostomes are too specialized or too degenerative in many respect. It is probable that many adult characteristics are adaptations for parasitic mode of feeding. Some of their specialized features are : (i) Suctorial mouth and buccal funnel with armature of horny spikes in lampreys for attachment to host body. (ii) Powerful, muscular tongue, heavily armed with sharp horny teeth serves as a rasping organ while feeding. (iii) Production of anticoagulants in saliva to feed on blood and body fluids of prey. (iv) Peculiar sac-like gill pouches located far behind head. (v) Posterior position of gill openings, probably an adaptation to burrowing. (vi) Complete separation of ventral sac-like respiratory pharynx from dorsal oesophagus. (vii) Respiratory water entering gill pouches as well as leaving them through external gill openings and not through mouth which mostly remains attached to rocks or fishes for feeding. (viii) Large mucous glands secreting enormous quantities of mucus in hagfishes. (ix) Dorsal position of single nostril high on head in lampreys.

[IV] Degenerate characters

The degenerate characters of cyclostomes include : (i) Simple, cylindrical eel-like body form compared to broad fish-like shape of ostracoderms. (ii) Lack of bony armour or exoskeleton. (iii) Lack of bony endoskeleton which is cartilaginous. (iv) Absence of paired fins and girdles. (v) Vestigial eyes covered by thick skin and muscle in hagfishes. (vi) Reduced liver and disappearance of gall bladder and bile duct in adult lamprey.

Phylogenetic Status of Cyclostomata

The oldest known group of vertebrates is regarded to be Agnatha which includes the extinct ostracoderms and the living cyclostomes. The living cyclostomes are regarded to be highly specialized relics of the ostracoderms line. Stensio (1927) believed that cyclostomes had descended from some group of ostracoderms by the evolution of a sucking mouth, loss of bony exoskeleton and paired limbs, and development of cartilage. Their structural organization has been considered higher than that of *Branchiostoma* (Cephalochordata) but lower than that of Gnathostomata (jawed vertebrates).

There is increasing evidence to believe that there were two major and not so much related groups of ostracoderms : (i) the *cephalaspides* having several pairs of gill slits, pairs fin-like appendages, heterocercal tail and a single median nostril; and (ii) the *pteraspids* having a single pair of gill-slits, no paired appendages, hypocercal tail and two separate nostrils where known. According to Stensio (1927), the lampreys (order *Petromyzontiformes*) represent derivatives of cephalaspid line and the hagfishes and slime eels (order *Myxiniformes*) are probably derived from pteraspid stock. This view holds that existing cyclostomes are diphyletic in origin.

In 1968, E. Jarvick in his article "Aspects of Vertebrate Phylogeny" in the book entitled "*Current Problems of Lower Vertebrate Phylogeny*", put forth a new idea that cyclostomes and gnathostomes are sister groups, and that gnathostomes betray several features even more primitive than the earliest recorded cyclostomes.

To conclude, the phylogenetic status or systematic position of cyclostomes remains doubtful. They are a dead line now. The gnathostomes had their origin much earlier than cyclostomes in the ostracoderm line.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give characters of Cyclostomata and discuss their phylogenetic status.
2. Discuss the affinities of Cyclostomata.
3. Tabulate the characters of Cyclostomata as primitive, specialized and degenerate.

» ***Short Answer Type Questions***

1. Compare and contrast lampreys and hagfishes.
2. Write short notes on—(i) *Eptatretus* (=*Bdellostoma*). (ii) *Myxine*.

» *Multiple Choice Questions*

1. Tail in Cyclostomes is :
   (a) Homocercal (b) Hetrocercal
   (c) Hypocercal (d) Diphycercal
2. Scales in Cyclostomes are :
   (a) Absent (b) Placoid
   (c) Cycloid (d) Ctenoid
3. The intestinal of gold in Cyclostomes is :
   (a) Endostyle (b) Typhlosole
   (c) Scroll valve (d) Velum
4. Cranial nerves in cyclostomes are :
   (a) 4-6 pairs (b) 6-8 pairs
   (c) 8-10 pairs (d) 10-12 pairs
5. Nasihypophyseal sac in Petromyzontiformes is :
   (a) Closed and connected to pharynx
   (b) Open and connected to pharynx
   (c) Closed and not connected to pharynx
   (d) Open and not connected to pharynx
6. Mouth in Myxiniformes is :
   (a) Terminal, with four pairs of tentacles
   (b) Subterminal, with four pairs of tentacles
   (c) Lateral, with four pairs of tentacles
   (d) Ventral, with four pairs of tentacles
7. Ear in Myxiniformes possess :
   (a) No semicircular duct (b) 1 semicircular duct
   (c) 2 semicircular ducts (d) 3 semicircular ducts
8. Ear in Petromyzontiformes possesses :
   (a) No semicircular duct (b) 1 semicircular duct
   (c) 2 simicircular ducts (d) 3 semicircular ducts
9. Members of order Myxiniformes are :
   (a) Some freshwater and some marine
   (b) All freshwater forms
   (c) All marine forms
   (d) Estuarine forms
10. Members of the order Myxiniformes are commonly known as :
    (a) Lungfishes (b) Sharks
    (c) Lampreys (d) Hagfishes

ANSWERS

1. (d) 2. (a) 3. (b) 4. (c) 5. (c) 6. (a) 7. (b) 8. (c) 9. (c) 10. (d)

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Class 3. Placodermi (Extinct)

The First Jawed Vertebrates

In the mid-Silurian, some 450 million years ago, as the ostracoderms were disappearing, a host of more efficient and jawed fishes appeared. Earlier grouped in a single category, they are now placed into two separate classes; *Placodermi* and *Acanthodii*. Taxonomists place them lower than Chondrichthyes in the evolutionary scale.

Aconthodians were little shark-like fishes covered by diamond-shaped scales. A common fossil genus, *Climatius*, was about 8 cm long. Between larger pectoral and pelvic fins, they had extra smaller paired fins some of which in the form of stout spines, hence the name 'spiny sharks' (Gr., *acantha*). Some of them featured *true teeth*, especially on the lower jaw. The acanthodians survived into early Permian before they became extinct.

Occurrence

Placodermi were earliest jawed vertebrates of fossil record. They appeared in Silurian, flourished in Devonian and Carboniferous and became extinct in Permian. They probably lived both in fresh water as well as seas. Some primitive agnath ostracoderms were probably the ancestors of placoderms. But their fossil record does not show any connecting link between the jawless and the jawed fishes. Like ostracoderms before them, the jawed fishes also appear fully formed without intermediates. Fossil evidence for the ancestry of Placodermi simply does not exist.

Important Features

The placoderms combined the heavy *external bony armour* of the ostracoderms with powerful *jaws* and efficient *fins*.

1. Bony armour. In their heyday the placoderms were highly diversified, ranging in length from a few centimeters to 3 metres or more. The giant predator, *Dunkleosteus*, grew to 10 meters. Despite the differences among them, all were characterized by the presence of a bony skeleton. Some in particular (*Dunkleosteus*) featured a heavy armour of bony plates over the head and anterior part of trunk, while the rest of the body was nearly naked. The name Placodermi means 'armoured fish' or 'plate-skinned' (Gr., *plakos*, plates + *derma*, skin). Their dermal armour links them genetically with their predecessors, the ostracoderms.

2. Jaws. All placoderms possess jaws which are supposed to have originated from the first pair of gill bars (mandibular arch) in front of the first gill slit. Hyoid gill arch persisted as a result of which spiracles failed to arise. Hyoid arch remained unmodified and extended support to the jaw. This type of primitive jaw suspensorium is called *aphetohyoidean* type. With paired fins and bony jaws they became more active, predaceous and specialized than the jawless ostracoderms. Jaws enabled them to spread into new habitats, make use of a wider variety of food and evolve immeasurably. Jaws also provided protection or defense and the ability to manipulate objects. With a biting mouth, heavy external armour probably became unnecessary and tended to disappear with the result that descendants could grow still larger and swim faster. No wonder the success of jawed fishes probably contributed to the extinction of the ostracoderms and the limitation of cyclostomes.

No placoderm ever developed teeth of a modern type as did the acanthodians. Also their jaws were immovably bound to cranium or rest of the head. These handicaps may have been involved in their eventual extinction.

3. Paired fins. Most placoderms possess paired fins. In an aquatic environment, development of strong mobile fins was coincident with the evolution of jaws, for swimming faster. The lateral fins served, like the elevators and ailerons of an aircraft, to produce turning movements in any direction (right, left, up or down) and to prevent roll, pitch, and yaw when swimming in a straight path.

Placoderms survived for a short period only and are often considered as 'unsuccessful ancient experiment', in the evolution of gnathostomes.

Classification

Various schemes of classification have been forwarded by workers. Berg (1940) and Romer (1959) forwarded detailed classification of fishes, which have been generally accepted. Bertin and Armbourg (1958) and Greenwood et. al., (1989) suggested altogether new scheme of classification, often called modern classification of fishes.

All the extinct earliest jawed fishes were once believed to be generally related and therefore placed in a single group or class, the *Placodermi*. But the spiny sharks are now placed in a separate class *Acanthodii*. Two groups, subclasses or orders of class Placodermi are generally recognized as follows :

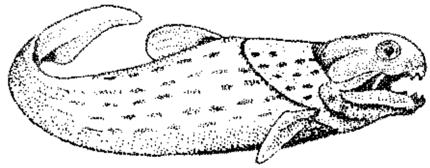

Fig. 1. *Dinichthyes*.

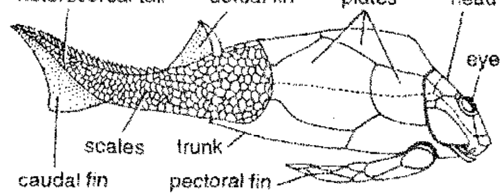

Fig. 2. *Pterichthyodes*.

Order 1. Arthrodiriformes

Earliest placoderms. Resembled ostracoderms in appearance and habitat. Heavy bony armour shields of head and trunk meeting in a movable joint (Gr., *arthros*, joint). Powerful gaping jaws with sharp shearing blades. Violently predaceous. Devonian. *Coccosteus, Dunkleosteus, Dinichthyes* (Fig. 1).

Order 2. Antiarchiformes

Bottom-dwellers and mud-feeders in fresh water. Ecologically similar to and competing with flat agnaths. Head and fore part of trunk covered by a depressed bony shield. These cephalic plates had a different arrangement and the mode of attachment of head with body shield was also different. Pectrol fins long. Devonian. *Bothriolepis, Pterichthyodes* (= *Pterichthys*) (Fig. 2).

Biological Significance

Placoderms were the earliest of the known fossil vertebrates with jaws, mostly creatures of the Devonian. Their bony armour links them genetically with their predecessors, the ostracoderms. With bony jaws and paired fins, they were more specialized than ostracoderms. A new era in the history of fishes opened with the advent of jaws. As Prof. A.S. Romer recalls in his book, *The Vertebrate Body*, that, "Perhaps the greatest of all advances in vertebrate history was the development of jaws and the consequent revolution in the mode of life of early fishes". There is no fossil evidence for the ancestry of placoderms. Some primitive ostracoderms were probably their ancestors. According to one view, the placoderms all became extinct by the end of the Palaeozoic era, without giving rise to any surviving forms. According to another view, the cartilaginous fishes or *Chondrichthyes* and the bony fishes or *Osteichthyes*, both arose in early Devonian from some primitive group of placoderms. Contrary to the former belief, the cartilaginous fishes did not give rise to bony fishes. Thus bone, rather than cartilage, is to be considered a primitive characteristic.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give important characters and biological significance of Placoderms.

» *Short Answer Type Questions*

2. Write short notes on — (i) *Climatius*, (ii) *Pterichthys*.

» *Multiple Choice Questions*

1. The earliest jawed vertebrates of fossil records are :
   (a) Placoderms (b) Ostracoderms
   (c) Cyclostomes (d) Acanthodii
2. Which of the following is true for placoderms :
   (a) Spiny sharks (b) Plate skinned
   (c) Hagfishes (d) Lampreys
3. Jaw suspensorium in placoderms is :
   (a) Autostylic (b) Holostylic
   (c) Aphetohyoidean type (d) Hyoidean type
4. Placoderms had :
   (a) Movable jaws (b) Upper jaw movable
   (c) Only lower jaw movable (d) Immovable jaws
5. The placoderms flourished during the :
   (a) Silurian (b) Devonian (c) Carboniferous (d) Permian

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (b).

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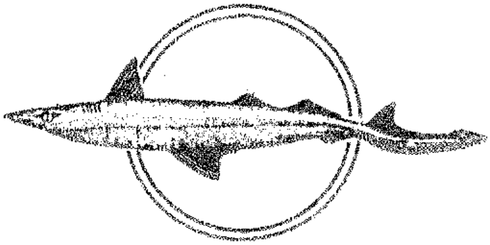

Type 5. *Scoliodon* : A Cartilaginous Fish : The Dogfish

Fishes are essentially aquatic and jaw-bearing true vertebrates. This class is specially known for their unimaginable number (about 40,000 species) and bewildering forms. They are characterized by having streamlined bodies, covered with scales. The presence of gills for respiration and paired fins for swimming. They belong to the superclass *Pisces* which can be sorted out into two distinct evolutionary lines : cartilaginous fishes or *Chondrichthyes* (Gr. *chondros*, cartilage + *ichthys*, fish) and bony fishes or *Osteichthyes* (Gr. *osteon*, bone).

The Chondrichthyes, also called elasmobranchs, comprise sharks, rays, skates, chimaeras, etc. Dogfish sharks are extensively studied nearly all over the world. The description included here belongs to the common Indian dogfish shark, *Scoliodon sorrakowah*, worked out by E.M. Thillayampallam and first published in 1928 in the series of Indian Zoological Memoirs.

Suitability for Study

Dogfish is chosen for study for several reasons. (i) It is commonly available in Indian Ocean. (ii) Its skeleton is not bony but cartilaginous, so that it is easy to dissect. (iii) It is neither too big nor too small but of a suitable size for dissection. (iv) It is not a popular article of diet. (v) Its not highly specialized and can represent a generalised fish. (vi) Its structure depicts the basic vertebrate plan. (vii) Some of its anatomical features are found in the embryos of higher vertebrates.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Division	Gnathostomata
Superclass	Pisces
Class	Chondrichthyes
Subclass	Selachii
Order	Squaliformes (Pleurotremata)
Family	Carcharinidae
Genus	*Scoliodon*
Species	*S. sorrakowah*

Distribution

The genus *Scoliodon* is widely distributed in the Indian, Pacific West Indies and eastern coasts of South America and Atlantic Oceans. Genus *Scoliodon* is distinguished from other sharks, in having elongated snout, depressed head and compressed body. They have similar teeth in upper and lower jaw. The caudal pit and sub-caudal lobe are distinct and prominent. Grace White recognises 9 species of which 4 found in the Indian waters are *S. sorrakowah, S. dumerilii, S. palasorrah and, S. walbeehmi*. The common Indian dogfish is *S. sorrakowah* which means 'black shark' in Tamil (*sorra*, a shark + *kowah*, black). Fossil records of *Scoliodon* have started to appear in the geological strata of lower Ecocene to subsequent periods.

Habits and Habitat

Like most sharks, *Scoliodon* is also marine, carnivorous and predaceous, feeding on crabs, lobsters, worms and fishes. It is a fast swimmer and catches hold of the prey by the sharp teeth. Sexes are separate, fertilization internal and development direct. It is viviparous giving birth to living young ones that develop inside the uteri.

External Features

Shape, size and colour. Body is elongated, fusiform or spindle-shaped and laterally compressed. Its highly stream-lined form reduces resistance to water, making movement easier and faster with minimum wastage of energy. A full grown individual measures about 60 cm in length and its body is divisible into three regions : head, trunk and tail. Head merging insensibly into trunk without a neck, is dorso-ventrally flattened and produced in front into a pointed *rostrum* or *snout*. *Trunk* is almost oval in transverse section and gradually tapers behind. *Tail* forming the posterior half of the body is slightly bent upwards. Body surface is rough due to backwardly projecting spines of *placoid scales* embedded in the skin. *Colour* of body is dark grey dorsally and pale white ventrally. As already mentioned earlier, the name of the species means 'black shark' in Tamil (*sorr,* shark + *kowah*, black). This colouration serves as a camouflage against predators in water.

Fins. Appendages of the dogfish are fins which are flap-like outgrowths of bodywall directed posteriorly and internally supported by cartilaginous rods and horny finrays. Two sets of fins occur : *unpaired* or *median* and *paired* or *lateral* (Figs. 1 & 2).

(a) Median fins. *Median fins* comprise two dorsals, one caudal and one ventral. *Anterior dorsal fin* is triangular, larger and present at about

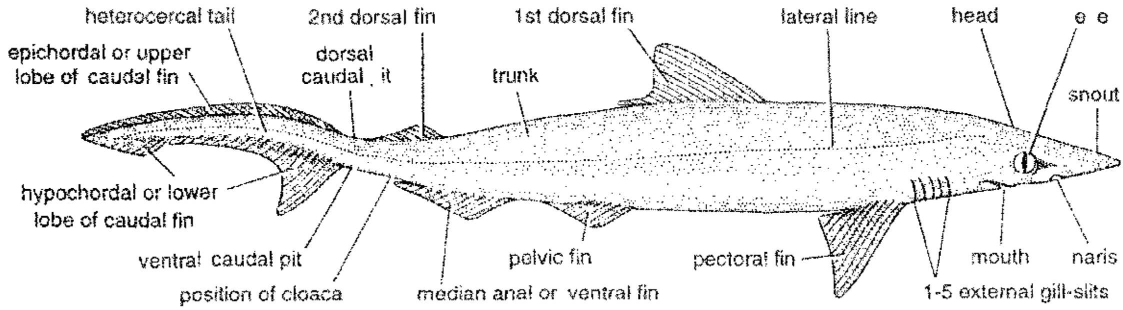

Fig. 1. Female Indian dogfish shark (*Scoliodon sorrakowah*) in lateral view.

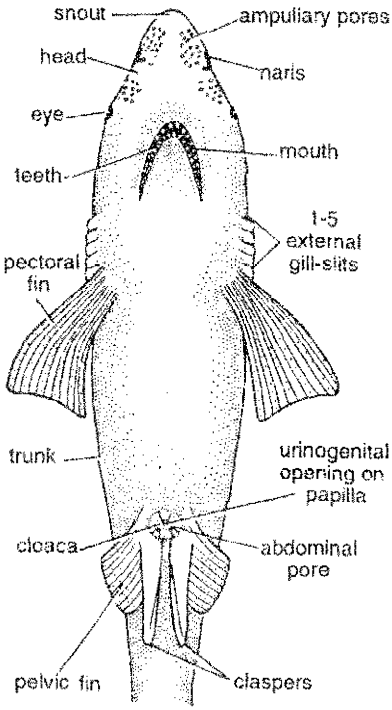

Fig. 2. Male Indian dogfish in ventral view.

the middle of body. *Posterior* or *second dorsal fin* is also triangular but much smaller and lying between the first dorsal and tip of tail. Tail is *heterocercal*, i.e., its posterior end is turned up and fringed with a *caudal fin* made of two unequal lobes. Upper lobe (*epichordal*) is reduced and lower lobe (hypochordal) well developed. The latter is further notched into a larger anterior and a smaller posterior portion. The *ventral* or *anal fin* lies about 5 cm in front of the caudal fin. Each of the dorsal and ventral fins gives behind a narrow long and fleshy process, the *basal lobe*.

(b) Lateral fins. Two pairs of triangular fins are attached ventro-laterally to the trunk region, the larger *pectoral fins* anteriorly and the much smaller *pelvic fins* posteriorly. In the male dogfish, the medial part of each pelvic fin is produced into a dorsally grooved, stiff and rod-like intromittent organ or *clasper* or *myxipterygium* which is used in copulation.

(c) Eyes. Two prominent circular eyes are present one on each lateral side of head. *Eyelids* are poorly developed outgrowths of skin and

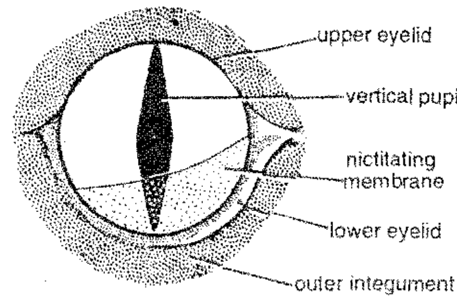

Fig. 3. Right eye of dogfish.

immovable. However, a movable *nictitating membrane* situated antero-ventrally can be spread over eye in time of danger. *Pupil* is narrow in form of vertical slit (Fig. 3).

Body apertures. The following important apertures are present on the bod surface.

(a) Mouth. It is a tra sverse somewhat crescentic opening lying ventrally on head near its anterior end. It is bounded by upper and lower jaws, eac bearing 1 or 2 rows of sharply pointed and backwardly directed *teeth* adapted for holding and tearing but not for chewing.

(b) Nares. Two crescentic apertures, the *nares* or *nostrils*, are present ventrally and anterior to mouth, one on either side. They are exclusively olfactory and have no respiratory function as they are not connected to mouth cavity by internal nostrils.

(c) External gill slits. Behind the eyes on either side and anterior to each pectoral fin are present in a series 5 oblique, vertically elongated *external gill slits* or *branchial clefts*. They lead internally into pharyngeal cavity via gill pouches and are respiratory in function.

(d) Cloacal apertures. At the root of tail between two pelvic fins is an elongated medial groove or *cloacal aperture*. It leads into a small chamber, the *cloaca*, which is the common exit for digestive and urinogenital systems. *Anus* opens into cloaca anteriorly, while a cone-shaped papilla, bearing urinary pore in female but urinogenital pore in male, lies immediately posterior to anus.

(e) Abdominal pores. Just within on either lateral edge of cloaca, an elevated papilla, opens an abdominal pore through which the abdominal body cavity opens to the exterior.

(f) Caudal pits. At the base of caudal fin, the tail bears two shallow depressions, one dorsal and one ventral, known as *caudal pits*, which are characteristic of the genus *Scoliodon*.

(g) Lateral line and pores. A faint lateral line runs along either lateral side of trunk and tail and over the head region. It marks the position of an underlying sensory lateral line canal system opening at intervals to outside through minute pores.

(h) Ampullary pores. On the head and snout open several groups of minute ampullary pores of the receptors called *ampullae* of *Lorenzini*. When pressed they exude mucus.

Skin

The body is invested by an outer leathery covering, called *skin* or *integument*. As in all the vertebrates, the skin consists of two layers : an outer ectodermal *epidermis* and an inner mesodermal *corium* or *dermis* (Fig. 5).

1. Epidermis. Epidermis is composed of many layers of stratified epithelial cells in young stage, the epithelial cells are ciliated but at adult stage cilia are lost. Basal or innermost layer is made of columnar or polyhedral cells, called *stratum germinativum*, which rests on a basement membrane. Cells of outer layers become progressively flattened and keratinized towards the surface. Many epidermal cells become specialized into mucus-secreting gland cells. Mucus lubricates the body surface.

2. Dermis. Dermis consists of areolar connective tissue, mingled with smooth muscle fibres, blood capillaries, pigment cells and nerves. Outer layers containing few loose fibres from *stratum laxum*. Inner layers with compact fibres form *stratum compactum*. The innermost layer is called *subcutaneous* layer, which is variable in thickness and contain five fibers arranged in reticular fashion. Pigment cells, called *chromatophores* or *melanophores* are grouped just below epidermis giving spotted appearance and darker colour on dorsal side of fish.

Functions of skin : (i) Like a wrapper, it protects internal organs against mechanical injuries. (ii) Secretion of slimy mucus makes body surface slippery and difficult to catch by predators, minimizes friction in locomotion and resists entry of microorganism into body. (iii) Its colouration imparts camouflage, as the fish blends with silvery surface of water when seen from below and with the dark bottom when seen from above, by predators. (iv) Skin receptors help in reacting to changes in the surrounding.

Exoskeleton

Skin of dogfish is coarse and has the feel of sand paper. Roughness is due to minute, hard and tooth-like dermal denticles, called *odontoids* or *placoid scales*, embedded in the skin in regular oblique rows and forming the *exoskeleton*.

1. Structure of a placoid scale. Placoid scales are characteristic of the skin of dogfishes. A typical placoid scale of *Scoliodon* consists of two parts : a wide rhomboidal *basal plate* and a flat trident *spine* arising from its centre. The *basal plate* is embedded in dermis firmly held by Sharpey's and other connective tissue fibres. It is formed by a bone-like loose trabecular calcified tissue called *cement*. The trident *spine* projecting out of the skin, is backwardly directed and formed by one median and two lateral spines. In vertical section, the spine consists chiefly of a hard substance called *dentine* with a central *pulp cavity* containing blood vessels, nerve endings, lymph channels and dentine-forming cells called *odontoblasts*. Through dentine ramify numerous very fine tubules or *canaliculi* containing long protoplasmic processes of odontoblasts. Spine is

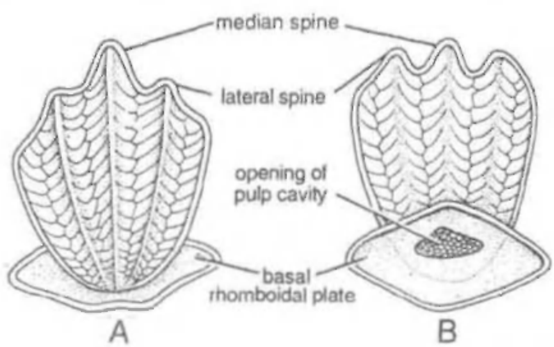

Fig. 4. *Scoliodon*. Placoid scales. A—Dorsal view. B—Ventral view.

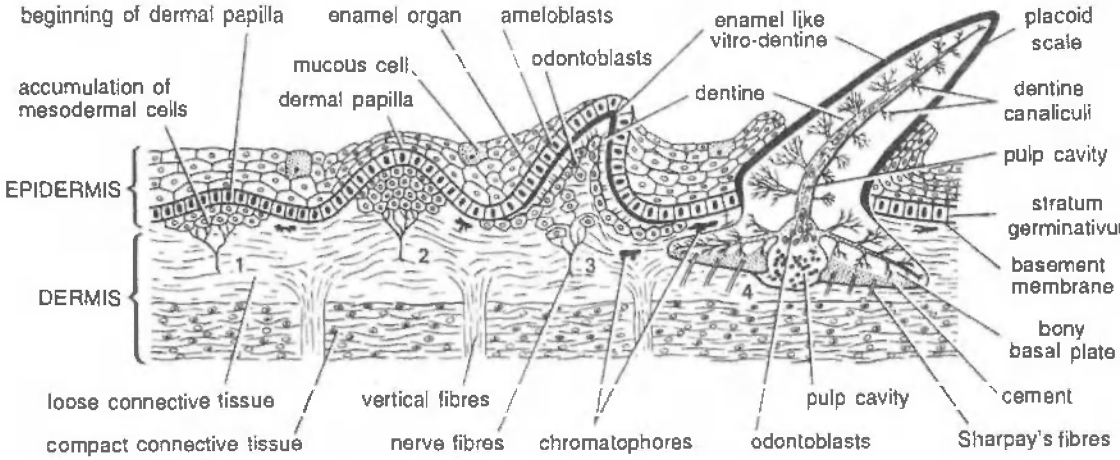

Fig. 5. *Scoliodon.* V.S. of skin showing development of a placoid scale. 1—Accumulation of dermal cells. 2—Formation of dermal papilla. 3—Growing spine. 4—V.S. of a fully formed scale.

coated externally with a layer of still harder, shiny, enamel-like *vitro-dentine* (Fig. 4).

2. Development of a placoid scale. The first sign of a developing scale is an aggregation of mesodermal cells of dermis, lying just beneath epidermis and forming a *dermal papilla.* As the epidermis is pushed up, the outermost cells of dermal papilla become *odontoblasts* (or *scleroblasts*) and deposit dentine between themselves and epidermis. Meanwhile, the overlying epidermal cells of stratum germinativum or Malpighian layer, now called *ameloblasts*, form the so-called *enamel organ* which deposits vitrodentine over dentine. Cement (basal plate) is formed from surrounding cells of dermis. In a growing scale, the dermal papilla forms nutritive *pulp* occupying the *pulp cavity.* In a fully formed scale, epidermis wears off around the spine which projects above the skin, while the basal plate remains embedded.

3. Homology of placoid scales. Placoid scales are presumed to be the forerunners of vertebrate teeth. They have essentially similar form, structure and embryonic development, indicating that they are homologous structures. In dogfish, the teeth are merely specialized placoid scales. In the skin continued over jaws into mouth, the placoid scales become especially large to serve as teeth. With their spines directed backwards, they are used for holding and tearing prey. As the mouth lining is

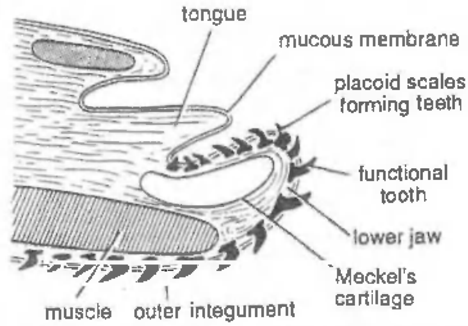

Fig. 6. *Scoliodon.* Lower jaw in section to show formation and replacement of teeth from placoid scales.

inturned skin, the teeth developed in it are also skin derivatives and thus homologous with placoid scales.

According to previous view, placoid scale is a composite structure having dual source of origin. Its basal plate (cement) and dentine are derived from mesoderm while vitrodentine is of ectodermal origin. But this view is not supported now. A tooth has an enamel covering derived from ectoderm but its presence is denied in the placoid scale. Instead, it has vitrodentine which is said to be formed by mesodermal cells. Thus a placoid scale is regarded entirely mesodermal like the scales of bony fishes.

Endoskeleton

The cartilaginous endoskeleton of *Scoliodon* has been described in chapter 35 in the Section on Vertebrate Osteology.

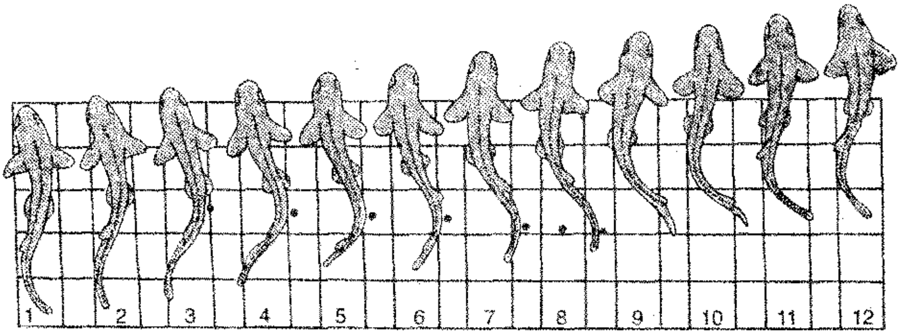

Fig. 7. *Scoliodon.* Successive positions of a swimming dogfish showing curvatures passing antero-posteriorly over body, alternately to right and left (After Gray).

Myotomes and Locomotion

Parietal muscles of bodywall beneath the skin form the bulk of body musculature. In a skinned dogfish, these will be seen arranged in a series of zigzag muscle bands or segments called *myotomes* or *myomeres*. They are separated from one another by tough connective tissue partitions or septa, called *myocommata*. In a surface view successive myotomes appear like hollow cones fitting into one another. However, in a transverse section they appear as concentric circles placed one below other dorsoventrally. Each myotome contains numerous parallel striped muscle fibres which run from one myocomma to the next. The myocommata, in turn, are inserted internally on the vertebral column and externally on the skin. When myotomes contract, they pull the myocommata which cause the bending of backbone and the rest of the body. However, in the head region muscles do not show any sign of segmentation. But they are specialized for the movement of pharynx, jaws and eyes. In the trunk region, muscles are greatly thickened on dorsal side of the vertebral column. But in tail region muscles are equally developed around vertebral column (Fig. 7).

The swimming movements of fishes are quite complicated and cannot here be discussed in detail. A wave of metachronal contraction passes over myotomes from infront backwards alternately on the right and left side. This contraction is called *metachronal contraction*. It has been estimated that about 54 waves of contraction are produced every minute, during steady swimming. What controls these contractions is not fully known. But transaction of spinal cord behind medulla oblongata is capable of producing swimming movements for several days. This suggests that rhythm of contraction is largely governed by the spinal cord. This brings about the lateral undulations of trunk and tail necessary for swimming. The stream-lined body form minimises resistance to water during progression. The fish is pushed forward by the strong lateral movements of the expanded heterocercal tail which acts like a single oar propelling a boat from astern. The hypo-chordal lobe of tail fin is flexible and epi-chordal lobe is rigid. The flexibility of hypochordal lobe helps in the vertical lift of the tail. The large pectoral fins help in turning and in maintaining stability in the vertical plane. The median fins acts like a keel, prevent rolling and yawning from side to side and maintain equilibrium in the horizontal plane. Pelvic fins are of no use as far as locomotion is concerned, it helps in reproductive function especially in males.

Coelom and Viscera

The body cavity or coelom of dogfish is a large space divided into two very unequal compartments, small anterior *pericardial cavity* and large posterior *abdominal cavity*, the two separated by a partition of tough connective tissue, the *septum transversum*. The septum is pierced by a *pericardio-peritoneal canal* through which the coelomic cavities communicate with one another.

Pericardial cavity lies beneath the pharynx and surrounds the heart. It is lined by a two-layered coelomic epithelium, the *pericardium*, with a colourless *pericardial fluid* filled in between the two layers (Fig. 8).

Abdominal cavity, also known as *perivisceral* or *peritoneal cavity* contains the viscera and opens to outside through a pair of *abdominal pores* located on papillae one on either lateral side of l . Th *viscera* i cl d s th lim t ry c l, liver, pancreas, spleen and gonads. The abdominal cavity contains a colourless *coelomic fluid* and is lined by coelomic epithelium, called *peritoneum*, which also covers the surface of visceral organs. The latter remain suspended from dorsal bodywall by a double fold of peritoneum with thin connective tissue in between, called *mesentery*.

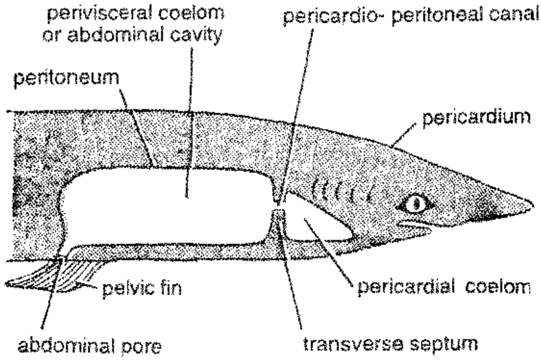

Fig. 8. *Scoliodon*. Coelomic body cavities in lateral view.

Different parts of alimentary canal are bound to one another by incomplete mesenteries called *omenta* (singular, *omentum*) (Fig. 9).

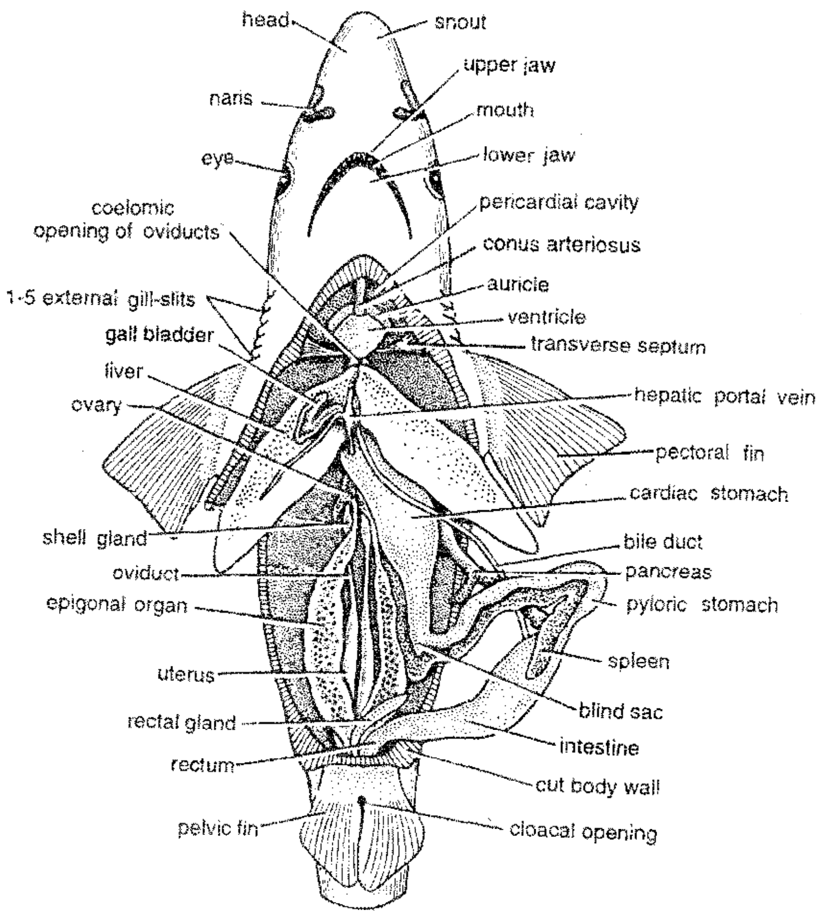

Fig. 9. *Scoliodon*. Dissection in ventral view showing visceral organs of a female dogfish.

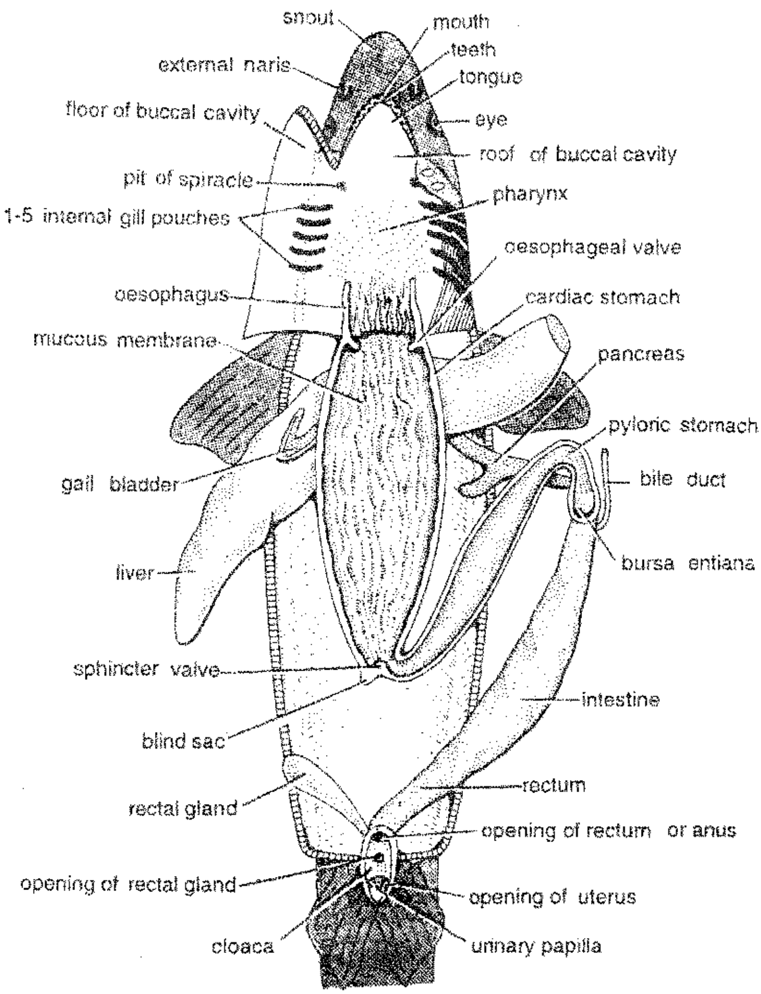

Fig. 10. *Scoliodon*. Dissection of digestive system in ventral view.

Digestive System

The digestive system includes the *alimentary canal* or *gut* through which the food passes and the *glands* that open into it (Fig. 10).

[I] Alimentary canal

Alimentary canal beings at mouth and terminates in anus. It is longer than the body and includes buccal cavity, pharynx, oesophagus, stomach and intestine

1. Mouth. It is a wide crescentic opening on the ventral side of head. It is bounded by folds of integument sometimes called *upper* and *lower lips*.

2. Buccal cavity. Mouth opens into a spacious dorso-ventrally flattened mouth cavity, lined by mucous membrane and bordered by the jaws. *Teeth* are not attached to the jaw cartilages, but are simply embedded in the skin like other placoid scales. They are all similar in shape (*homodont*), sharply pointed and directed backwards. They are arranged in several rows. If lost or destroyed they are replaced by others several times in life time (*polyphyodont*) teeth work in succession as they are in several rows (lyodont). Teeth serve to grasp the prey which is usually swallowed whole. On the floor of the buccal cavity lies the so-called

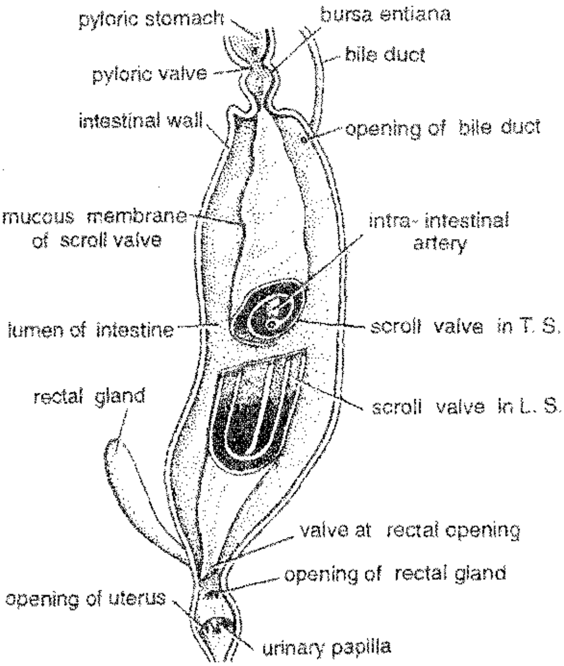

Fig. 11. *Scoliodon*. Intestine cut open to show scroll valve.

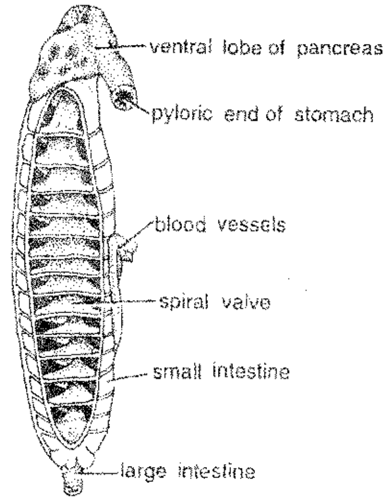

Fig. 12. Small intestine of the spiny dogfish (*Squalus acanthias*) cut open to show spiral valve.

'*tongue*'. It is merely a thick, flat, non-muscular, non-glandular and non-protrusible fold of mucous membrane supported internally by the flat basihyal cartilage.

3. Pharynx. Posteriorly the buccal cavity merges insensibly with the larger cavity of pharynx lined by endoderm. Either lateral side of pharynx contains an oval pit of *spiracle* and five separate vertical *internal gill-slits* of gill pouches. In *Scoliodon*, the spiracles are vestigial without gill-lamellae and external apertures. Mucous lining of pharyngeal wall contains numerous dermal denticles.

4. Oesophagus. Pharyngeal cavity narrows down posteriorly into a short but wide tube, the *oesophagus*, with thick muscular wall. Its mucous lining is thrown into longitudinal folds.

5. Stomach. The oesophagus passes backwards into the abdominal cavity to open into a large muscular and U-shaped stomach. Its proximal limb is longer, wider and distensible. It is called the *cardiac stomach*. The distal limb is shorter and narrower and called the *pyloric stomach*. The oesophageal opening into cardiac stomach is guarded by an *oesophageal valve* formed by a circular fold of mucous membrane. The mucous lining of cardiac stomach also forms longitudinal folds like those of oesophagus. At the junction of cardiac and pyloric stomachs is present a small blind outgrowth, the *blind sac*, as well as a *sphincter valve*. The lining of pyloric stomach is mostly smooth, though and slightly folded distally. At the end of pyloric stomach is present a strong circular muscle band, called *pyloric valve*, guarding its opening into a small but thick-walled muscular chamber, the *bursa entiana*.

6. Intestine. Bursa entiana is followed by intestine. It is a straight wide tube about the diameter of cardiac stomach in the middle of its length. Its narrow anterior part receives the bile and pancreatic ducts. In *Scoliodon*, the inner mucous lining of intestine becomes folded anticlockwise into a longitudinal spiral or scroll of about two and a half turns. This is called the *scroll valve* or *spiral valve*. In a transverse section, it looks like a watch-spring. It serves to delay the passage of food and offers increased surface for absorption, like the typhlosole of earthworm. In some other genera of dogfishes (e.g. *Scylliorhinus* and *Squalus*), the spiral valve is very well developed made of about 14-15 turns arranged in the manner of a spiral staircase in a tower (Figs. 11 & 12).

The last part of intestine is called *rectum*. It is a short and narrow tube opening behind through *anus* into the ventral *cloaca*. A small finger-like *caecal* or *rectal gland* of unknown function opens dorsally into the rectum.

[II] Glands of alimentary canal

1. Liver. Liver of dogfish is a massive yellowish bilobed gland. The two lobes extend backwards freely into abdominal cavity, but they are united anteriorly and attached to septum transversum by a ligament. A V-shaped thin-walled *gall bladder*, in which bile is collected, lies embedded in the right lobe of liver. A narrow bile duct, about 3 cm long, leaves the gall bladder, and opens into the anterior end of the intestine near the commencement of scroll valve. Bile duct also receives branches from the lobes of liver. Liver secretes bile, stores glycogen and fat, and destroys worn out erythrocytes of blood.

2. Pancreas. It is a compact, whitish or pale bilobed gland consisting of a longer dorsal lobe running parallel to the posterior part of cardiac stomach and a smaller ventral lobe closely applied to the pyloric stomach. The small pancreatic duct traverses the entire length of the gland to open into the intestine just opposite the opening of the bile duct.

3. Caecal or rectal gland. It is a small finger-like body attached by its duct to the dorsal side of rectum into which it opens. It has a central cavity lined by cuboidal epithelial cells. It is highly vascular and composed of lymphoid tissue but discharges a fluid in the intestinal lumen.

4. Spleen. It is a large gland closely attached like a fringe to the cardiac and pyloric stomachs. But it has no physiological relation with alimentary canal and functionally associated with circulatory system. It is a lymphoid organ which produces lymphocytes.

[III] Food and physiology of digestion

Scoliodon is a predaceous carnivore, feeding mainly on other fishes. Its diet may also include crabs, lobsters and worms. Food is swallowed without mastication. No digestion occurs in buccal cavity which lacks salivary glands. The gastric juice in stomach contains pepsin and hydrochloric acid. It converts proteins into syntonin, proteoses and peptones, but cannot digest chitin. Bile makes the semidigested food alkaline in intestine while pancreas secretes trypsinogen, amylopsin and lipase for digestion of proteins, starches and fats, respectively.

Scroll valve in intestine serves to retard the passage of food and affords a large surface for absorption of the products of digestion.

Respiratory System

Since dogfish is an aquatic animal, it depends wholly upon oxygen dissolved in sea water for respiration. Thus, respiration is *aquatic* and carried on entirely by vascular gills (Figs. 13 & 14).

[I] Respiratory organs

The respiratory organs of *Scoliodon* consist of 5 pairs of *gill pouches* containing *gills*. Five gill pouches are present in a series on either side in the lateral wall of pharynx, behind the hyoid arch. Each gill-pouch is compressed antero-posteriorly. It opens into pharynx by a large *internal branchial aperture* and to outside by a narrow vertical *external branchial aperture* or *gill-slit*. Two adjacent gill-pouches are completely separated from each other by a vertical fibro-muscular partition, the *interbranchial* or *gill septum*. The inner or pharyngeal border of each gill septum is supported by a cartilaginous *visceral arch* or *gill arch* with its slender *branchial rays*. The septum is covered by an epithelium and contains blood vessels, nerves, etc.

The mucous membranes of a septum is raised into numerous horizontal leaf-like folds, called *gill lamellae* or *gill filaments*. These constitute the *gill proper* and are richly supplied with blood-capillaries. Each septum bears two sets of gill-lamellae, one on its anterior face and the other on its posterior face. Each set makes a half gill called *demibranch* or *hemibranch*, while both the sets attached to a gill arch and its gill septum constitute a complete gill called *holobranch*. The posterior demibranch of a septum has longer

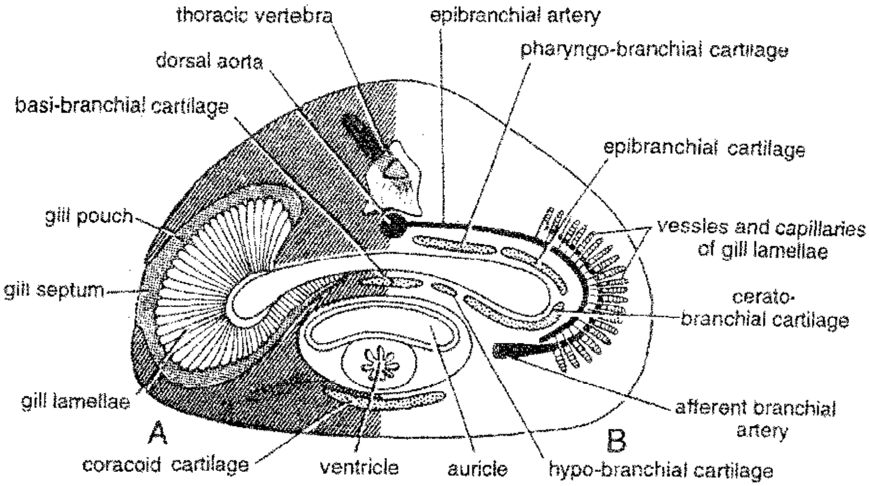

Fig. 13. *Scoliodon.* Diagrammatic representation of respiratory system in T.S. of body. A — A gill pouch opened to show a gill in surface view. B — Parts of a branchial arch and blood supply to gill lamellae.

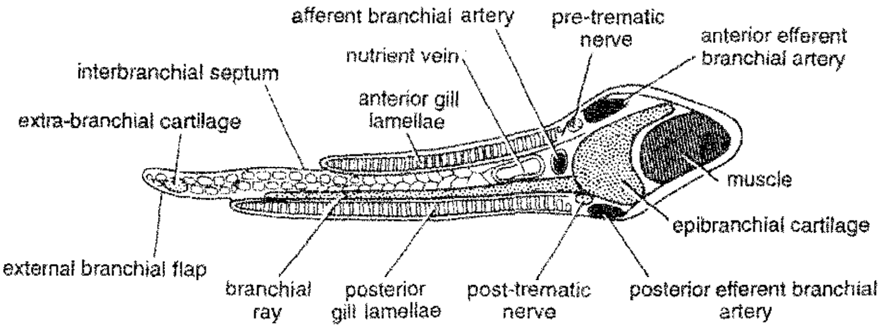

Fig. 14. *Scoliodon.* A holobranch in horizontal section.

lamellae than those of the anterior demibranch. A gill pouch thus contains two demibranchs belonging to two adjacent gills. In *Scoliodon*, the hyoid arch bears only a demibranch on its posterior face, the first four branchial arches bear holobranchs, while the fifth branchial arch is a branch or without any gill. In *Scoliodon* and other elasmobranch fishes, the interbranchial septa extend well beyond their gill lamellae to form flaps which protect the gills as well as external gill slits. Such gills are called *lamelliform* and are regarded more primitive than those of bony fishes.

In *Scoliodon*, in front of hyoid arch or the first internal gill slit, on either lateral side of pharynx, is present an oval pit of *spiracle*. It has no gill lamellae and no external opening and is regarded a vestigial gill pouch. But in most others elasmobranch fishes, it contains minute gill lamellae forming a false gill or *pseudobranch* and opens to the exterior by an external aperture just behind the eye.

[II] Mechanism of respiration

During respiration, water taken into the mouth, passes through internal gill slits bathing gill lamellae and passes out of the external gill slits. Breathing movements occur in two steps, the pharynx working as a sort of force pump (Fig. 15).

1. Inspiration. A series of hypobranchial muscles, running from pectoral girdle to basihyal and hypobranchial cartilages, contract and the gill arches expand, thus pulling down the floor of the buccopharyngeal cavity and enlarging its cavity. As the external gill slits are tightly closed, water

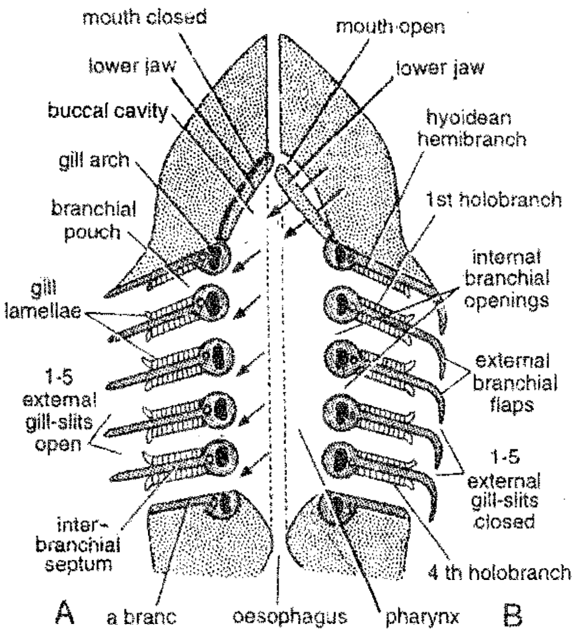

Fig. 15. *Scoliodon*. Breathing mechanism. A — Expiration. B — Inspiration.

enters the enlarged bucco-pharyngeal cavity through the open mouth.

2. Expiration. Next, the mouth is closed by the action of adductor muscle. At the same time the constrictor and interbranchial muscles contract raising the floor of pharynx and reducing its volume. As a result, water is forced into gill pouches, over the gill lamellae, and out through the open external gill slits.

The spiracles are occasionally used as accessory pathways for entry of water for respiration, instead of the mouth, when it is occupied otherwise.

[III] Physiology of respiration

Each gill lamella has an extensive system of sinusoids which receive venous blood from an *afferent branchial artery* and pass it on to an *efferent* or *epibranchial artery*. During the passage of blood through this network, it becomes oxygenated. Fresh sea water entering the gill pouches contains O_2 dissolved in it. This O_2 passes by diffusion through the thin membranous and permeable capillary walls into blood. At the

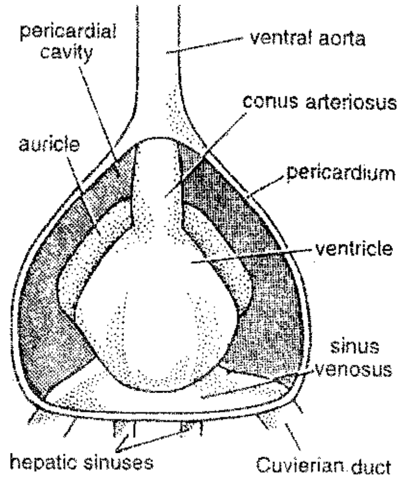

Fig. 16. *Scoliodon*. Heart and pericardium in ventral view.

same time CO_2 of venous blood passes out by diffusion into outgoing water current. This process is *external respiration*. As this oxygenated blood circulates through body, its O_2 is used by tissues to oxidise food-stuffs and CO_2 thus formed is surrendered to blood which again becomes venous. This process is *internal respiration*.

Blood Vascular System

The circulatory system comprises 4 parts : (i) Heart and pericardium, (ii) arteries, (iii) veins and (iv) blood.

[I] Heart and pericardium

As in cyclostomes and other fishes, heart of *Scoliodon* receives venous blood only which it pumps into gills for aeration. Such a heart is called a *venous* or *branchial heart* (Figs. 16–18).

1. Position. The heart is situated mid-ventrally in head beneath the pharynx, supported below by the coracoid cartilages of the pectoral girdle. It lies within the *pericardial cavity* in a two-layered membranous *pericardium*.

2. Structure. Heart is a reddish-brown, muscular and dorso-ventrally bent, S-shaped tube differentiated into a series of 4 chambers : *sinus venosus*, *auricle*, *ventricle* and *conus arteriosus*, arranged in tandem formation. Of these only two, the auricle and ventricle, are considered to be true

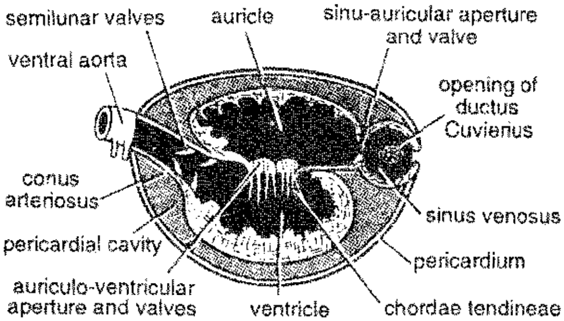

Fig. 17 *Scoliodon.* Heart and pericardium in sagittal section.

chambers so that heart is only *two-chambered* in fishes.

(a) ***Sinus venosus.*** It is the most posterior chamber. It is triangular, elastic, thin-walled and extending transversely across the posterior wall of pericardium to which it is fused. It receives venous blood through two large veins, called *ductus Cuvieri,* laterally one on either side, and through a pair of *hepatic sinuses* posteriorly. Apex of sius venosus opens anteriorly into auricle by a *sinu-atrial* or *sinu-auricular aperture* which is guarded by a pair of membranous valves which prevent backward flow of blood. It is highly contractile and the beating of the heart originates from this part of the heart.

(b) Auricle. The *atrium* or *auricle* lies in front of sinus venosus dorsally upon the ventricle. It is a large, triangular sac moderately muscular and with walls thicker than those of sinus venosus. Its two lateral sides projecting beyond the ventricle appear like ears. It opens into ventricle through an *auriculo-ventricular aperture* also guarded by two pocket like valves to prevent backward flow of blood.

(c) Ventricle. Ventricle is the most prominent and pear-shaped chamber of heart. Relatively small in size it has very thick muscular walls since it must propel blood to all parts of body. From the wall project internally numerous muscular strands thus giving it a spongy texture. *Chordae tendineae* are attached to opposite walls to prevent ventricle from expanding beyond its capacity.

(d) Conus arteriosus. Ventricle tapers anteriorly into a stout and muscular tube, the

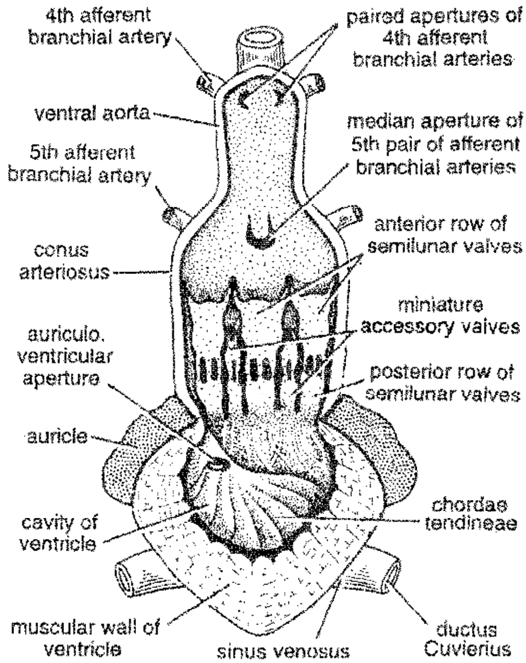

Fig. 18. *Scoliodon.* Heart dissected from ventral side to show internal structure.

conus arteriosus. Cavity of conus contains two transverse rows of semilunar valves to block the regurgitation or backward flow of blood into ventricle. Each row has three valves, one dorsal and two ventro-lateral in position. A small accessory valve is also present on either side of each dorsal valve. Anterior valves are larger than the posterior ones. After perforating the anterior wall of pericardium the conus continues forward as the ventral aorta.

3. **Working.** Sinus venosus and auricle constitute the receiving chambers of the heart. Whereas, ventricle and conus arteriosus constitute the forwarding part of the heart. Heart of *Scoliodon* receives only deoxygenated or venous blood (*venous heart*). In a complete circuit of body, the blood passes through heart only once (*single circulation*). Heart works like a *muscular pump* for pumping its venous blood to the gills for aeration. To achieve this, different parts of the heart rhythmically contract at regular intervals and in a definite succession, first sinus venosus, then auricle, then ventricle and finally the conus

arteriosus. Each contraction, called *systole*, is followed by a relaxation, called *diastole*. Different valves of the heart serve to prevent the backward flow of blood into preceding chambers through the apertures that they guide. The walls of the heart are supplied oxygenated blood through special coronary arteries.

[II] Arterial system

Arteries are stronger and their walls are more muscular than veins. When venous blood from conus of heart enters the ventral aorta, it has entered the arterial system. It can be described under five categories, as follows (Fig. 19) :

1. Ventral aorta and afferent branchial arteries. *Ventral aorta* is a single stout artery running straight ahead, mid-ventrally below the floor of pharynx. Reaching upto the hyoid arch, it bifurcates into two short right and left *innominate arteries*. Each innominate immediately divides into *first* and *second branchial arteries* (af_1 and af_2). *Third, fourth and fifth branchial arteries* also arise from ventral aorta almost at regular intervals. While others arise independently, the fifth

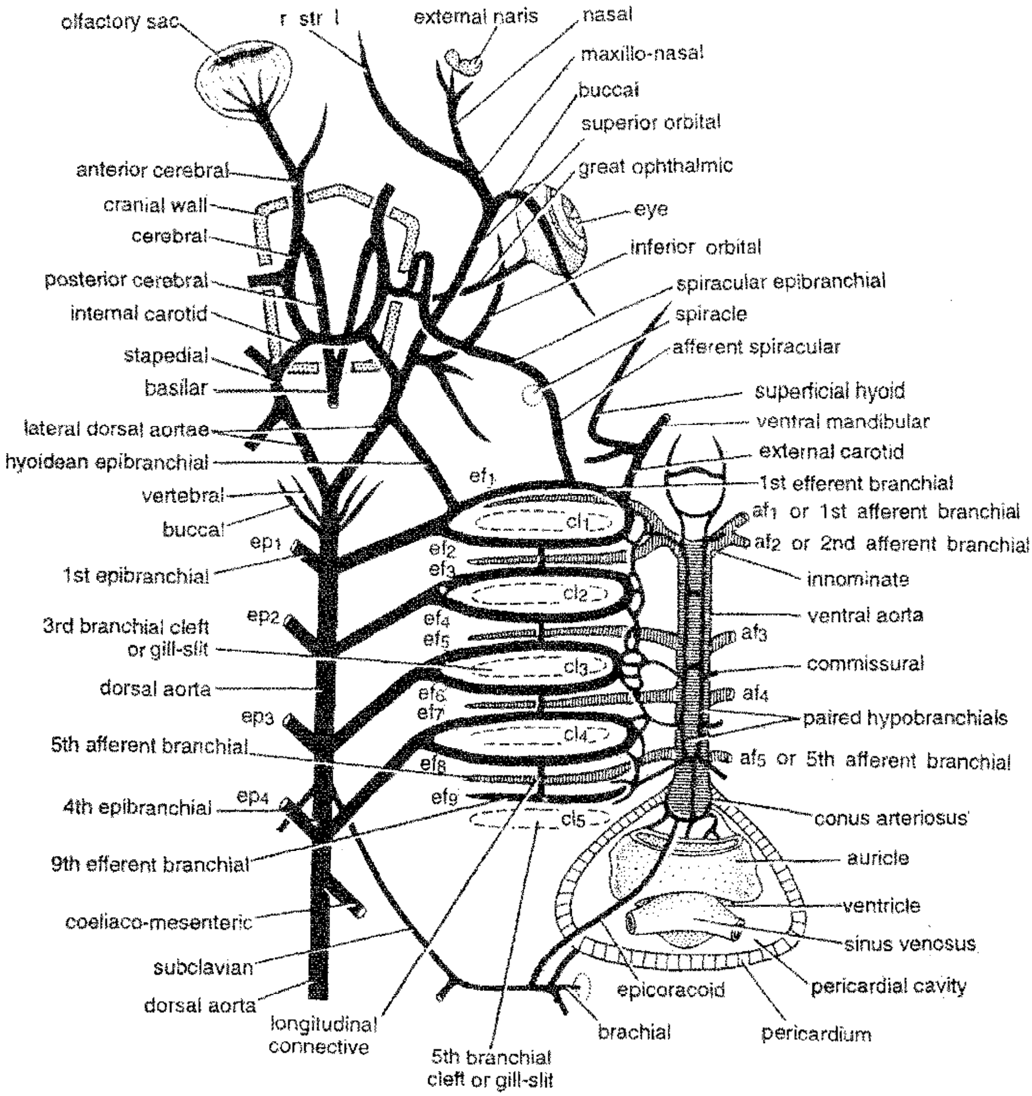

Fig. 19. *Scoliodon*. Arterial system. Afferent arteries (stippled) in dorsal view and efferent arteries (black) in ventral view.

branchials of both sides arise by a common median aperture from ventral aorta. The anterior most or the first afferent branchial runs along the posterior border of hyoid arch supplying branches to gill lamellae of its demibranch. One of each of the remaining four branchials enters one of the four interbranchial septa to supply branches to its holobranchs, *i.e.*, gill lamellae of both sides. The afferent vessels break up into capillaries in the gill lamellae for aeration of blood.

2. Efferent branchial and epibranchial arteries. Aerated blood from capillaries of gills is collected by a series of nine *efferent branchial arteries* (ef_1 to ef_9). Those running along the anterior (pretrematic) and posterior (posttrematic) sides of a gill pouch join together forming a complete *loop* encircling the gill pouch. Thus, the first eight efferent vessels form four complete loops around the first four gill pouches. The single ninth efferent vessel (ef_9) runs alone along the anterior side of fifth gill pouch. Adjacent loops are interconnected by short *longitudinal connectives.*

From the upper end of each efferent branchial loop arises an *epibranchial artery*. The four epibranchials thus formed run backwards and inwards to join a large median *dorsal aorta*.

3. Hypobranchial blood plexus. The ventral wall of ventral aorta carries a pair of narrow, longitudinal *median hypobranchial arteries* interconnected by transverse vessels. Four *commissural vessels* connect each hypobranchial with a network of *lateral hypobranchial chain* which further connects the ventral ends of the efferent branchial loops. Posteriorly, the two median hypobranchials unite to form a *median coracoid artery* which branches into a *coronary artery* to heart and a *pericardial artery* sending further branches to pericardium and coracoid region of pectoral girdle.

4. Arteries of head. The head region is supplied blood mostly by three branches originating from the *hyoidean* or *first efferent*.

(a) The external carotid arises ventrolaterally. It branches into a *ventral mandibular* to coraco-mandibular muscles and a *superficial hyoid* to *skin* muscles and subcutaneous tissue of hyoid arch.

(b) The afferent spiracular, arising in the middle, is a stout artery. It continues forward as the *spiracular epibranchial* which enters the cranial cavity after giving a *great ophthalmic* branch to the eye ball. Inside, cranium it unites with a branch from internal carotid forming *cerebral artery* which divides into *anterior* and *posterior cerebral arteries* supplying blood to brain.

(c) The hyoidean epibranchial arises from the dorsal end of hyoidean efferent. It runs forward and inward to join one lateral branch (or radix) of dorsal aorta and then divides into two : an internal carotid and a stapedial. (i) The *internal carotid* enters the cranium where it divides into two branches, one joining its fellow of the opposite side, while the other uniting with spiracular epibranchial to form the cerebral. (ii) The *stapedial* gives off an *inferior orbital* to eye muscles and continues as *superior orbital*. It sends a *buccal artery* to lower jaw muscles and further continues as *maxillo-nasal* which divides into a *nasal* to olfactory sac, *maxillaries* to upper jaw muscles and a *rostral* to the rostrum.

5. Dorsal aorta and its branches. The median dorsal aorta is a large vessel running along the whole length of trunk and tail beneath the vertebral column. As already mentioned, it collects oxygenated blood from gills through four pairs of *epibranchial arteries*. It distributes oxygenated blood to the trunk, fins and tail through numerous paired and unpaired branches during its course. It gives off the following branches from in front backwards :

(1) *Lateral aortae* or *radices*. Anterior end of dorsal aorta bifurcates into two. Each lateral aorta or radix joins with the hyoidean epibranchial of its side, as already mentioned.
(2) *Vertebral*. One pair to vertebral column.
(3) *Buccal*. One pair to roof of buccal cavity.
(4) *Epibranchials*. Four pairs from gills.
(5) *Subclavian*. One pair to pectoral fins.
(6) *Coeliaco-mesenteric*. Large, unpaired. To stomach, liver, pancreas and intestine.

(7) *Lieno-gastric.* Unpaired to gonads, spleen and stomach.
(8) *Posterior mesenteric.* Unpaired to rectal gland.
(9) *Iliac.* Paired to pelvic fins.
(10) *Parietals.* Several small airs of segmental arteries to myotomes, spinal cord, lateral line canal, kidneys and gonads.
(11) *Caudal.* Posteriorly, the dorsal aorta continues into tail as *caudal artery* lying in the haemal canal of caudal vertebrae.

[III] Venous system

Venous blood from body is returned to heart by *veins* which have thinner walls than arteries and frequently contain valves to prevent a backward

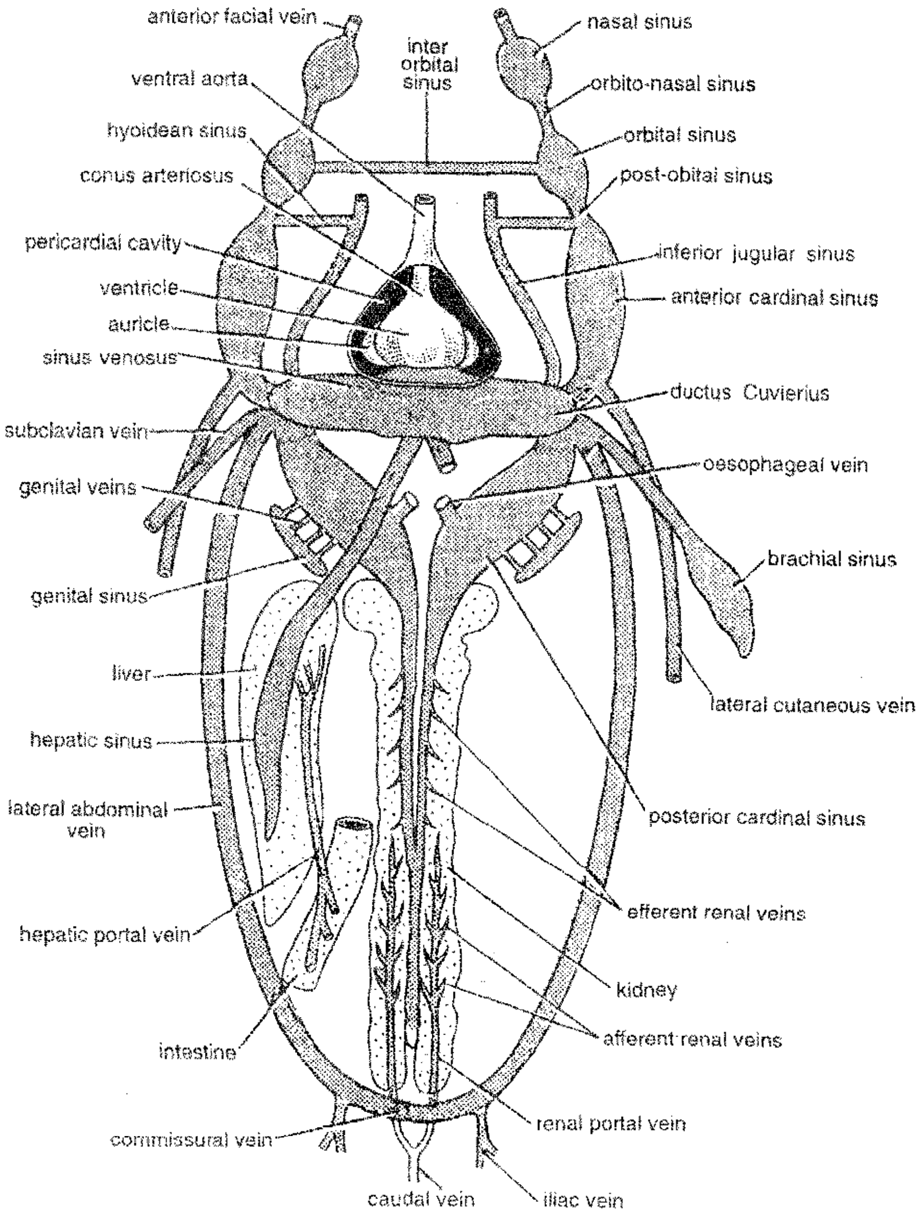

Fig. 20. *Scoliodon.* Venous system in ventral view (diagrammatic).

flow of blood. A characteristic feature of venous system in dogfish is that many veins are in the form of simple, primitive and wide irregular spaces without definite walls, more properly called *sinuses*. Existence of extensive blood sinuses is a characteristic feature of *Scoliodon* venous system. Venous system of *Scoliodon* can be described under the following five heads (Fig. 20) .

1. Anterior cardinal system. Blood from head region is returned on either side by two sinuses.

(a) Inferior jugular sinus. It is the smaller median ventral sinus. It collects blood from the floor of bucco-pharyngeal region, gill pouches and pericardial region, before opening into the ductus Cuvierius.

(b) Internal jugular vein or sinus. It is the larger dorso-lateral sinus. It collects blood from the dorsal region of head and gill pouches. It starts as an *anterior facial vein* from rostrum joining an *olfactory* or *nasal sinus* behind the olfactory sac. It is joined by a narrow neck (*orbito-nasal*) to a large *orbital sinus* behind the eye. An *interorbital vein* or *sinus* lying in the skull floor connects the orbital sinuses of both sides. Orbital sinus leads through a narrow *postorbital sinus* into a large *anterior cardinal sinus*, entering the ductus Cuvierius behind. A *hyoidean sinus* located just infront of the first gill, connects together the anterior cardinal and inferior jugular sinuses, each of which also receives five nutrient branchial sinuses from gills.

2. Posterior cardinal or renal portal system. The renal portal system is encountered for the first time in the Chondrichthyes. Blood from tail is collected by a median *caudal vein*. It runs forward, ventral to caudal artery in the haemal canal of tail vertebrae. Dorsally to cloaca, it bifurcates into right and left *renal portal veins*. Each of these continues forwards dorsal to the kidney of its side giving off numerous *afferent renal veins* which break up into capillaries in the kidney. Small *parietal veins* from bodywall also join each renal portal vein. Several *efferent renal veins* collect blood from both kidneys and pour into a single vessel which lies between them. Anteriorly this single vessel divides into two *posterior cardinal sinuses*. In front of kidneys both the sinuses become enormously enlarged. Each receives an *oesophageal vein* from oesophagus and several *genital veins* from a large *genital sinus*, and finally opens into *ductus Cuvierius* which in turn empties into the sinus venosus.

3. Hepatic portal system. Hepatic portal system occurs in all vertebrates beginning with the cyclostomes. Blood from different parts of alimentary canal and associated glands is drained by several branches, which unite to form a single large *hepatic portal vein*. It runs to the liver lobes into which it breaks up into capillaries. From each liver lobe blood is collected by a large *hepatic sinus* which opens into the sinus venosus near its partner of the opposite side.

4. Lateral abdominal system. Blood from inner lateral part of bodywall, cloacal region and paired fins on either side of the body is collected by a large *lateral abdominal vein*. Posteriorly, they are connected together by a *commissural vein*, and each receives an *iliac vein* from the pelvic fin. Anteriorly, each joins a branchial vein from pectoral fin forming the *subclavian vein* which enters the ductus Cuvierius laterally.

5. Cutaneous system. It includes a mid-*dorsal*, a *mid ventral* and two *lateral cutaneous veins*, collecting blood from their respective parts of skin and finally pouring it into the sinus venosus via ducti Cuvieri.

[IV] Blood

Scoliodon blood consists of colorless plasma and corpuscles suspended in it. Corpuscles are of two types– RBC (erythrocytes) are oval and nucleated bodies and contain respiratory pigment, haemoglobin and WBC (leucocytes) are ameboid cells resembling with lymphocytes of other vertebrates.

Nervous System

The nervous system of *Scoliodon* consists of three parts :

1. Central nervous system. It includes brain and spinal cord.

2. Peripheral nervous system. It includes cranial and spinal nerves.

3. Autonomic nervous system.

[I] Brain

Brain of dogfish is more advanced than that of the sea lamprey. It lies enclosed within the chondrocranium and is made of the same three basic parts of the vertebrate brain-forebrain, midbrain and hindbrain (Fig. 21).

1. Forebrain. It has two main subdivisions : cerebrum and diencephalon.

(a) Cerebrum. *Cerebrum* is the large, undivided anterior part. The cerebral hemisphere is relatively larger, in comparison to other fishes. It has no mid-dorsal groove indicating right and left cerebral hemispheres of higher vertebrate animals. From either antero-lateral side of cerebrum arises a narrow but a stout *olfactory stalk* or *peduncle* terminating into a large bilobed *olfactory lobe*. It lies immediately behind the large *olfactory sac* that opens to outside through the nostril or nares. The midventral surface of cerebrum has a small opening, the *neuropore*. Two delicate *terminal nerves*, each bearing a ganglion, come out of neuropore to innervate the mucous membrane of the olfactory sacs.

(b) Diencephalon. Posterior to cerebrum lies the small and narrow *diencephalon* completely hidden by the cerebellum. Its thin, membranous and vascular roof is called the *anterior choroid plexus*. From posterior mid-dorsal part of diencephalon, extends upward a slender *pineal stalk* which ends in a small rounded *pineal body* or *epiphysis* of unknown function. Ventral surface of diencephalon shows some prominent features. Near its anterior margin lies the *optic chiasma* formed by the crossing of the two optic nerves. Just behind the chiasma the floor gives off a backward hollow projection, the *infundibulum*. On its either side lies a thick-walled sac, the *inferior lobe*. Attached posteriorly to infundibulum is a sac-like *hypophysis* and both make up the *pituitary body*. Dorsal side of hypophysis is thin-walled, wrinkled and glandular and known as *saccus vasculosus*. It is of unknown function and present only in fishes.

2. Midbrain. It remains mostly concealed dorsally by cerebellum and ventrally by the infundibular outgrowths. It consists mainly of a

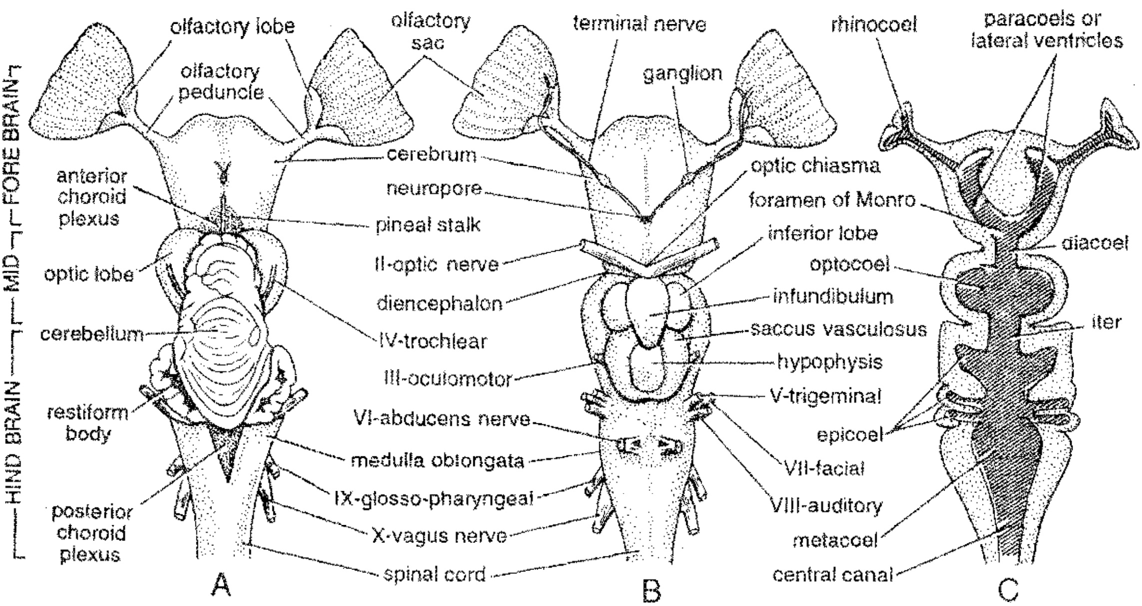

Fig. 21. *Scoliodon*. Structure of brain. A—Dorsal view. B—Ventral view. C—Horizontal longitudinal section.

pair of large, rounded dorsal swellings, the *optic lobes* or *carpora bigemina*, which are the centres for sight and hearing. III and IV cranial nerves arise from midbrain.

3. Hindbrain. It comprises two parts, cerebellum and medulla oblongata.

(a) Cerebellum. *Cerebellum* is a large, elongated and rhomboidal structure overhanging the optic lobes in front and part of medulla behind. Its dorsal surface is irregularly folded and divided into three lobes by two transverse furrows. Sometimes, a median longitudal furrow may also divide cerebellum into right and left halves.

(b) Medulla oblongata. *Medulla oblongata* forms the last part of brain. It is a triangular structure, wider in front but tapering behind to pass insensibly into the spinal cord. Its antero-dorsal end bears on either side a hollow outgrowth, the *restiform body*. A transverse band of nervous tissue lying just behind the cerebellum connects together the restiform bodies of both sides. Medulla is roofed over by a thin, non-glandular and vascular membrane, the *posterior choroid plexus*. V, VI, VII, VII, IX and X cranial nerves arise from medulla. Hindbrain controls swimming movements.

Cavities of brain. Sections of brain reveal that it is hollow from within. Different cavities of brain are called *ventricles*. They communicate with one another and are continuous with the central canal of spinal cord. Cavities contain a liquid, the *cerebrospinal fluid*. Names of cavities and their connections are as follows :

(i) Rhinocoels. Cavities of olfactory sacs.

(ii) Lateral ventricles. Cavities of cerebrum, also called *paracoels* or I and II ventricles.

(iii) Foramen of Monro. Opening between I and II ventricles of cerebrum and III ventricle.

(iv) Diacoel. Cavity of diencephalon, also called III ventricle.

(v) Iter. Cavity of midbrain. Also called *Aqueduct of Sylvius*. Communicates together III and IV ventricles, epicoel and optocoels.

(vi) Optocoels. Cavities of optic lobes.

(vii) Epicoel. Cavity of cerebellum.

(viii) Metacoel. Cavity of medulla, also called IV ventricle.

[II] Spinal cord

Spinal cord extends from medulla oblongata almost to the end of tail, protected by the neural canal of vertebrae, showing an advance over the condition in cyclostomes. Spinal cord is surrounded by pia matter only. In structure, it resembles that of higher vertebrates in having dorsal and ventral fissures, central canal and inner grey and outer white matters. The gray matter is arranged into dorsal and ventral horns. The dorsal horns are united to form a single broad region, as a result the gray matter assumes inverted 'T' shape. Its T.S. shows that it is made of two halves connected together by a bridge.

[III] Cranial nerves

Brain gives off 10 pairs of cranial nerves which are identified by their serial Roman numbers as well as names. Besides, an additional pair of anterior *terminal nerves* is present numbered as "O" because they were discovered long after the others were already numbered. The serial numbers, names, origin and distribution of cranial nerves in *Scoliodon* are almost similar to those of higher vertebrates. All are paired (Fig. 22).

*__Nerve "O" Terminal or pre-olfactory.__ Thin nerve arising through neuropore of cerebrum and innervating the olfactory region. Sensory.

Nerve I Olfactory. Arises from olfactory lobe as nerve fibres passing singly or in small groups to olfactory sac. Sensory, in relation to smell.

Nerve II Optic. Thick and short nerve. Arises from optic thalamus or ventral side of diencephalon, crosses over forming optic chiasma and innervates retina of eye. Sensory, in relation to sight.

Nerve III Oculomotor. Slender nerve. Arises from ventral surface of midbrain. Divides into four

* A new cranial nerve discovered first in *Protopterus* in 1894. It is a sensory nerve having one or more ganglia. It is best developed in Elasmobranchs. The functional significance of this nerve is not fully ascertained. It is believed that it represents the remnant of an anterior branchial nerve which have lost its significance on course of evolution.

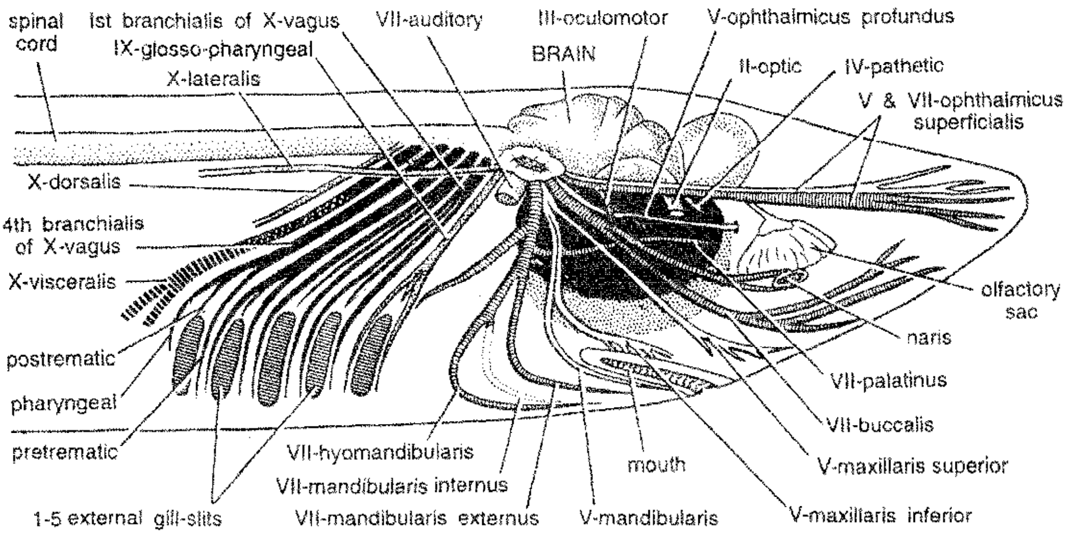

Fig. 22. *Scoliodon*. Cranial nerves in right lateral view.

branches which innervate the inferior, superior and anterior recti muscles and the inferior oblique muscles of eye. Motor, controlling movements of eyeball, iris and lens.

Nerve IV Trochlear or Pathetic. Arises dorso-laterally from midbrain and supplies the superior oblique muscle of eye. Motor, helping in rotation of eyeball.

Nerve V Trigeminal. A very large, mixed nerve arising from antero-lateral side of medulla along with VII and VIII nerves. Bears a *Gasserian ganglion* while still inside cranium. Divides into 4 main branches as follows :

(a) Ophthalmicus superficialis. Passes forward above the orbit, intermingled with fibres of similarly named branch of VII. Sensory, supplies skin of snout.

(b) Ophthalmicus profunds. Passes forward along the inner surface of eyeball to join the superficial opthalmic branch. Sensory, supplies the dorsal skin of snout.

(c) Maxillaris. It is divided into two branches. *Maxillaris superior* is a flat, ribbon-like nerve. It extends forward on the floor of orbit along with buccal branch of VII. It is sensory, tactile, innervating ventral skin of snout. *Maxillaris inferior* supplies the skin of posterior part of upper jaw.

(d) Mandibularis. It passes down along the posterior wall of orbit to supply the muscles of lower jaw, tongue and gill region. It is a mixed nerve.

Nerve VI Abducens. It is a small, slender and motor nerve, arising midventrally from medulla to innervate the posterior rectus muscle of eye.

Nerve VII Facial. Another large nerve arising from the side of medulla, bearing a ganglion and closely associated with V or trigeminal nerve in its distribution. It is both sensory and motor. It has four main branches as follows :

(a) Ophthalmicus superficialis. As already mentioned, it is a large flattened nerve running forward along the upper border of orbit with the similarly named branch of V or trigeminal nerve. It supplies the ampullae of Lorenzini on the dorsal side of snout.

(b) Buccalis. It runs forward on the floor of orbit along with the maxillaris superior branch of V. Together they form the large infraorbital nerve. Fibres of buccalis supply the infraorbital canal and associated ampullae of Lorenzini.

(c) Palatinus. Running across the floor of the orbit, it supplies the roof of buccal and pharyngeal cavities.

(d) Hyomandibular. It runs down along the posterior wall of orbit giving off the following 3 main branches :

(i) Hyoidean (or *hyomandibular*) to muscles of throat (hyoid arch).

(ii) Mandibularis internus to mucous membrane of buccal floor.

(iii) Mandibularis externus to mandibular canal.

Nerve VIII Auditory. A very short and thick nerve arising from medulla and passing into auditory capsule to innervate the membranous labyrinth. It is sensory conducting sound waves to brain.

Nerve IX Glossopharyngeal. It is a mixed nerve arising ventrolaterally from medulla. It divides into three branches : (i) the *pretrematic* running along the anterior border of first gill pouch, (ii) the *post-trematic* along its posterior border, and (iii) the *pharyngeal* to the mucous membrane of pharynx.

Nerve X Vagus or pneumogastric. It is a mixed nerve arising by several roots from the posterior lateral side of medulla behind the IX. It is perhaps the largest cranial nerve. It divides into 3 main branches as follows :

(a) Lateralis. It runs backwards along the whole length of fish under the lateral line canal innervating its neuromast organs.

(b) Visceralis. It enters the body cavity behind where it supplies the heart, digestive tract and other viscera.

(c) Branchialis. There are 4 branchialis nerves one supplying each of the remaining gill pouches from second to fifth. Each branchial further breaks into 3 branches : an anterior *pre-trematic* and a posterior *post-trematic* to the respective sides of the gill pouch, and a middle *pharyngeal* to the mucous lining of pharynx.

[IV] Spinal nerves

Several pairs of spinal nerves arise from spinal cord at regular intervals along its entire length. Each nerve, originates by two roots, a sensory *dorsal root* and a motor *ventral root*. Dorsal root bears a ganglion. After piercing through the neural arch, both the roots unite outside to form a mixed spinal nerve. Each spinal nerve divides into three branches : (i) *ramus dorsalis* and (ii) *ramus ventralis* to the dorsal and ventral bodywall muscles and skin, and (iii) *ramus communicans* joining the autonomic system. A *branchial plexus* is formed at the level of pectoral girdle, but no plexus is formed in the pelvic region.

[V] Autonomic nervous system

Autonomic system is better discussed in higher vertebrates. In Dogfish, it includes a series of paired and irregularly arranged ganglia in the dorsal wall of posterior cardinal sinuses, and in dorsal parts of kidneys. The gastric ganglion is the largest ganglion and sends nerves to visceral organs. Usually there is one ganglion in each segment. In case of *Scoliodon*, the successive ganglia are not in well defined continuous chain.

Sense Organs

The main receptor or sense organs of dogfish include (i) olfactory organs, (ii) eyes, (iii) ears, (iv) neuromasts or lateral line organs, and (v) ampullae of Lorenzini.

[I] Olfactory organs

Olfactory organs include a pair of *nasal* or *olfactory sacs* situated ventrally in the snout one on either side. They are characteristically large in elasmobranchs correlated with a highly developed sense or smell for perception of chemical substances dissolved in water. Each olfactory sac is a large, oval, ectodermal blind pouch covered by a thin membrane and housed inside the thin cartilaginous olfactory capsule of the skull. The inner wall of olfactory sac is raised into two rows of numerous closely set lamellae or folds, called *Schneiderian folds*, held in place by a median connective tissue band, called *median raphe*. The folds are covered by *olfactory epithelium* containing long *receptor* as well as *supporting cells*. Sensory hairs project from the free ends of

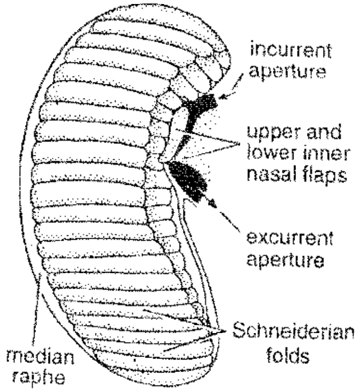

Fig. 23. *Scoliodon*. Nasal sac dissected out to show its relation to inner nasal flaps.

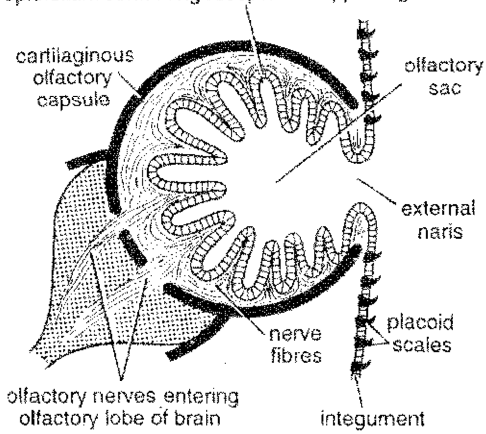

Fig. 24. *Scoliodon*. Olfactory sac in T.S. with its cartilaginous capsule and olfactory lobe of brain.

receptor cells, while their basal ends are continued into fibres of *olfactory nerve* going to the olfactory lobe of brain. The olfactory sac opens to outside ventro-laterally by the *external nares*. Three flaps of skin or *nasal flaps* over the nares direct water in along a lateral *incurrent siphon*, and out through a median *excurrent siphon*.

[II] Eyes

Scoliodon has a pair of large and well developed *eyes* or *photoreceptors*. These are housed in socket like depressions, the *orbits*, one on either side of cranium (Figs. 25 & 26).

1. Eye muscles. The eye ball is elliptical in shape. It remains attached to the inner wall of orbit by 6 *eye muscles* and a cartilaginous stalk called *optic pedicle*. Eye muscles are inserted in two groups. One group includes 2 *oblique muscles* attached to the anterior angle of orbit. *Superior oblique* is attached to anterior-dorsal side and *inferior oblique* to anteroventral side of the eyeball. Their action twists the eyeball. Other group includes 4 *recti muscles*. These arise from the posterior median corner of orbit. *Superior* and *inferior rectus muscles* are attached to the postero-dorsal and postero-ventral surface of

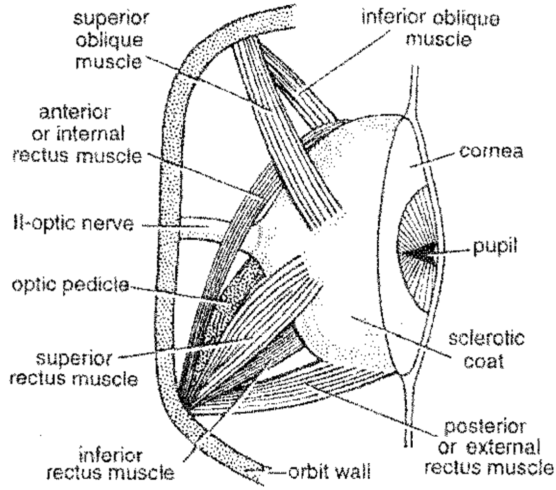

Fig. 25. *Scoliodon*. A dorsal view of right eye to show the eye muscles.

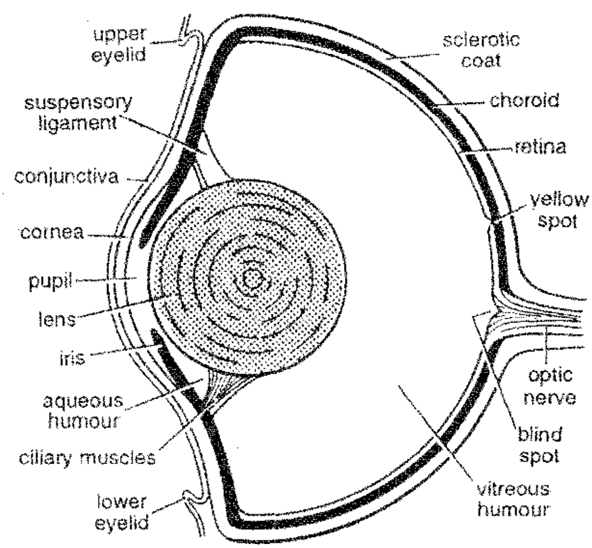

Fig. 26. *Scoliodon*. Diagrammatic V.S. of eyeball.

eyeball and serve to rotate it in the vertical plane. The *anterior* (or internal) and *posterior* (or external) rectus muscles are inserted anteriorly and posteriorly and serve to rotate the eyeball in the horizontal plane. The movements are of limited extent only but they serve to direct the pupil towards specific objects.

2. Internal structure. The three coats of the eyeball-*sclerotic, choroid* and *retina*-are similar to those of other vertebrates. *Sclerotic* is cartilaginous and opaque. Its frontal transparent part or *cornea* is flat and fused with an outer *cunjunctiva* which is continuous with the lining of immovable eyelids. *Choroid* is richly vascular and pigmented. In the front part, it separates from sclerotic forming a circular curtain-like *iris* around a vertical slit-like *pupil* which can not be dilated or contracted. The innermost layer or *retina* consists mainly of elongated receptor cells, or *rods*, which are connected with the fibres of the *optic nerve*. In elasmobranchs, choroid contains cells with guanin crystals forming a light-reflecting surface called *tapetum lucidium*. In dim light it reflects light back upon retinal cells to increase their stimulation. In bright light it is covered by pigment so that light is not reflected. A large *crystalline lens* lies immediately behind pupil and held by a *suspensory ligament* with *ciliary muscles*. A transparent saline fluid, the *aqueous humour*, fills the small chamber in front of the lens. A jelly-like mass, the *vitreous humour*, fills the very large chamber behind the lens.

3. Working. Eyes in sharks are large but far separated, so that binocular vision is not possible. Power of accommodation is poor because of non-contractile pupil and little change in shape of lens. However, lens can be shifted forward to catch more light. Sharks can also achieve maximum light stimulation in dim conditions and prevent light scattering (blurring or halation) in bright condition, due to presence of tapetum of guanin plates. A shark is normally long sighted and also colour blind due to absence of cones in retina.

[III] Internal ears

1. Structure. In dogfish there are no external or middle ears. Only an internal ear is present called *membranous labyrinth*. It is a delicate membranous ectodermal sac found embedded in the cartilaginous *olfactory capsule*, one on either postero-lateral side of cranium. The main body or *vestibule* of membranous labyrinth is laterally

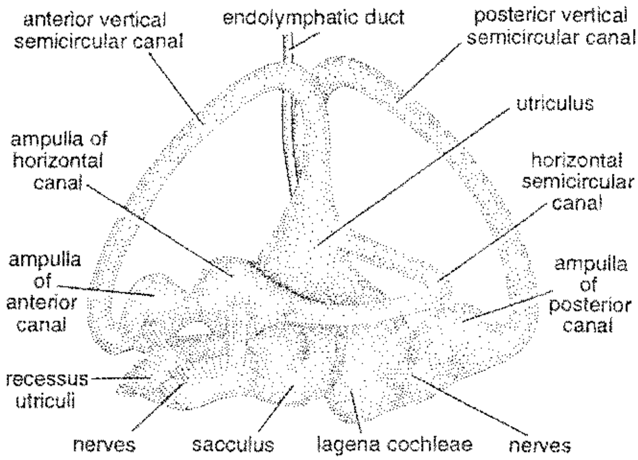

Fig. 27. *Scoliodon*. Left membranous labyrinth in outer view.

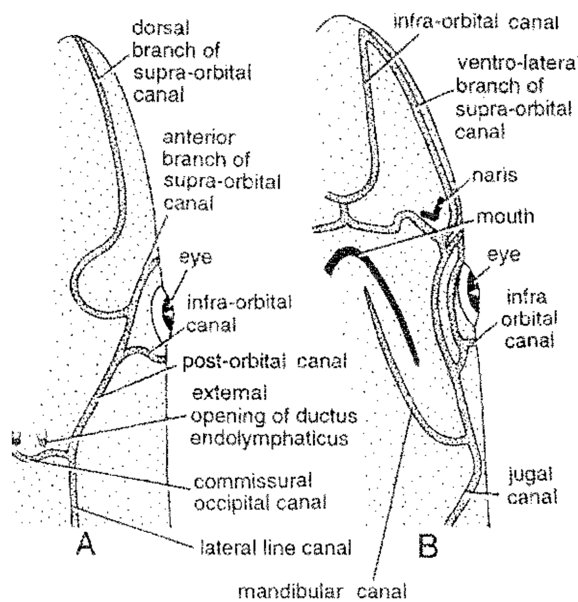

Fig. 28. *Scoliodon*. Distribution of lateral line and cephalic canals on head. A—Dorsal surface. B—Ventral surface.

compressed and made of a dorsal *utriculus* from which projects a ventral and posterior lobe, the sacculus. A posterior outgrowth of *sacculus* is called *lagena cochleae*, which is the forerunner of an elaborate cochlea of higher forms, especially the mammals. An anterior outgrowth of utriculus is known as *recessus utriculi*. Arising from vestibule are three slender tubes, called *semicircular canals*. They are at right angles to one another and one end of each bears a swelling or *ampulla*. The *anterior vertical* and *horizontal canals* arise from top of utriculus and open into its middle after forming their ampullae which lie anteriorly above the recessus utriculi. The *posterior vertical canal* originates dorsally from sacculus and opens by its ampulla posteriorly into lagena cochleae (Fig. 27).

The cavity of membranous labyrinth contains a fluid, the *endolymph*, in which float minute calcareous particles, the *otoliths*. From the endolymphatic cavity of sacculus arises a slender tube, the *ductus endolymphaticus*. It opens to outside on the top of cranium by its aperture lying in the parietal fossa. The space between auditory capsule and membranous labyrinth is the perilymphatic space, also containing a fluid, the *perilymph*. The large external opening of *perilymphatic space*, called *fenestra*, also lies behind the small aperture of endolymphatic duct on the top of cranium.

Membranous labyrinth is innervated by the *auditory nerve*. Groups of receptor or sensory cells bearing stiff hairs are confined to definite spots, those of utriculus and sacculus called *maculae*, and those of ampullae of semicircular canals called *cristae*.

2. Functions. Internal ears or membranous labyrinths of dogfish are also called stato-acoustic organs because of their two important functions, as follows :

(a) Static function. Internal ears are primarily concerned with balance or equilibrium. Movements of endolymph and otoliths stimulate sensory nerve endings in ampullae and vestibule, thus informing the animal about its position in water. The animal can detect changes in speed, direction and orientation and adjust accordingly.

(b) Accoustic function. Sacculus and lagena perhaps receive auditory stimuli forming organs of hearing.

[IV] Neuromast or lateral line system

It is a system of sense organs concerned with life in water. Besides fishes, it is also found in cyclostomes and aquatic stages of Amphibia. In dogfish it includes (1) lateral lines, (2) neuromast organs, and (3) pit organs.

1. Lateral lines. A faint lateral line runs along either lateral side of trunk and tail. It contains below the surface a slender mucus-filled ectodermal canal sunk into dermis. It opens to the surface by minute pores at intervals through a series of vertically running tubes. The two lateral line canals are continued anteriorly into a system of canals, named after their relative position on the head. Dorsally a transverse *commissural occipital canal* connects both the lateral line

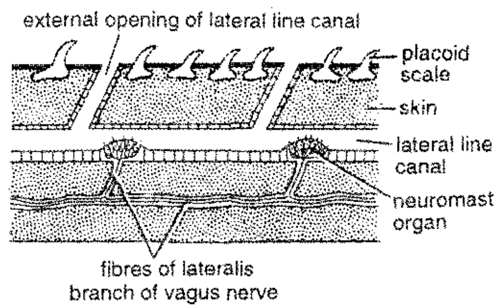

Fig. 29. *Scoliodon*. L.S. of lateral line canal through two neuromast organs.

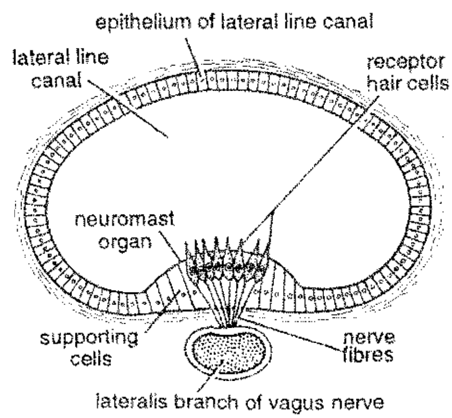

Fig. 30. *Scoliodon*. T.S. of lateral line canal through a neuromast organ.

canals, each of which forms a *post-orbital canal*. The latter divides into a *supra-orbital* and an *infra-orbital canal*. The supra-orbital further divides into *anterior* and *dorsal branches*. Dorsal branch is continued as *ventro-lateral branch*. It joins the infra-orbital and continues behind as *jugal canal* which gives off a *mandibular canal* to lower jaw (Figs. 29 & 30).

2. Neuromast organs. These are little groups of receptor and supporting ectodermal cells found in the lateral line canals. Receptor or sensory cells bear tiny stiff sensory hairs which project into the canal. They are supplied with nerve fibres of facial, glossopharyngeal or lateralis branches of vagus nerves. Neuromast organs are *rheoreceptors* or current receptors. They can perceive vibrations of very low frequency and detect disturbances in water such as caused by the movements of other fishes.

3. Pit organs. Small ectodermal pits are found scattered on the dorsal and lateral surfaces of head of dogfish. Each pit organ consists of sensory hair cells with supporting cells and innervated by nerve fibres of VII cranial nerve. Pit organs are regarded to be isolated individual neuromasts or rheoreceptors. They are especially abundant in rays (Fig. 31 C).

[V] Ampullae of Lorenzini

These are situated in grape-like bunches in the snout of dogfish, and open on the dorsal and ventral surfaces of head by their minute individual apertures. Each pore leads to an elongated mucus-filled *tubule* beneath the skin, and terminates below in 8 to 9 bulb-like chambers, the *ampullary sacs*, arranged radially around a central core, the *centrum*. Two types of cells occur in ampullae : pear-shaped *gland cells* and pyramidal *sensory hair cells*. Each ampulla or ampullary sac is supplied with a delicate nerve fibre from the branches of VII cranial nerve (Figs. 31A & B).

Ampullae of Lorenzini were previously regarded as neuromast organs. However, studies by Sand (1938) indicate that they are really *thermoreceptors* responding to slight changes in temperature.

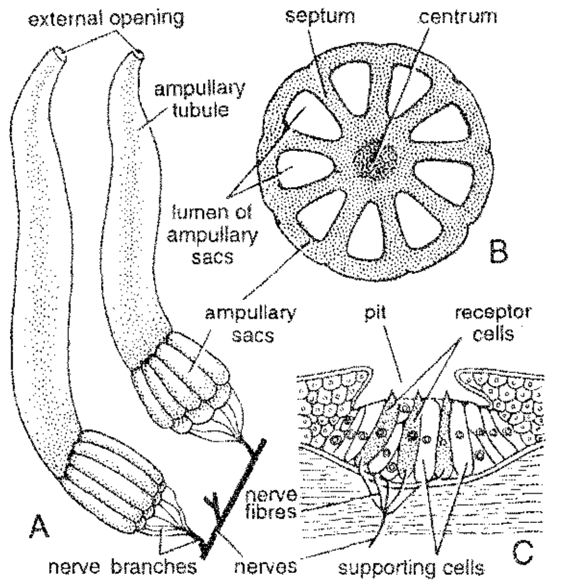

Fig. 31. *Scoliodon*. A—Two complete ampullae of Lorenzini in side view. B—T.S. through ampullary sacs. C—A pit organ in V.S.

Urinogenital System

The excretory and reproductive systems are so closely related to each other in vertebrates that they are considered together under the name of "urinogenital system". In *Scoliodon*, the two *sexes* are separate. *Sexual dimorphism* occurs as in male dogfish, the medial portions of pelvic fins are modified into *claspers* for transfer of spermatozoa during copulation.

[I] Male urinogenital system

1. Excretory organs. Excretory organs of male dogfish are a pair of long, flattened ribbon-like, mesonephric *kidneys*. They are attached to the dorsal abdominal wall, above the peritoneum, one on either side of the median line. They extend nearly the whole length of the body cavity from root of liver in front upto cloaca behind. Each kidney is differentiated into distinct anterior and posterior parts. The anterior part is greatly reduced, non-excretory, narrower and genital in function, hence called *epididymis*. The posterior part is greatly developed, excretory, thicker and forms the *functional adult kidney*, called *opisthonephros* according to Graham Kerr (1919).

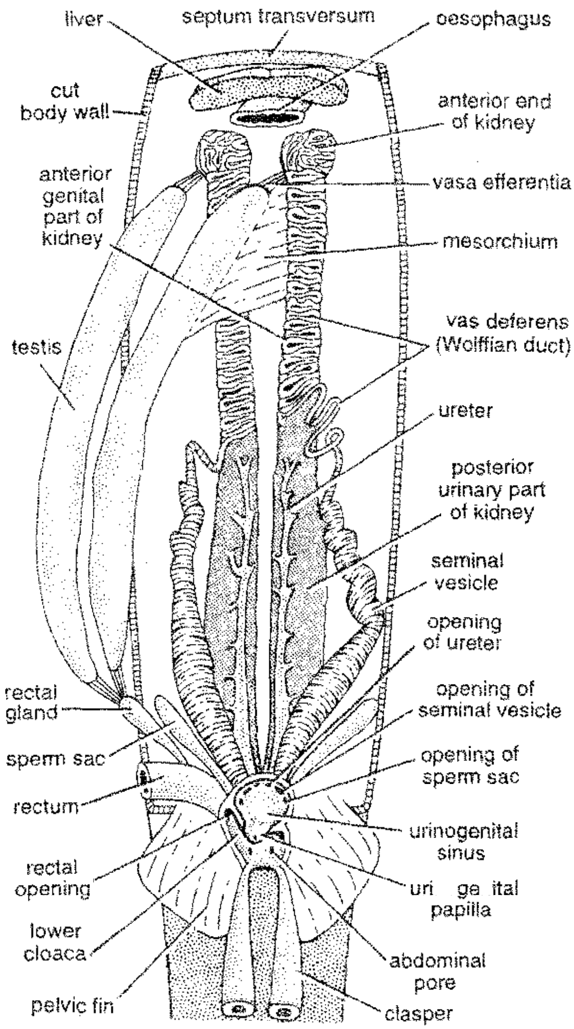

Fig. 32. *Scoliodon*. Male urinogenital system.

Each opisthonephros is formed by several coiled, glandular *uriniferous tubules* with Bowman's capsules enclosing glomeruli. The tubules have a special urea-absorbing segment in them. All the collecting tubules open into a thin-walled common kidney duct or *ureter*. Posteriorly both the ureters open into a wide median *urinogenital sinus*, which itself opens into cloaca through its aperture placed at the tip of a short *urinogenital papilla* (Fig. 32).

2. Reproductive organs. Male reproductive organs include a pair of very large elongated *testes*, attached to the mid-dorsal abdominal bodywall by a double fold of peritoneum (mesentery) called *mesorchium*. Their posterior ends are attached to a *caecal* or *rectal gland* by a non-glandular tissue. From each testis several very fine tubules are given off, the *vasa efferentia*, which run in the mesorchium to the anterior end of a large Wolffian or mesonephric duct now called the *vas deferens*. Spermatozoa developed from germ cells in seminiferous tubules of the testis are carried to the vas deferens. The vas deferens forms a very large narrow and extremely coiled duct along the entire ventral surface of the anterior genital part of kidney or epididymis which produces a nourishing fluid for the spermatozoa. But posteriorly it expands into a wide straight tube, the *seminal vesicle*, in which spermatozoa are stored. Like ureters, the seminal vesicles of both the sides open behind separately into the urinogenital sinus. This gives off in front on either side an elongate club-shaped blind sac, the *sperm sac*, of doubtful function.

Accessory parts of male reproductive system comprise the *claspers* and *siphon*. *Claspers* are present on the pelvic fins of male dogfish. They serve as intromittent organs in coition. Each clasper bears a closed groove with anterior opening called apopyle, lying near cloaca, and posterior exit called *hypopyle*. Spermatozoa enter apopyle from urinogenital papilla of male and transferred to the cloaca of female during copulation. *Siphon* is a muscular sac beneath skin of posterior ventral pelvic region. It has two channels closed anteriorly but opening posteriorly into apopyle of the grooved clasper of its side. During copulation, sea water is drawn into siphon and forced down the clasper groove flushing spermatozoa accumulated there into the female cloaca.

[II] Female urinogenital system

1. Excretory organs. In female dogfish also, the kidneys show the same differentiation into anterior non-excretory and posterior excretory portions. But there is no connection between kidneys and genital organs. Therefore, the anterior part of kidney is extremely reduced to a long narrow tapering

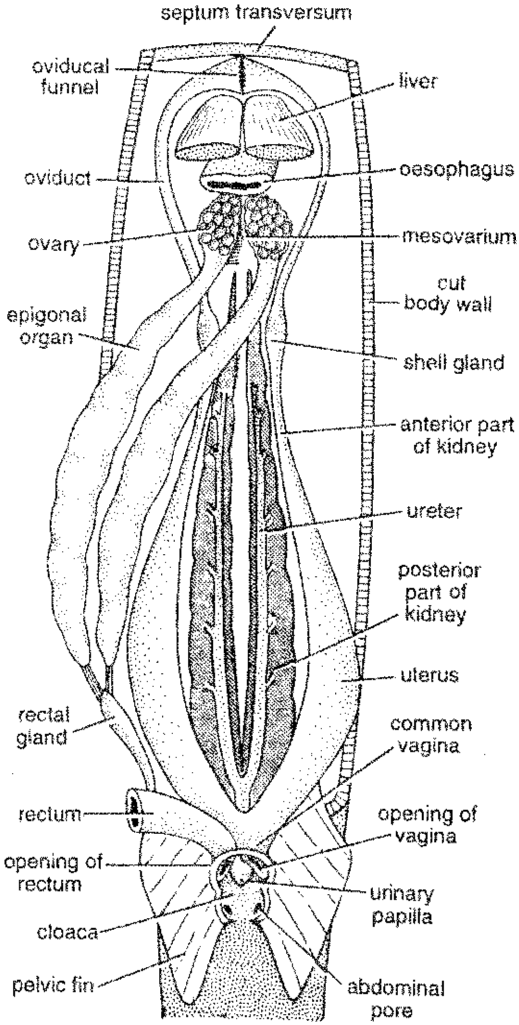

Fig. 33. *Scoliodon*. Female urinogenital system.

strand. The uriniferous tubules of posterior functional part open into a long thin-walled Wolffian or mesonephric duct, the *ureter*. Unlike male, the two ureters of female dogfish unite into a common median ureter opening behind into the large median *urinary sinus*. The sinus in turn opens into cloaca at the tip of a short *urinary papilla* (Fig. 33).

2. Reproductive organs. Female genital organs are one pair of small *ovaries*. They are lobulated bodies, attached one on either side mid-dorsally to anterior abdominal wall by a fold of peritoneum, the *mesovarium*. Their form and size varies with the age. A pair of long tubular *epigonal organs* extend between ovaries in front and the *caecal* or *rectal gland* behind. Surface of ovaries projects into rounded follicles or egg sacs each containing a developing ovum inside. Mature ova are shed into the abdominal cavity from where they enter the oviducts.

The two *oviducts* or Mullerian ducts are large tubes, extending the whole length of body cavity. Their narrow anterior ends unite mid-ventrally, below oesophagus near septum transversum to open into coelom by a single longitudinal slit, the *ostium* or *oviducal funnel*. A short distance posteriorly, each oviduct bears a slight rounded enlargement, the *shell gland*. It secretes a thin membrane over the descending eggs which are fertilized between oviducal funnel and shell gland. The oviduct narrows down again, but, posteriorly it dilates into a wide chamber, the *uterus*, in which development of the embryos takes place. The two uteri unite posteriorly into a common *vagina* which opens into cloaca by a large aperture.

Reproduction

1. Copulation. Reproduction occurs almost throughout the year. During copulation, the male twines round the female. Spermatozoa are transferred through the agency of grooved erected claspers of male, one or both of which are inserted into the cloaca of female.

2. Fertilization. As in all the elasmobranchs, fertilization in dogfish is internal. It takes place in the narrow anterior parts of oviducts in front of the shell glands.

3. Development. Some dogfishes, such as *Scoliodon* and *Squalus*, are *ovoviviparous*. Their eggs develop inside uteri so that they give birth to living young. 3 to 7 embryos may develop in each uterus depending upon the species. The mucous lining of uterus forms protective fluid-filled compartments, one for each embryo. In the beginning, gut of each embryo is connected by a tubular *yolk stalk* with a *yolk sac* containing yolk for nourishment. When the yolk is exhausted, the yolk sac becomes shrivelled and embedded in the uterine wall forming a *yolk sac placenta*. Later on,

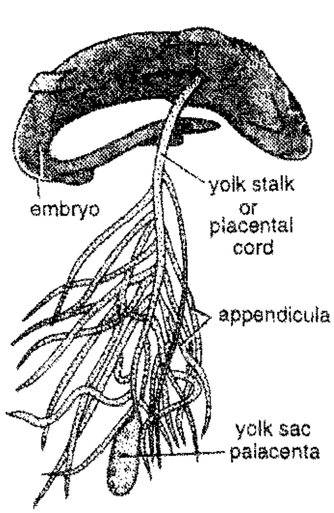

Fig. 34. *Scoliodon*. Embryo with placenta.

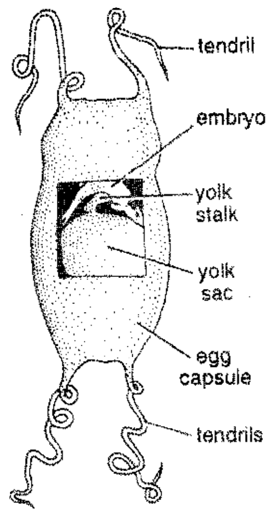

Fig. 35. The egg case or mermaid's purse of dogfish *Scyllium*.

when blood vessels develop, the tubular connection of yolk stalk with embryo disappears. Instead the embryo is attached to uterine wall by a *placental cord* which gives off numerous slender tubular outgrowths, the *appendicula* (Fig. 34).

Some sharks and rays are *oviparous*. Their fertilized eggs are laid encased in protective horny capsules or egg-cases secreted by the shell glands. The egg case of the dogfish *Scyllium*, familiarly known as a 'mermaids purse', is a rectangular box-like structure. Each of its four corners is produced into a long tendril-like thread. These tendrils become coiled about sea weeds to anchor firmly the egg case. The fully formed young hatch out in 6 to 9 months after rupturing the egg case. Usually one embryo develops in one egg case (Fig. 35).

Economic Importance

All sharks are carnivorous, predaceous and destructive to lobsters, crabs and food fishes. *Scoliodon* is eaten by poor people, living along the sea coasts. Though not considered palatable, its flesh is highly nutritious and easily digestible. Its dried skin provides *shagreen* which is used as an abrasive for polishing furniture, metals, etc. It is a suitable animal for study by dissection in the laboratory.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give an account of the geographical distribution, habitat, habits and external features of a Dogfish.
2. Describe the structure of gill and the mode of respiration in *Scoliodon*.
3. Give an account of the arterial and venous system in *Scoliodon*.
4. Describe the structure of heart and course of blood circulation through it in *Scoliodon*.
5. Give an account of the central nervous system of Dogfish.
6. Describe the urinogenital system in male and female *Scoliodon*.

» *Short Answer Type Questions*

1. Give an account of the structure and development of placoid scales.
2. Describe the skin of *Scoliodon* and compare it with the skin of a mammal.
3. Give the origin, distribution and nature of cranial in *Scoliodon*.
4. Describe the structure of eye and eye muscles in *Scoliodon*.
5. Give an account of the internal ear of *Scoliodon*.
6. Describe the lateral line system in *Scoliodon*.
7. Draw well labelled diagrams of *Scoliodon* — (i) Arterial or venous system, (ii) Brain and cranial nerves, (iii) Male or female urinogenital system, (iv) Internal ear, (v) T.S. through pharyngeal region, (vi) T.S. through intestinal region, (vii) V.L.S. of a holobranch.
8. Write short notes on — (i) Ampullae of Lorenzini, (ii) Mermaid's purse, (iii) Neuromast organs, (iv) Placoid scale, (v) Spiral valve.

» *Multiple Choice Questions*

1. Super class pisces includes organisms with :
(a) Stream lined body, covered with scales
(b) Stream lined body, covered with bony plates
(c) Irregular body, covered with scales
(d) Irregular body, covered with bony plates
2. The fossil records of *Scoliodon* appear in :
(a) Middle Eocene (b) Lower Eocene
(c) Upper Eocene (d) Lower pliocene
3. *Scoliodon* is :
(a) Marine, herbivorous (b) Freshwater, carnivorous
(c) Marine, carnivorous and predator
(d) Freshwater, omnivorous
4. Body in *Scoliodon* is covered by :
(a) Dermal plates (b) Cycloid scales
(c) Ctenoid scales (d) Placoid scales
5. Median fins in *Scoliodon* comprise :
(a) Two dorsal, one caudal and one ventral fin
(b) One dorsal, one caudal and one ventral fin
(c) One dorsal, two caudal and one ventral fin
(d) One dorsal, one caudal and two ventral fins
6. Tail in *Scoliodon* is :
(a) Homocercal (b) Heterocercal
(c) Hypocercal (d) Hypercercal
7. The intromittant organ in *Scoliodon* is :
(a) A part of pectoral fin (b) A part of first dorsal fin
(c) Medial part of pelvic fin
(d) Medial part of ventral fin
8. The eyes in *Scoliodon* are protected by :
(a) Eyelids
(b) Immovable nictitating membrane
(c) Cuticle
(d) Movable nictitating membrane
9. The teeth in *Scoliodon* are meant for :
(a) Biting and tearing (b) Only biting
(c) Only chewing
(d) Biting, tearing and chewing
10. Nostrils in *Scoliodon* are :
(a) Dorsal and olfactory (b) Ventral and olfactory
(c) Dorsal and respiratory (d) Ventral and respiratory
11. In *Scoliodon* mucous is secreted by :
(a) Cells in stratum laxum
(b) Cells in stratum germinativum
(c) Cells in stratum compactum
(d) Melanophores
12. A placoid scale consists of :
(a) A wide triangular basal part and a flat trident spine
(b) A wide rhomboid basal part and a flat trident spine
(c) A wide rectangular basal part and a flat trident spine
(d) A wide circular basal part and a flat trident spine
13. Spine of placoid scale is made up of :
(a) Calcite (b) Calcium carbonate
(c) Dentine (d) Tunicine
14. The pulp in placoid scales in formed by :
(a) Odontoblasts (b) Ameloblasts
(c) Scleroblasts (d) Dermal papilla
15. The teeth in Dogfish are modified :
(a) Placoid scales (b) Bony plates
(c) Cycloid scales (d) Ctenoid sclaes
16. Myotomes in Dogfish are separated by :
(a) Adipose tissue (b) Odontoblasts
(c) Malpighian layer (d) Myocommata
17. The rhythm of contraction of myomeres is governed by :
(a) Myocommata (b) Brain
(c) Spinal cord (d) Medulla oblongata
18. The pericardial and abdominal cavity in Dogfish is separated by :
(a) Septum longitudinum (b) Diagonal septum
(c) Muscle sheath (d) Septum transversum
19. The pericardial and abdominal cavity in the Dogfish communicate with one another through :
(a) Pericardio-peritoneal canal
(b) Pericardio-periabdominal canal
(c) Peritoneal canal
(d) Abdominal canal
20. Different parts of alimentary canal in Dogfish are bound to one another by :
(a) Circular muscle fibres
(b) Incomplete mesenteries or omenta
(c) Complete mesenteries
(d) Substance produced by cement glands
21. Dentition in Dogfish is :
(a) Heterodont, polyphyodont and lyodont
(b) Heterodont, diphyodont and lyodont
(c) Homodont, polyphodont and lyodont
(d) Homorodont, diphyodont and lyodont

22. The oesophageal opening into the cardiac stomach is guarded by :
    (a) Blind sac (b) Sphincter valve
    (c) Scroll valve (d) Oesophageal valve
23. Sphincter valve is present :
    (a) At the junction of pharynx and cardiac stomach
    (b) At the junction of cardiac stomach and pyloric stomach
    (c) At the junction of pyloric stomach and oesophagus
    (d) At the junction of oesophagus and intestine
24. The scroll valve serves to :
    (a) Speed up the passage of food
    (b) Delay the passage of food
    (c) Mix the food with bile juice
    (d) Digest the food quickly
25. Liver of Dogfish is :
    (a) Single lobed (b) Bilobed
    (c) Trilobed (d) Four lobed
26. Sinusoids in the gill lamella of *Scoliodon* receive venous blood from :
    (a) Afferent branchial artery
    (b) Efferent branchial artery
    (v) Ventral aorta
    (d) Epibranchial artery
27. The heart in *Scoliodon* receives :
    (a) Both venous and arterial blood
    (b) Only arterial blood
    (c) Only venous blood
    (d) Blood only from gills
28. The 'S' shaped heart of *Scoliodon* is differentiated into :
    (a) One auricle and one ventricle
    (b) Sinus venosus, auricle and ventricle
    (c) Auricle, ventricle and conus arteriosus
    (d) Sinus venosus, auricle, ventricle and consus arteriosus
29. The heart in fishes is :
    (a) Single chambered (b) 2 chambered
    (c) 3 chambered (d) 4 chambered
30. Sinus venosus receives blood from :
    (a) Ductus Cuvieri and hepatic sinuses
    (b) Ventral Aorta
    (c) Ductus Cuvieri
    (d) Hepatic sinuses
31. Erythrocytes in *Scoliodon* are :
    (a) Circular, nucleated (b) Circular, enucleated
    (c) Oval, nucleated (d) Oval, enucleated
32. Brain of *Scoliodon* is enclosed in :
    (a) Cranium (b) Bony skull
    (c) Muscular cover (d) Chondrocranium
33. Cranial nerve arising from the mid brain of *Scoliodon* :
    (a) III and IV (b) IV and V
    (c) V and VI (d) VI and VII
34. Restiform body is present in :
    (a) Cerebellum (b) Medulla oblongata
    (c) Cerebrum (d) Midbrain
35. The swimming movement of *Scoliodon* are controlled by :
    (a) Cerebrum (b) Mid brain
    (c) Hind brain (d) Spinal cord
36. Foramen of Monro in *Scoliodon* is the opening between :
    (a) Olfactory sacs (b) Cavities of cerebrum
    (c) III and IV ventricle
    (d) I and II ventricle of cerebrum and III ventricle
37. The cranial nerve numbered as 'O' in *Scoliodon* is :
    (a) Terminal or pre-olfactory (b) Olfactory
    (c) Optic (d) Oculomotor
38. Gasserian ganglion is present in :
    (a) Oculomotor (b) Trigeminal
    (c) Olfactory (d) Optic
39. In dogfish, ampullae of Lorenzini are supplied by :
    (a) Buccalis (b) Palatinus
    (c) Opthalmicus superficialis (d) Hyomandibularis
40. Otoliths are found in :
    (a) Aqueous humor (b) Vitrous homor
    (c) Recessus utriculi
    (d) Endolymph of membranous labyrinth

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (b) 12. (b) 13. (c) 14. (d) 15. (a) 16. (d) 17. (c) 18. (d) 19. (a) 20. (b) 21. (c) 22. (d) 23. (b) 24. (b) 25. (b) 26. (a) 27. (c) 28. (d) 29. (b) 30. (a) 31. (c) 32. (d) 33. (a) 34. (b) 35. (c) 36. (d) 37. (a) 38. (b) 39. (c) 40. (d).

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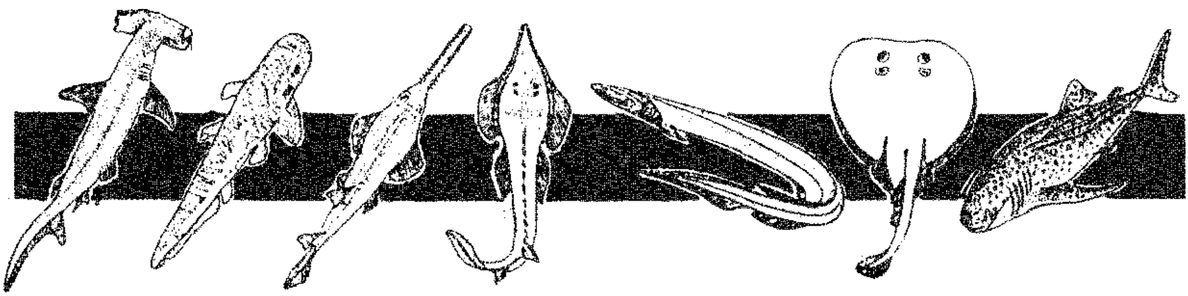

Class 4. Chondrichthyes : The Cartilaginous Fishes

General Characters

1. Mostly marine and predaceous.
2. Body fusiform or spindle shaped.
3. Fins both median and paired, all supported by fin rays. Pelvic fins bear claspers in male. Tail heterocercal.
4. Skin tough containing minute placoid scales and mucous glands.
5. Endoskeleton entirely cartilaginous, without true bones (Gr., *chondros*, cartilage + *ichthys*, fish). Notochord persistent. Vertebrae complete and separate. Pectoral and pelvic girdles present.
6. Mouth ventral. Jaws present. Teeth are modified placoid scales. Stomach J-shaped. Intestine with spiral valve.
7. Respiration by 5 to 7 pairs of gills. Gill-slits separate and uncovered. Operculum absent. No air bladder and lungs.
8. Heart 2-chambered (1 auricle and 1 ventricle). Sinus venosus and conus arteriosus present. Both renal and hepatic portal systems present. Temperature variable (poikilothermous).
9. Kidneys opisthonephric. Excretion ureotelic. Cloaca present.
10. Brain with large olfactory lobes and cerebellum. Cranial nerves 10 pairs.
11. Olfactory sacs do not open into pharynx. Membranous labyrinth with 3 semicircular canals. Lateral line system present.
12. Sexes separate. Gonads paired. Gonoducts open into cloaca. Fertilization internal.

Oviparous or ovoviviparous. Eggs large, yolky. Cleavage meroblastic. Development direct, without metamorphosis.

Classification

The class *Chondrichthyes* (Gr., *chondros*, cartilage + *ichthys*, fish), also called *Elasmobranchii* (Gr., *elasmos*, plate + *branchia*, gills), including the sharks, rays, skates and chimaeras, comprises about 600 living species (according to Schultz) of cartilaginous fishes. The classification followed here is based after that of Romer (1959).

Subclass 1. Selachii
(Gr., *selachos*, a shark)

1. Multiple gill slits on either side protected by individual skin flaps.
2. A spiracle behind each eye.
3. Cloaca present.

Order 1. Squaliformes or Pleurotremata
(Gr., *pleuro*, side + *trema*, opening)

1. Body typically spindle-shaped.
2. Gill slits lateral, 5 to 7 pairs. Spiracles small.
3. Pectoral fins moderate, constricted at base.
4. Tail heterocercal.

Examples : True sharks. About 250 living species. Dogfishes (*Scoliodon, Chiloscyllium, Mustelus, Carcharinus*), spiny dogfish (*Squalus*), seven gilled shark (*Heptanchus*), zebra shark (*Stegostoma*), hammer-headed (*Sphyrna*), whale shark (*Rhineodon*).

Order 2. Rajiformes or Hypotremata
(Gr., *hypo*, below + *trema*, opening)

1. Body depressed, flattened dorso-ventrally.
2. Gill slits ventral, 5 pairs.
3. Pectoral fins enlarged, fused to sides of head and body.
4. Spiracles large, highly functional.

Examples : Skates and rays. About 300 species. Skate (*Raja*), stingray (*Trygon*), electric ray (*Torpedo*), eagle ray (*Myliobatis*), guitar fish (*Rhinobatus*), sawfish (*Pristis*).

Subclass 2. Holocephali
(Gr., *holos*, entire + *kephale*, head)

1. Single gill opening on either side covered by a fleshy operculum.
2. No spiracles, cloaca and scales.
3. Jaws with tooth plates.
4. Single nasal opening.
5. Lateral line system with open groove.

Examples : Rat fishes or chimaeras. About 25 species. *Hydrolagus* (= *Chimaera*).

Other Chondrichthyes

1. Dogfishes. Dogfishes are widely used for study in laboratories because of their small size which rarely exceeds 1 metre. The types commonly described in books are the common European spotted dogfish, *Scyliorhinus* (=*Scyllium*) *caniculus*, spiny dogfish, *Squalus acanthias, Brachaelurus*, etc. They all resemble the Indian dogfish, *Scoliodon*, in their general anatomy and possess a spiracle and 5 gill slits on either side. They are widely distributed in temperate and tropical seas. *Scyliorhinus caniculus* occurs in the coastal waters of Europe. *Squalus* and *Acanthias* are abundant in both North Atlantic and North Pacific Oceans. They are so named for a prominent spine associated with each dorsal fin. *Mustelus* is the smooth dogfish in the sense that it lacks dorsal spines. Dogfishes are bottom dwellers and live on mixed diets including crustaceans and molluscs.

2. Sharks. Sharks are pleurotrematic elasmobranchs comprising about 300 living species. Most of them are marine, occurring in the warm waters of the tropics. As a group they are distinguished by their muscular strength, agility of movements and acuteness of their sight and smell. On the average sharks are very large animals, the largest of all fishes. A mature whale shark, *Rhincodon* (=*Rhineodon*) *typicus*, may reach 15-17 metres in length. With the exception of whales, they are the largest living vertebrates. Sharks are all predaceous carnirvores, capacious scavengers and active swimmers. They feed voraciously with

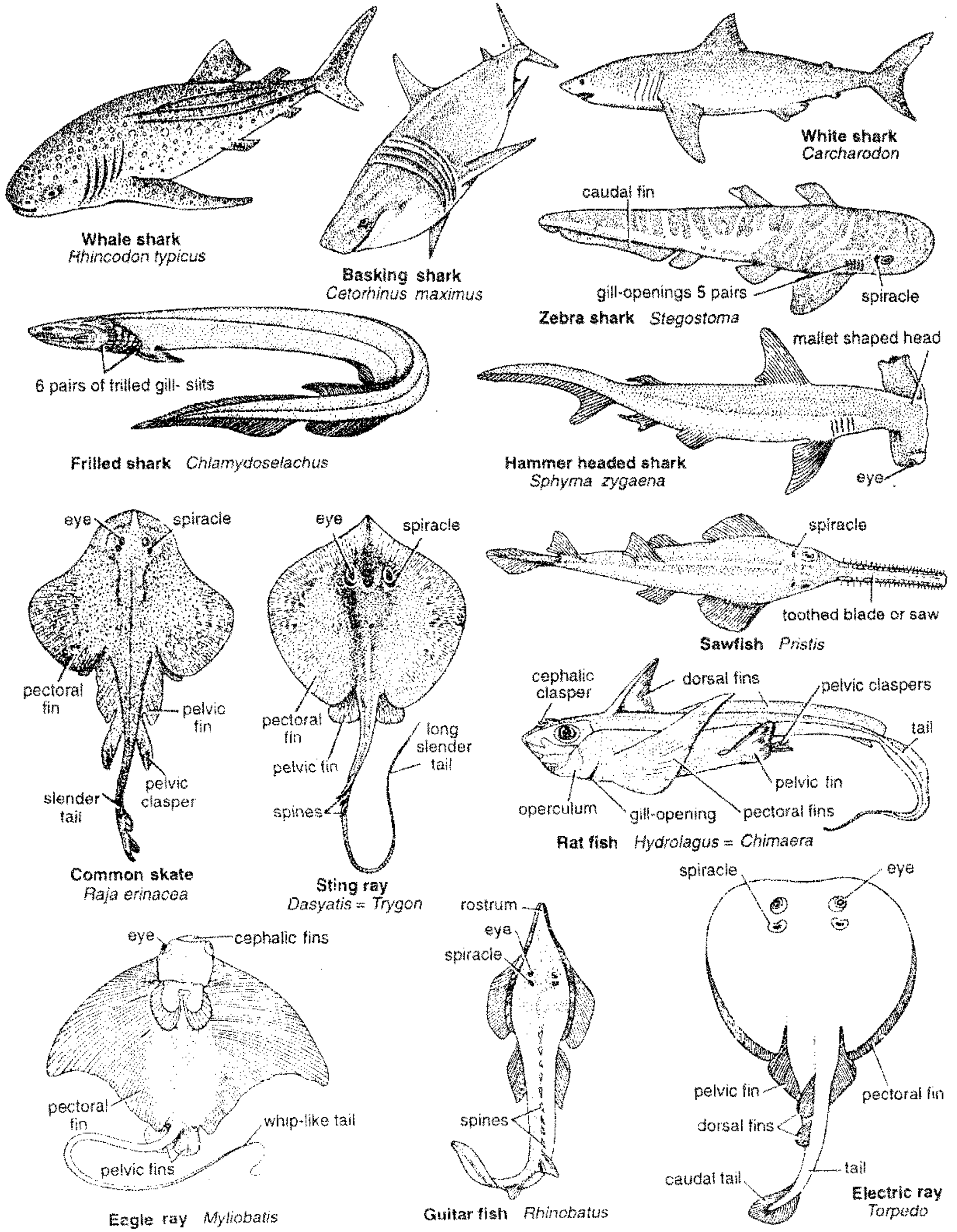

Fig. 1. Class Chondrichthyes. Some cartilaginous fishes.

their sharp, triangular-teeth upon other fishes, crustaceans, sea urchins and certain molluscs. But strangely, the two largest sharks, the whale shark (*Rhincodon*) and the basking shark (*Cetorhinus maximus*) 10 metres long or more, have minute teeth. They are sluggish filter-feeders living exclusively on zooplankton which they strain from sea water with their filamentous gill rakers. Water passes out of their gill slits while the planktonic food is retained in their pharynx by branchial sieve. The great white shark, *Carcharodon carcharias*, which often reaches a length of 12 metres, has earned the name of 'man-eater' by occasionally devouring a human being. The most ferocious of the Indian sharks is the Ganges shark *Carcharinus gangeticus*. Specially fond of living human flesh, it is a great menace to bathers in the Hooghly at Calcutta. The most primitive sharks (*Hexanchus*) have a single dorsal fin, a simple vertebral column, a sub-terminal mouth and more than 5 pairs of gill slits. *Hexanchus* and the frilled shark *Chlamydoselachus* have 6 pairs of gill slits. *Heptranchias* and the fossil *Cladoselache* have 7 pairs of gill slits plus spiracles. Other interesting sharks include tiger sharks and hammerheads. The tiger or zebra shark (*Stegostoma*) measures 3 to 5 metres in length. It shows brilliant colouration of dark stripes over yellow background. It is viviparous and a nuisance to fisheries. The hammer-headed shark *Sphyrna* (=*Zygaena*) or *Reniceps*, abundant in Indian Ocean, grows to 4 to 5 metres in length. It is peculiar in that it has a mallet-shaped head due to a prominent lateral lobe on either side bearing an eye on its distal end.

3. Skates and rays. Skates and rays are hypotrematic elasmobranchs more diverse than the sharks and comprise about 400 living species. They differ from sharks in having their body greatly flattened dorso-ventrally with enormously developed pectoral fins for swimming broadly joined to head and trunk so that they look diamond or disc-like in shape. Their tail is slender, with a dorsal and a caudal fin. Gill slits reduced to 5 pairs only on the flat ventral surface of head. They are modern derivatives of sharks and specialized for bottom-dwelling. Their mouth is often buried in the bottom sand or mud so that water for respiration enters pharynx through a pair of large dorsally situated spiracles with valves and leaves through ventral external gill slits. Most skates and rays have flattened grinding teeth for crushing their food consisting mainly of shelled molluscs, crustaceans and an occasionally small fish. However, some have developed highly specialized feeding adaptations. In general, they are small marine creatures 30 to 60 cm broad. However, the giant mantas or devil fishes (*Manta, Mobula*) of tropical waters may have a pectoral fin-spread of 6 metres and weigh nearly half a ton. Their greatly enlarged pectoral fins are used in swimming like wings. They have small teeth and feed on small fishes and plankton which are driven by their large pectoral fins into their mouth. They can easily upset small boats and harpooning them is an exciting sport. The common skates (*Raja, Raia*) measure 2-3 metres in width. Viewed from above, they look like kites with a sharp tail. The eagle rays or sea vampires (*Myliobatis*) grow to 4.5 metres and have a long tapering whip-like tail, often with stings. The famous stingrays (*Trygon or Dasyatis*) live half buried in sand along the sea coasts and need special protection from predators approaching them from above. They have large flexible whip-like tails modified into a stinging defensive organ. The dorsal fin at the base, forms a large and barbed or serrated spine provided with a poison gland in the skin. It can be driven into the body of anyone stepping on the ray, inflicting a painful and dangerous slow-healing wound. The electric rays (*Torpedo* or *Astrape*) are nearly circular in shape and have developed electric organs for defense and predation. Certain dorsal muscles have modified into a powerful electric organ on either side between the eye and pectoral fin and innervated by cranial nerves. They are capable of giving a powerful electric shock to stun their preys and enemies. In some electric rays, even the unborn young in the uterus have been shown to produce discharges of fairly high voltage.

4. Sawfish and guitarfish. These are also hypotrematic elasmobranchs, but their bodies are not flattened and broadened like skates and rays to which they are related. The sawfish (*Pristis*) may attain a length of 3 to 6 metres. Its characteristic feature is the greatly elongated blade-like rostrum or snout, armed on either lateral side with a row of sharp tooth-like scales, which make it is formidable weapon for defense as well as food capture. As the sawfish swims through schools of small fishes, it swings the saw from side to side thus disabling many and eat them at leisure. Common sawfishes of Indian coasts are *P. cuspidatus* and *P. microdon*. The guitar fish or banjo ray (*Rhinobatus*) is somewhat shark-like, but so named beacause of its guitar-like outline. *R. granulatus* is common along the Bombay sea coast.

5. Chimaeras. Chimaeras, frequently called the ghost fishes, rat fishes or king of herrings, are deep sea forms. They belong to the genus *Hydrolagus* (=*Chimaera*) having 25 very poorly known species. They are grotesque-looking a typical chondrichthyans having external gill slits covered by a fleshy boneless skin flap or operculum. The spiracle is closed. The upper jaw, unlike that in elasmobranchs, is solidly fused with the chondrocranium. Instead of teeth, the jaws are covered by hard, flat plates with which they crush and eat molluscs. Lateral line is an open groove. Male has a frontal or cephalic clasper in addition to usual pelvic claspers. All are oviparous and lay a single egg at a time.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give the general characters of class Chondricthyes and classify it upto orders, giving example of each group.

» ***Short Answer Type Questions***

1. Write short notes on—(i) *Chimaera*, (ii) Hammer-headed shark, (iii) *Pristis*, (iv) *Rhinobatus*, (v) *Torpedo*.

» ***Multiple Choice Questions***

1. Chondricthyes are mostly marine and :
   (a) Predaceous (b) Sanguivorous
   (c) Herbivorous (d) Parasitic
2. Body of cartilaginous fishes is streamlined and :
   (a) Circular (b) Spindle shaped
   (c) Cylinderical (d) Oval
3. Tail in Chondricthyes is :
   (a) Hypocercal (b) Homocercal
   (c) Heterocercal (d) Hypercercal
4. Respiration in Chondricthyes is by :
   (a) 2 to 4 pairs of gills (b) 3 to 5 pairs of gills
   (c) 4 to 6 pairs of gills
   (d) 5 to 7 pairs of gills
5. In Chondricthyes :
   (a) Both renal and hepatic portal system are present
   (b) Only renal portal system present
   (c) Only hepatic portal system present
   (d) Portal systems absent altogether
6. Kidney in Chondricthyes is :
   (a) Mesonephric (b) Opisthonephric
   (c) Metanephric (d) Pronephric
7. In subclass Holocephali gill opening on either side is :
   (a) 2, covered by operculum
   (b) 2, uncovered
   (c) Single, covered by operculum
   (d) Single, uncovered

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c).

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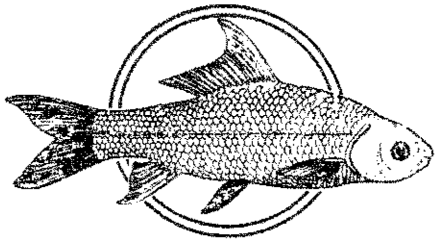

Type 6. *Labeo rohita* : Rohu, A Bony Fish

Class Osteichthyes (Gr., *osteon*, bone + *ichthyes*, fish) comprises the true, bony fishes, both freshwater and marine. They are the familiar and most successful living group of aquatic vertebrates. One half of all vertebrates are bony fishes belonging to well over 20,000 living species. Their scientific study is known as *Ichthyology*. They vary greatly in shape and proportions, but they are built on the same basic plan. They have a spindle-shaped, streamlined body covered by dermal scales, also have bony endoskeleton, swim by fins and breathe by gills. They are superficially similar to dogfish sharks. Several types of bony fishes (*Lates, Mugil, Labeo*) have been prescribed by different Indian Universities for study. The following description relates mainly to *Labeo rohita* which is perhaps the commonest of Indian freshwater bony fishes and the one most generally esteemed for eating purposes. It is a good example of a bony fish.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Division	Gnathostomata
Superclass	Pisces
Class	Osteichthyes
Subclass	Actinopterygii
Superorder	Teleostei
Order	Cypriniformes
Type	*Labeo rohita* (Rohu)

Distribution

Labeo is a large, essentially tropical genus of carps distributed in tropical Africa and East Indies. About two dozens of species are known from India, the most common being *Labeo rohita* (Rohu) and *Labeo calbasu* (Kala bans) which

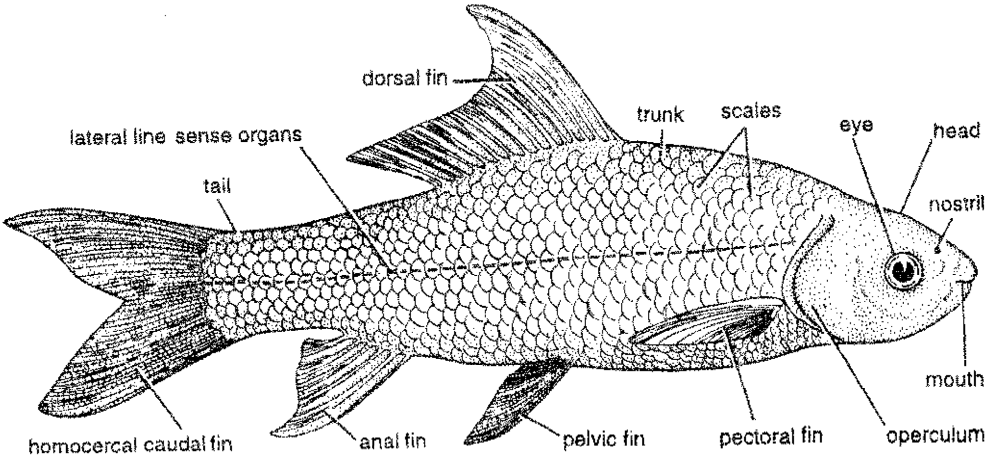

Fig. 1. *Labeo rohita*. External features in side view.

occur almost throughout India, Pakistan and Bangla Desh.

Habits and Habitat

Rohu is commonly found in freshwater ponds, rivers, lakes and estuaries. It prefers clean water and respires by means of gills. It is chiefly herbivorous and a bottom, feeder, eating algae and aquatic plants. But frequently it comes to water surface, to take air into the air bladder. It is oviparous and breeds in running water in July and August. Fertilization takes place externally in water.

External Features

Shape, size and colour. Body is spindle-shaped. Colour is greyish or blackish on back and silvery white or pale on the two sides and belly. A full grown individual measures 1 metre in length and 20 to 25 kg in weight. The body is divisible into head, trunk and tail.

1. Head. Head extends from tip of snout to hind edge of operculum. Snout is depressed, short and obtuse. Mouth is subterminal. It is a large transverse aperture, bounded by thick and fleshy lips. Usually only two small, thread-like sensory *maxillary barbels* are present at the corners of mouth, the rostral barbels being generally absent. Teeth are lacking on jaws. Snout bears dorsally a pair of small *nostrils*, they are peculiar as they do not communicate to the buccal cavity. The lateral *eyes* on head are without eyelids but protected by a transparent protective membrane. Behind the eye, on either side is a large movable bony gill cover or *operculum* with free posterior and ventral margins. Beneath each operculum lie four comb-like gills in a branchial chamber.

2. Trunk. It is the thick middle part of body. It is higher than wide and oval in cross section. On either side of trunk extending from the back of operculum upto tail there is a dark line on the mid ventral portion of the body called, *lateral line*. Fins are well developed and supported by bony finrays. On the back of the middle of trunk is a single large somewhat rhomboidal *dorsal fin*. Just behind operculum are a pair of larger ventro-lateral *pectoral fins*, followed behind by a pair of smaller ventral *pelvic fins*. Mid-ventrally at the posterior end of trunk lie in a series three small apertures : anterior *anus*, middle *genital* and posterior *urinary*.

3. Tail. It comprises about one-third posterior part of body. It is laterally compressed and narrower behind. At the end of the tail is a median *homocercal caudal fin* deeply notched into two similar lobes. On the ventral side of tail is a median *anal fin* lying just posterior to urinary aperture. The tail makes the principal locomotor organ.

Bodywall

Trunk and tail are covered by thin, rounded, overlapping dermal *cycloid* scales. The concentric or ring-like markings on scales called circulii are used to determine the age of fish. The *skin* comprises of two parts : outer epidermis and inner dermis. A thick basement membrane is present between dermis and epidermis. The epidermis consists of several layers but stratum corneum is absent. The dermis is made up of connective tissue, blood vessels, nerves and smooth muscle fibers. Scales are found ambedded in the dermis. The epidermis of fishes contains large mucous cells or Becker's cells and chromatocytes. Chromatocytes are also found in dermis. Two type of sensory cells viz., granular sensory cells and club cells are also present. The dermis is composed of stratum laxum, stratum compactum and subcutaneous layer, sharply demarcated from each other. Stratum laxum is a laminated fibrous layer, in which the scales are found embedded by Sharpey's fibers. Stratum compactum is made of reticulum of delicate fibers. The mucus or slime produced by epidermal mucous glands makes the fish slippery. The principal muscles of trunk and tail are arranged in zigzag *myotomes* as in other fishes and vertebrates. Muscles are lined internally by *peritoneum* which also lines the body cavity or coelom and covers the visceral organs. The colour of fishes is produced by the cells present in the dermis. These cells are of two types– *chromatophores* and reflecting cells or *iridocytes*. Chromatophores are branched cells containing pigment granules called *melanosomes*. Melanosomes may be black (melanin), white, red, orange, yellow (carotenoids or flavins). The iridocytes contain stacks of platelets of guanine.

Exoskeleton

Scales and finrays constitue the exoskeleton of *Labeo rohita*. Scales are cycloid type, thin overlapping bony plates, partly covered by skin. Exposed part of scales bear pigment cells. Centrally each scale has an area called focus. Around focus ther exist concentric rows of ridges called circulii, used to count the age of fishes. Moreover there are several radial lines, starting from focus and extending upto the periphery, called radii. Finrays are fin supporting structures. They are of two types– spines (single ray) and soft rays (segmented rays). Spines in the fins of *Labeo* are unsegmented, uniserial structures. Soft rays are segmented, often branched and biserial.

Endoskeleton

Bony endoskeleton of *Labeo rohita* has been described in chapter 36 in the section on Vertebrate Osteology.

Digestive System

Digestive system comprises the *alimentary canal* and the associated *digestive glands*.

1. Alimentary canal. Alimentary canal starts from the mouth and terminates in the anal opening. The subterminal *mouth*, bounded by fleshy lips, beset with sensory papillae, opens into a broad, dorso-ventrally compressed *buccal cavity*. *Teeth* and a distinct *tongue* are lacking in rohu. *Pharynx* is also dorso-ventrally compressed and differentiated into a broad anterior respiratory part and a narrow posterior masticatory part. Anterior part is perforated laterally by four pairs of internal gill slits leading into branchial chambers. From branchial arches project into pharyngeal cavity small spiny *gill rakers*, to prevent passage of food through gill slits. Either ventro-lateral wall of posterior pharyngeal chamber bears 3 rows of homodont *teeth* or masticating plates with truncated crowns for crushing and grinding food. Teeth are borne by the inferior pharyngeal bones (reduced 5th branchial arches). Floor of pharynx is folded transversely. Pharynx leads posteriorly into a short, narrow tubular *oesophagus*. Its mucous lining forms prominent longitudinal folds. A pneumatic duct from air bladder of fish opens dorsally into oesophagus. *Labeo* and many other teleost fishes do not have *stomach* which is difficult to understand. Oesophagus opens behind straight into an elongated, swollen, thick-walled *intestinal bulb*. Opening between the two is guarded by an *oesophageal valve* to prevent regurgitation of food. The intestinal bulb has an anterior broader *cardiac part* into which open dorsally the pancreatic and bile ducts, and a posterior narrower *pyloric part* without pyloric caeca so common in other teleost fishes. The

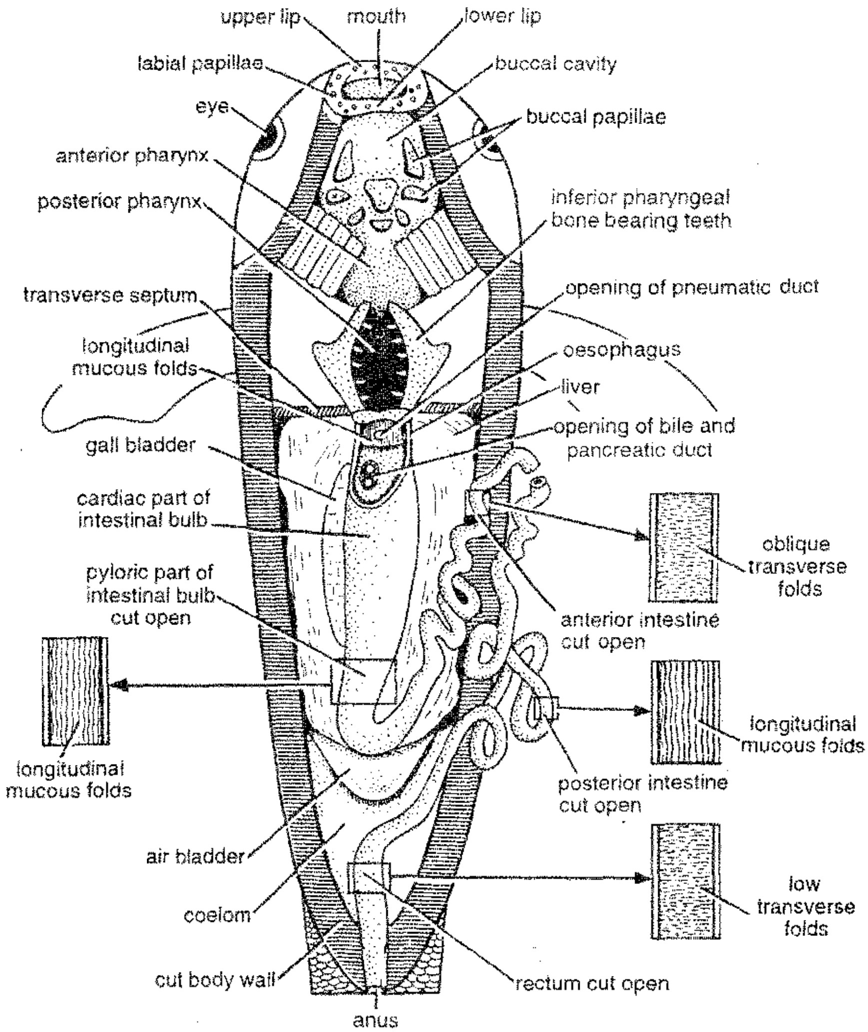

Fig. 2. *Labeo rohita*. Dissection of digestive system. Some regions of alimentary canal cut open to show folds of mucous lining.

mucous lining of cardiac part shows honey-comb-like folds, and that of pyloric part contains bold longitudinal folds. Gastric glands are lacking. Intestinal bulb is followed by a thin-walled, narrow and extremely elongated (about 8 metres long) *intestine*. It is a much coiled tube of practically uniform diameter. The mucous lining forms oblique transverse folds in its anterior region, and distinct longitudinal folds in the posterior region. Pyloric caeca, intestinal villi and scroll valve are absent. Intestine is longer in *Labeo* because of its herbivorous habit but it tends to be shorter in carnivorous fishes. The rectum which follows is nearly 1 metre long, slightly wider and thin-walled. Rectal gland is lacking. Internal lining forms inconspicuous transverse folds. Rectum opens to the exterior by *anus* mid-ventrally just in front of the anal fin. It functions for the muscular expulsion of the faecal material.

2. Digestive glands. Digestive glands of *Labeo* are liver and pancreas. *Liver* is a large, dark brown gland. It consists of a narrower right lobe and a broader left lobe interconnected anteriorly, by connecting median lobes. A thin-walled elongated sac-like *gall bladder*, 8 cm

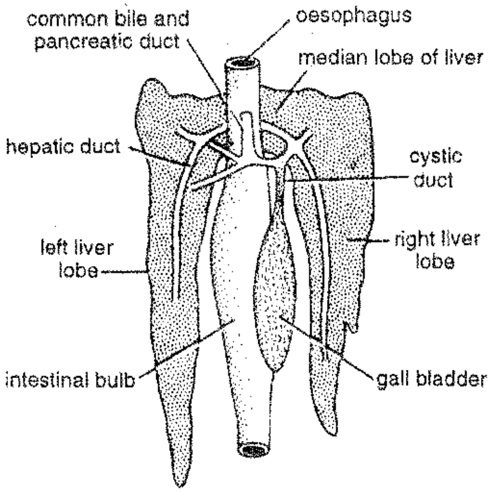

Fig. 3. *Labeo rohita*. Liver and gall bladder in dorsal view.

long and 2.5 cm broad, lies dorsally between right liver lobe and intestinal bulb. A *cystic duct* arises from the anterior end of gall bladder, receives three hepatic ducts from the liver lobes and forms a *bile duct* which opens dorsally into the roof of cardiac part of intestinal bulb.

Pancreas is rather diffused, found scattered in liver, spleen and intestinal mesentery. A *pancreatic duct*, which is enclosed in a common sheath with bile duct, opens separately in the intestinal bulb.

Air Bladder

Air bladder is also called the *swim bladder*. It lies in the body cavity, but outside coelom, above the intestinal bulb and ventral to the vertebral column. It is an elongated white, thin-walled sac filled with a gas. It is divided by a transverse constriction into a small *anterior chamber* and a large *posterior chamber* which are interconnected with each other. The air bladder is connected to the roof of oesophagus by a slender *pneumatic duct* and such a fish is called *physostomous*. Air bladder functions like a *hydrostatic organ*. It regulates specific gravity of body by secretion or absorption of gas in the air bladder. The inner lining of the swimbladder is highly vascularized, forming red bodies or rate mirabile. The rate mirabile located in the anterior chamber has extraordinary power of isolating oxygen, carbon dioxide and nitrogen from the blood and to fill this chamber with these secreted gases. But rate mirabile of posterior chamber serves reverse role i.e., it absorbs these gases. Besides acting as hydrostatic organ it also performs a variety of other functions like-gas secretion, gas resorption, respiratory function, sensory function auditory function and sound production etc.

Respiratory System

Respiration of *Labeo* is aquatic, the fish depending on O_2 dissolved in water. The respiration is performed by four pairs of gills located in gill chambers.

[I] Respiratory Organs

Labeo respires with 4 pairs of filiform gills supported by the first 4 pairs of gill arches. Four gills are present on either side of pharynx in a common *gill chamber*. Each gill chamber is covered externally by a skin flap, the *operculum*, supported by bony plates. A branchiostegal membrane is attached to the posterior margin of operculum. The chamber opens to outside by a large crescentic *branchial* or *gill aperture* behind the operculum and in front of the pectoral fin. Each gill consists of two rows (hemibranchs) of slender *gill filaments*. In *Labeo* and other teleosts the filaments are attached to an extremely reduced interbranchial septum so that their distal ends hang freely in the gill chamber. This type of gill is called *filiform* or *pectinate*. In contrast, the gills of dogfish and other elasmobranchs are called *lamellibranch* in which the gill lamellae are attached throughout their length to an elongated septum. The hyoid arch and the fifth gill arch bear no gill filaments. The pseudobranch of the spiracle of dogfish is also represented in *Labeo* attached to the inner surface of operculum, and may have a secretory function. Thus there are 8 hemibranchs or 4 holobranchs only attached to first 4 branchial arches, and 5 gill slits on either side beneath an operculum. The inner or pharyngeal border of each gill arch has teeth-like processes, the *gill rakers*, which do not permit food particles to enter the gill

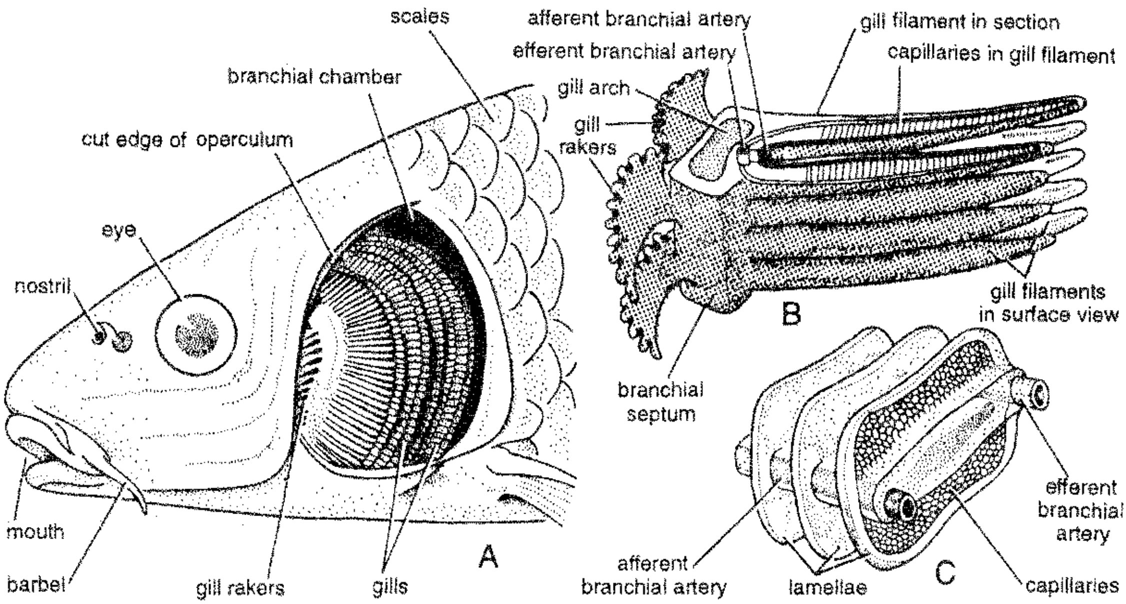

Fig. 4. Gills of a bony fish. A—Operculum cut away showing gills in the left gill-chamber. B—Part of a gill showing gill rakers and filaments. C—Three lamellae of a gill filament showing blood supply.

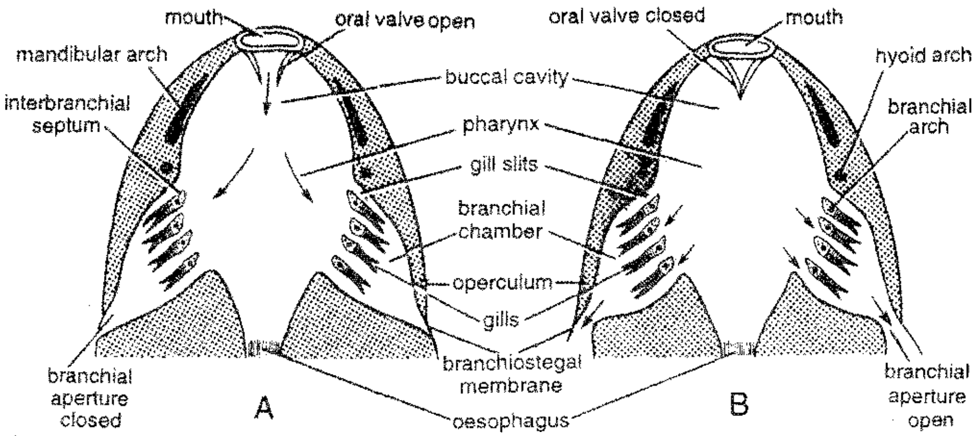

Fig. 5. Respiratory mechanism of a bony fish. Arrows show direction of respiratory water currents. A—Inspiration. B—Expiration.

chambers. Every gill filament bears several minute transverse plates or *lamellae* covered with thin epithelium and containing capillaries between the afferent and efferent branchial arteries.

[II] Mechanism of respiration

Breathing movements occur in two steps, the gill chambers working as suction pumps.

1. Inspiration. During inspiration, opercula and branchiostegal membranes press against the body keeping the two external branchial apertures tightly closed. The gill arches bulge laterally enlarging the internal capacity of bucco-pharyngeal cavity which acts like a suction pump. As a result, the oral valves open and water flows in through opened mouth to fill the bucco-pharyngeal cavity.

2. Expiration. Now the oral valves close shutting the mouth, the gill arches contract and the opercula and branchiostegal membranes lift, opening the external branchial apertures.

Consequently, water under pressure is forced to pass over gill filaments and out through the external branchial apertures.

[III] Physiology of respiration

The *afferent branchial artery* bringing deoxygenated blood, breaks up into capillaries into lamellae of gill filaments where exchange of gases occurs by diffusion through their thin walls. As fresh respiratory water passes over gill filaments, their blood gives up CO_2 and absorbs O_2 from water. The *efferent branchial artery* carries away oxygenated blood from gill to the body. The fish needs a constant supply of fresh O_2-bearing water for life. If water is depleted of O_2 or fish is removed from water, it soon dies due to lack of oxygen, called *asphyxiation*.

Blood Vascular System

The blood vascular system and physiology of circulation are practically the same as in the dogfish *Scoliodon*. The 2-chambered *heart* lies in an anterior portion of coelom, the pericardium, beneath pharynx. *Sinus venosus* is large and spongy and bears a pair of lateral appendages characteristic of cyprinoid fishes including *Labeo*. It opens into thin-walled *auricle*, thence into thick-walled *ventricle*, all having valves to prevent reverse flow of blood. Conus arteriosus is absent. Instead, an enlargement of *ventral aorta*, the elastic *bulbus arteriosus* is present. Short ventral aorta distributes blood to gill capillaries for oxygenation by 4 pairs of *afferent branchial arteries*. Oxygenated blood is collected by 4 pairs of *efferent branchial arteries* into *dorsal aorta* which sends branches to all parts of the head and body. Principal *veins* include paired anterior and posterior *cardinals*. Hepatic and renal portal systems are both present. The *erythrocytes* of bony fishes are considerably smaller than those of cartilaginous fishes and nucleated. Blood is pale colored fluid in whichery throcytes and ameboid leucocytes are found suspended.

Nervous and Sensory Systems

The nervous and sensory systems of a bony fish are very similar to those of a dogfish. However, the brain of *Labeo* (bony fishes) is more highly developed than that of *Scoliodon* (cartilaginous fishes). Olfactory lobes, cerebrum (undivided) and diencephalon are somewhat smaller while the optic lobes and cerebellum larger than in dogfish. There are 10 pairs of *cranial nerves*. Besides 10 pairs of cranial nerves the terminal nerve (cranial nerve

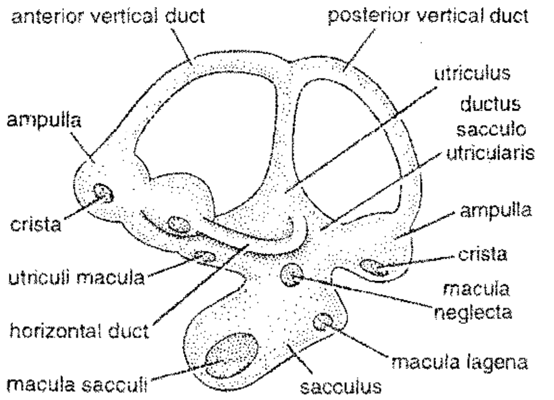

Fig. 6. Internal ear of a bony fish.

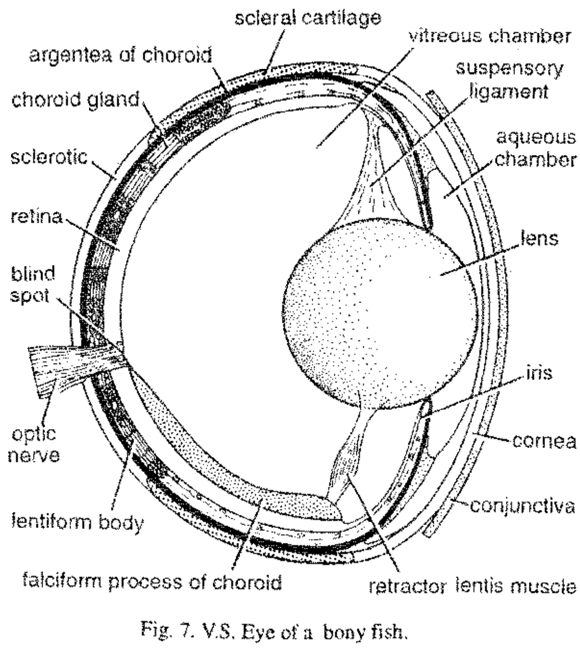

Fig. 7. V.S. Eye of a bony fish.

'O') is also present. The spinal nerves are paired and supply the trunk and tail regions. Like *Scoliodon* each spinal nerve originates by a dorsal sensory root and ventral motor root. The sympathetic nervous system is more advanced than that of *Scoliodon*. The sympathetic nerve trunks are without any ganglions.

Bony fishes share the keen senses of smell and taste with cartilaginous fishes. The *olfactory sacs* do not communicate with mouth cavity and take no part in respiration. *Taste buds* are abundant on lips and in and around mouth. *Tactile organs* are found all over the body surface, especially on lips and barbels. The organs of hearing and equilibrium are a pair of *internal ears*. Each ear is made of the usual parts— utriculus, sacculus, lagena and 3 semicircular canals. The *otoliths* are larger in size. *Eyes* are typically fish-like, devoid of eyelids, with a flat cornea a large pupil and the lens almost spherical. A vascular, sickleshaped fold of choroid, called *falciform process* extends from black spot to the back of lens where it meets a knob-like muscle from lens, the *campanula Halleri* or *retractor lentis*. Together they form the accommodation apparatus which helps in focussing the eye on distant or near objects by shifting the lens. The *lateral line system* is also important and detects vibrations and pressure changes in water.

Urinogenital System

Sexes are separate and excretory and reproductive organs are quite independent in *Labeo*.

[I] Excretory organs

Two elongated and brownish mesonephric or opisthonephric *kidneys* lie just beneath the vertebral column in abdominal cavity. Their free anterior ends have knob like *head kidneys* which are non-renal and pronephric. Their broad middle and narrow posterior parts are united and form the renal part containing uriniferous tubules. Nitrogenous waste is carried posteriorly from each

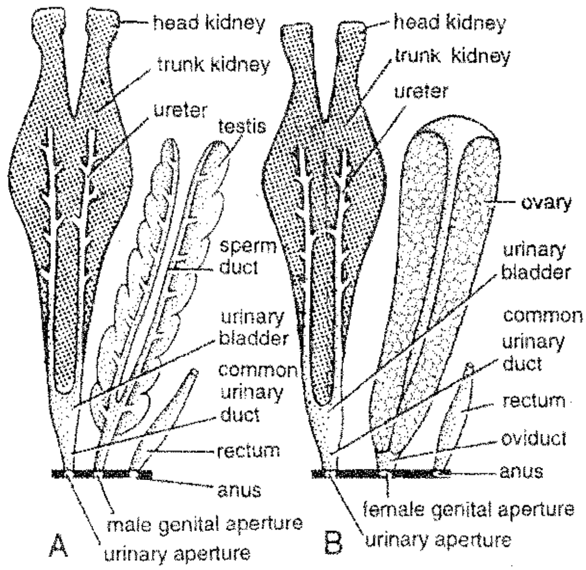

Fig. 8. *Labeo*. Urinogenital system (diagrammatic). A—Male. B—Female.

kidney in a slender, tubular *ureter*. Both the ureters unite into a *common urinary duct* with a thin-walled *urinary bladder* is mesodermal in origin which is not homologous with that of the tetrapods. Excretory fluid is temporarily stored in the bladder and then expelled through the midventral *urinary aperture* situated behind the anus.

[II] Reproductive organs

One pair of elongated gonads, *testes* in male and *ovaries* in female, lie posteriorly in the abdominal cavity beneath the air sac. They are suspended from the bodywall by folds of peritoneum, called *mesorchia* in male and *mesovaria* in female. The mature gonads become exceptionally enlarged during breeding season. A pair of gonoducts are formed by peritoneum, called *sperm ducts* in male and *oviducts* in female. Both the ducts join posteriorly to open by a single *genital aperture* lying mid-ventrally between anus and the urinary aperture.

Labeo is oviparous. The female lays thousands of relatively small and yolky eggs which sink to the bottom. The male fertilizes the eggs by depositing sperm (milt) over them. Thus *fertilization* is external, taking place in water. Cleavage is meroblastic and development direct. Newly hatched young about 2-3 mm long are called *fry*. They start feeding and grow into *fingerlings* when 5 to 15 mm long. Adult size and sexual maturity is reached in about two years.

Economic Importance

Labeo is a large genus containing several fine species which are of considerable importance as an article of food. *Labeo rohita* or rohu is perhaps the commonest of Indian fish and most generally esteemed for eating purposes. It is also a much domesticated freshwater fish because of its excellence as food.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give an account of geographical distribution, habitat, habits and external features of Rohu.
2. Describe the organs and mechanism of respiration in a bony fish.

» *Short Answer Type Questions*

1. Describe the alimentary canal and associated glands in *Labeo*.
2. Write short notes on—(i) Air bladder, (ii) Gill rakers, (iii) Operculum.

» *Multiple Choice Questions*

1. Icthyology is the study of
   (a) True bony fishes　(b) Cartilaginous fish
   (c) Cyclostomes　(d) Placoderms
2. Rohu is chiefly :
   (a) Carnivorous　(b) Herbivorous
   (c) Predator　(d) Parasitic
3. The principal locomotary organ in Rohu is :
   (a) Pectoral fins　(b) Pelvic fins
   (c) Tail　(d) Dorsal fins
4. The circulii of the cycloid scales are used to determine the :
   (a) Nutrition value of fish　(b) Sex of fish
   (c) Viability of fish　(d) Age of fish
5. The epidermis in the skin of Rohu lacks :
   (a) Stratum corneum　(b) Stratum germinativum
   (c) Stratum laxum　(d) Stratum compactum
6. In Rohu homodont teeth are present in :
   (a) Buccal cavity　(b) Posterior pharyngeal chamber
   (c) Anterior pharyngeal chamber
   (d) Oesophagus
7. In Rohu stomach is :
   (a) U shaped　(b) J shaped
   (c) Cylindrical　(d) Absent
8. The air bladder in Rohu is connected to the roof of Oesophagus by :
   (a) Oesophageal duct　(b) Pharyngeal duct
   (c) Pneumatic duct　(d) Glandular duct
9. In Rohu gill rackers :
   (a) Prevent the entry of food into gill chambers
   (b) Promote the entry of food into gill chambers
   (c) Prevent regurgitation of food into buccal chamber
   (d) Promote regurgitation of food into buccal chamber

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (d) 8. (c) 9. (a)

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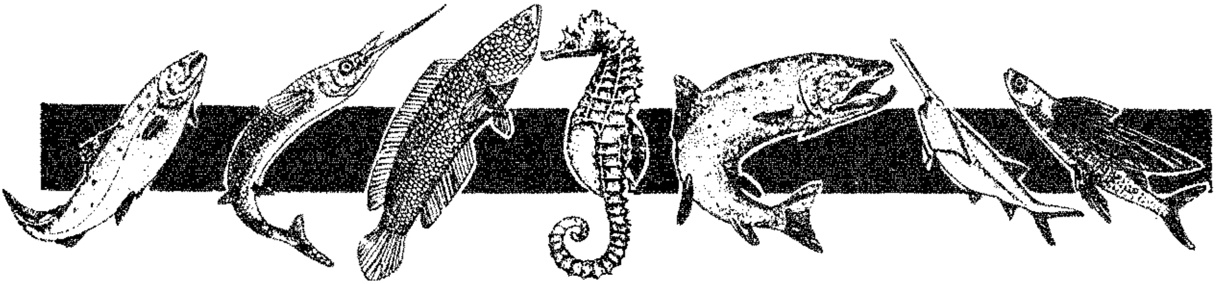

Class 5. Osteichthyes : The Bony Fishes

General Characters

1. Inhabit all sorts of water—fresh, brackish or salt; warm or cold.
2. Body spindle-shaped and streamlined.
3. Fins both median and paired, supported by fin rays of cartilage or bone. Tail usually homocercal.
4. Skin with many mucous glands, usually with embedded dermal scales of 3 types; ganoid, cycloid or ctenoid. Some without scales. No placoid scales.
5. Endoskeleton chiefly of bone (Gr., *osteon*, bone + *ichthyes*, fish). Cartilage in sturgeons and some others. Notochord replaced by distinct vertebrae. Pelvic girdle usually small and simple or absent. Claspers absent.
6. Mouth terminal or subterminal. Jaws usually with teeth. Cloaca lacking, anus present.
7. Respiration by 4 pairs of gills on bony gill arches, covered by a common operculum on either side.
8. An air (swim) bladder often present with or without duct connected to pharynx. Lung-like in some (Dipnoi).
9. Ventral heart 2-chambered (1 auricle + 1 ventricle). Sinus venosus and conus arteriosus present. Aortic arches 4 pairs. Erythrocytes oval, nucleated. Temperature variable (poikilothermous).
10. Adult kidneys mesonephric. Excretion ureotelic.
11. Brain with very small olfactory lobes, small cerebrum and well developed optic lobes and cerebellum. Cranial nerves 10 pairs.
12. Well developed lateral line system. Internal ear with 3 semicircular canals.

13. Sexes separate. Gonads paired. Fertilization usually external. Mostly oviparous, rarely ovoviviparous or viviparous. Eggs minute to 12 mm. cleavage meroblastic. Development direct, rarely with metamorphosis.

Classification

The class Osteichthyes includes a large assemblage of true bony fishes. There are well over 30,000-40,000 living species, both freshwater and marine. Some of the freshwater forms are the carp, perch, bass, trout, catfish, sucker, etc. Representatives of marine fishes are the tarpon, meckerel, tuna, sailfish, barracula, flying fish, etc. The classification of class Osteichthyes given below has been largely followed after A.S. Romer (1966) which has also been adopted by most authors including Storer and Usinger. However, several new schemes of classification, viz., Greenwood et. al., (1966), Lander and Liem (1983), Nelson (1984) and Pough et. al. (1989) is also known. Two subclasses are recognized : Sarcopterygii and Actinopterygii. Only important orders of each subclass have been included.

Subclass I. Sarcopterygii
(Gr., *sarcos*, fleshy + *pterygium*, fin)

1. Paired fins leg-like or lobed, with a fleshy, bony central axis covered by scales.
2. Dorsal fins 2. Caudal fin heterocercal with an epichordal lobe.
3. Olfactory sacs usually connected to mouth cavity by internal nostrils or *choanae*, hence the previous name of subclass, *Choanichthyes* (Gr., *choana*, funnel + *ichthyes*, fish).
4. Popularly called *fleshy* or *lobe-finned*, or *air breathing fish*. Divided into 2 superorders or orders : Crossopterygii and Dipnoi.

Order 1. Crossopterygii
(Gr., *crossoi*, a fringe + *pteryx*, fin)

1. Paired fins lobate. Caudal fin 3-lobed.
2. Premaxillae and maxillae present.
3. Internal nares present or absent. Spiracles present.
4. Air bladder vestigial.

Example : Primitive fleshy-finned extinct fishes. Single living genus *Latimeria*.

Order 2. Dipnoi
(Gr., *di*, *double* + *pnoe*, breathing)

1. Median fins continuous to form diphycercal tail.
2. Premaxillae and maxillae absent.
3. Internal nares present and spiracles absent.
4. Air bladder single or paired, lung-like.
   Examples : Lung fishes. Only 3 living genera : *Neoceratodus*, *Protopterus* and *Lepidosiren*.

Subclass II. Actinopterygii
(Gr., *actis*, ray + *pteryx*, fin)

1. Paired fins thin, broad, without fleshy basal lobes, and supported by dermal finrays.
2. One dorsal fin, may be divided.
3. Caudal fin without epichordal lobe.
4. Olfactory sacs not connected to mouth cavity.
5. Popularly called ray-finned fishes. Divided into 3 infraclasses or superorders : Chondrostei, Holostei and Teleostei.

Superorder A. Chondrostei
(Gr., *chondros*, cartilage + *osteon*, bone)

1. Mouth opening large.
2. Scales usually ganoid.
3. Tail fin heterocercal.
4. Primitive ray-finned fish or cartilaginous ganoids.

Order 1. Polypteriformes

1. Rhomboid ganoid scales and lobed pectoral fins.
2. Dorsal fin of 8 or more finlets.
3. Ossified skeleton.
   Example : *Polypterus* (Bichir).

Order 2. Acipenseriformes

1. Scaleless except for bony (ganoid) scutes.
2. Skeleton largely cartilaginous.
   Examples : *Acipenser* (Sturgeon), *Polyodon* (Paddlefish).

Superorder B. Holostei
(Gr., *holos*, entire + *osteon*, bone)

1. Mouth opening small.
2. Ganoid or cycloid scales.
3. Tail fin heterocercal.
4. Intermediate ray-finned fish, transitional between Chondrostei and Teleostei.

Order 1. Amiiformes

1. Thin, overlapping cycloid scales.
2. Snout normal, rounded.
3. Long dorsal fin.
   Example : *Amia* (Bowfin).

Order 2. Semionotiformes

1. Scales rhomboidal ganoid in oblique rows.
2. Snout and body elongated.
   Example : *Lepidosteus* or *Lepisosteus* (Garpike).

Superorder C. Teleostei
(Gr., *teleos*, complete + *osteon*, bone)

1. Mouth opening terminal, small.
2. Scales cycloid, ctenoid or absent.
3. Tail fin mostly homocercal.
4. A hydrostatic swim bladder usually present.
5. Advanced or modern ray-finned fishes.
6. Spiracle is lost.
7. Spiral valve in the intestine absent.
8. Conus arteriosus greatly reduced. There is an enlarged bulbus arteriosus.

Order 1. Clupeiformes

Scales cycloid. Head and operculum not scaled. Fins without spines. Tail fin homocercal. Pelvic fins abdominal. Air bladder with open duct to pharynx. No auditory vesicles. Weberian apparatus is lacking. *Clupea* (Herring), *Salmo* (Atlantic salmon), *Sardinops* (Pacific sardine), *Esox* (Pike), *Notopterus* (Chital fish).

Order 2. Scopeliformes

Deep sea forms with phosphorescent organs. Mouth wide with numerous minute teeth. Swim bladder absent. Dorsal and anal fins without spines. *Harpodon* (Mumbai duck).

Order 3. Cypriniformes or Ostariophysi

Air bladder with duct to pharynx. Weberian ossicles between air bladder and internal ear. Representatives of this order are grouped in two divisions— (i) Cyprini : Body may be scaleless. The scales when present are without bony plates. The third and the fourth vertebrae do not fuse with each other. (ii) Siluri : The body is naked reduced maxillary bone supports the barbells. Second, third, fourth and fifth vertebrae are generally fused. *Cyprinus* (Carp), *Labeo rohita* (Rohu), *Catla, Botia, Carassius* (Goldfish), *Clarius* (Magur), *Heteropneustes* or *Saccobranchus* (Singhi), *Wallago* (Lachi), *Mystus* (Tengra), *Electrophorus* (Electric eel).

Order 4. Anguiliiformes

Body long and slender, snake-like. Scales vestigial or absent. Dorsal and anal fins long and confluent. Pelvic fins, if present, abdominal. Air bladder with duct. *Anguilla* (Freshwater eel), *Muraena* (Moray).

Order 5. Beloniformes or Synentognathi

Scales cycloid. Pectoral fins large and high on body. Ventral fins are shifted to abdominal sides *Exocoetus* and *Cypselurus* (Flying fishes), *Hemirhamphus* (half beak), *Belone* (garfish).

Order 6. Syngnathiformes or Solenichthyes

Protective scales or bony rings on body. Snout tubular with suctorial mouth. Swim bladder closed. Males possess brood pouch for the development of the young. *Hippocampus* (Sea horse), *Syngnathus* (Pipe fish), *Fistularia* (Flute fish).

Order 7. Ophiocephaliformes or Channiformes

Head depressed with plate-like scales. Air bladder long and without duct. Accessory respiratory organs present. *Ophiocephalus* or *Channa* (Snake head).

Order 8. Symbranchiformes

Body elongated, eel or snake-like. Gill slits join to form a transverse ventral slit. Paired fins, fin rays and air bladder lacking. *Amphipnous, Symbranchus* (Eels).

Order 9. Mastacembeliformes

Body eel-like. Free spines in front of dorsal fin. Nostrils on tubular tentacles at end of snout. Dorsal, caudal and anal fins become united to form a continuous fin, but in *Macrognathus* caudal fin has separate entity. *Mastacembelus, Macrognathus.*

Order 10. Perciformes or Percomorphi

Fin spines present. Dorsal fins 2. Weberian apparatus absent. Air baldder without duct. *Anabas* (Climbing perch), *Perca* (Yellow perch), *Lates* (Bhetki).

Order 11. Scorpaeniformes

Enlarged heads and pectoral fins. Projecting spines from gill covering. *Pterois* (Scorpion fish).

Order 12. Pleuronectiformes

Bottom dwellers. Body flat, lying on one side. Head asymmetrical, both eyes present on upper or dorsal side. Swim bladder absent. Dorsal and anal fins fringing body. Flatfishes : *Pleuronectes, Synaptura, Solea.*

Order 13. Echeneiformes or Discocephali

First dorsal fin forms a flat oval adhesive disc or sucker on head. Scales cycloid. No Air bladder. *Echeneis* or *Remora* (Sucker fish).

Order 14. Tetraodontiformes or Plectognathi

Strong jaws with a sharp beak. Scales often spiny. Some inflate by swallowing water. *Diodon* (Porcupine fish), *Tetrodon* (Globe fish), *Ostracion* (Trunk fish).

Order 15. Lophiiformes or Pediculati

First of a few dorsal flexible spines with a bulblike tip over head to lure prey into wide mouth. Luminescent organs present. *Lophius* and *Antennarius* (Angler fishes).

Other Osteichthyes

The class Osteichthyes of bony fishes is truly the most successful group of aquatic vertebrates. It includes the dominant fishes of seas today. No other group surpasses them in evolutionary diversity and nowhere else do we see better example of adaptive radiation. There are probably 30,000–40,000 living species of bony fishes. Of these, the superorder Teleostei, comprising about 20,000 described species, constitutes perhaps the single largest group of living vertebrates. For convenience, these fishes may be considered into 4 groups as under :

[I] Lobe-finned fish

Latimeria. Crossopterygians or lobe-finned fish are now represented only by fossils. They were very dominant in Devonian times about 280 million years or more ago and became extinct by the end of Cretaceous. However, several living specimens of a specialized side branch, the coelacanths, have been found in recent years since 1938 near Comoro Islands between Africa and Madagascar. Dr. J.L.B. Smith of Rhodes University named this "living fossil" *Latimeria chalumnae*. The generic name was given in honour of Miss Courteny Latimer, curator of East London Museum (S. Africa), who recognized it as unusual. The specific name refers to the first site of capture, offshore the mouth of Chalumna river of South Africa. *Latimeria* is steely blue-grey with irregular white spots and highly reflective golden eyes. Size ranges from 0.75 to slightly over 2 meters. The scales have hollow tubercles, overlap each other to form a strong, thick protective covering. The anteriorly situated first dorsal fin is unlobed and caudal fin is diphycercal with distinct 3 lobes. Notochord is unconstricted, vertebral column is cartilaginous, but both neural and haemal spines are ossified. Spines present at the back of fish have coelome, thus the name Coelocanth is given. Like Osteolepids, skull has movable hinge between parietals and post parietals. Below the lower jaw a pair of bony plates called gular plates are found.

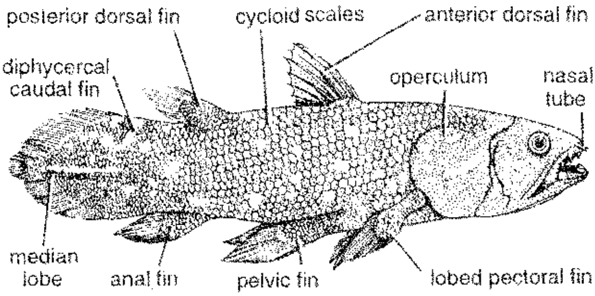

Fig. 1. *Latimeria chalumnae*. The living coelacanth.

Gill arches are 5. Internal nostrils are absent. Alimentary canal consists of muscular oesophagus, followed by a well developed stomach having gastric glands. Intestine is along tube having spiral valve. It opens into rectum, opening into cloaca. Rectal gland is present. Liver is bilobed, with large gall bladder. Pancreas is present. Near its well-developed olfactory capsules are present a pair of sac-like rostral organs opening to the surface through a series of six pores. They are perhaps electroreceptors. They have a well ossified internal skeleton and small conical teeth suited for seizing prey. Kidneys are fused and are attached to the ventral wall of abdominal cavity which is peculiar. Each kidney has a ureter which enlarges to form a bladder. In this way two urinary bladders are present. A pair of testes lies posterior to anus. Urinogenital opening is situated between pelvic fins. Copulatory organs are absent. Fertilization is internal. In the absence of claspers how male *Latimeria* achieve copulation is unknown. Among degenerate characters are more cartilaginous parts and calcified or vestigial swim bladder. There are evidences to show that the crossopterygians were not only ancestral to all bony fish, but they also gave rise to the earliest amphibians and other vertebrates that were to master the land (Fig. 1).

Zoological significance of crossopterygii. The crossopterygians were dominant fishes of fresh water in Devonian period. By the end of the Palaeozoic, most were extinct. One branch, the coelacanth, persisted through Mesozoic as large predaceous marine fishes, to become finally extinct in Cretaceous. With the exception of the sole living coelacanth, *Latimeria*, which was discovered in 1938 off the coast of South Africa, crossopterygians are all extinct now. They are of special interest because of their resemblance to amphibians :

(1) The skeletal elements of paired fins lobes resem.led the proximal skeletal elements of tetrapod limbs.

(2) Skull was similar to that of earliest amphibians.

(3) Freshwater forms migrated from one body of water to another because they could use their air bladders like lungs.

(4) Many had internal nares piercing the roof of mouth cavity, although not meant for breathing.

Because of these and other morphological traits, one group of extinct Crossopterygii, the freshwater carnivorous rhipidistians, are believed to have given rise to the earliest amphibians. There is evidence to show that this group was ancestral not only to Amphibia and all bony fishes, but also to all higher terrestrial vertebrates.

[II] Lung-fish

The Dipnoi, commonly known as *lung fish*, are considered to be specialized or degenerate descendants of the more primitive lobe fins which they closely resemble. They were once supposed to be the ancestors of the amphibians, a view no longer held. They are large, bizarre fishes represented only by three living genera and furnishing an example of *discontinuous distribution*. In all three, the air bladder serves functionally as a lung by which they can breathe air when necessity arises. The endangered monotypic Australian lungfish, *Neoceratodus* (=*Epiceratodus*) *forsteri*, restricted to fresh waters, attains a length of 1.5 meters or more. It has a single lung (Monopneumona) and cannot survive out of water. The monotypic South American lungfish is *Lepidosiren paradoxa*, while the African lungfish, *Protopterus*, has four or so related species. These two genera have weekly developed gills so that they will drown if prevented from using their paired lungs

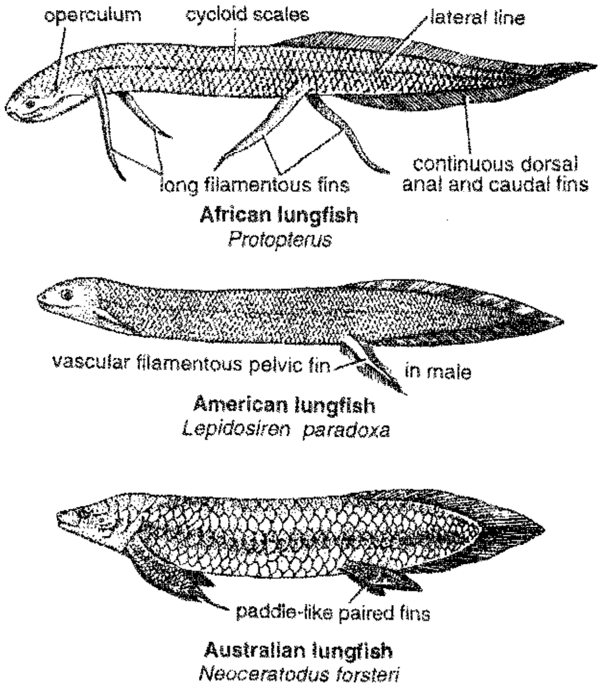

Fig. 2. Lung fishes (Dipnoi).

(Dipneumona). They live on mudy swamps or marshes. During drought, when the marshes dry up, they aestivate by secreting mucous cocoons in mud, in which they become dormant and breathe atmospheric air through burrow openings. These 1 to 2 meters long, elongated, eel-like or snake-like forms have unique filamentous but highly mobile paired appendages. Lungfishes are mostly cartilaginous. They have specialized crushing tooth plates to feed effectively upon shell fish. Their embryogeny is more primitive than that of other living bony fishes. Cleavage of eggs is holoblastic and gastrulation occurs by invagination. Their tadpole like larva has external gills as accessory respiratory structures (Fig. 2).

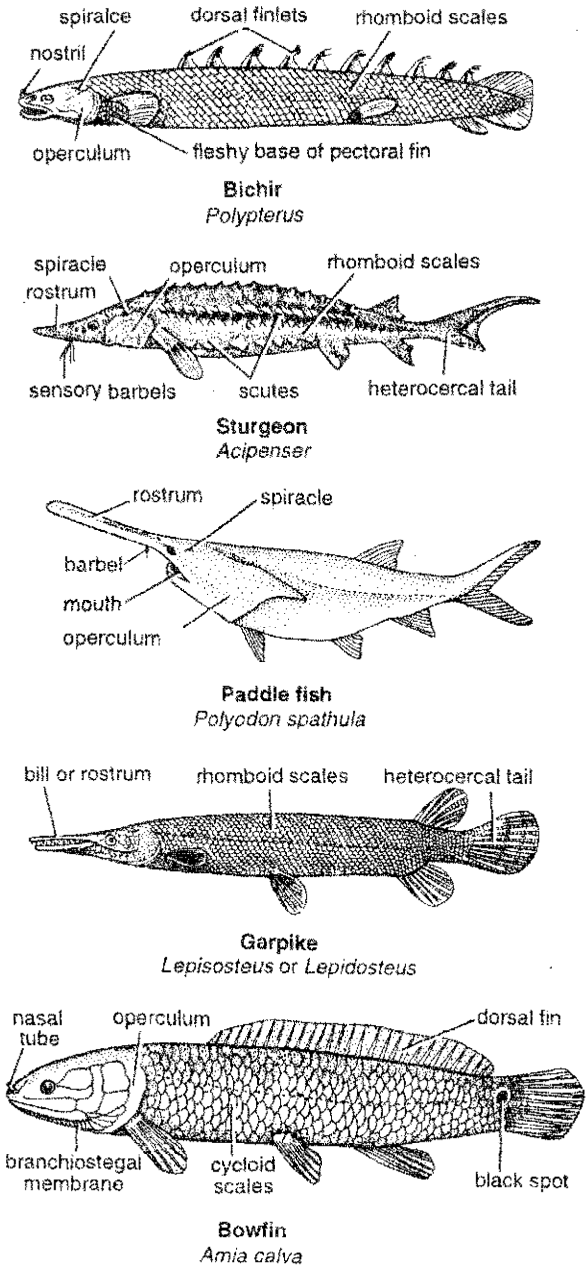

Fig. 3. Ganoid fishes (Chondrostei and Holostei).

[III] Ganoid fish

The actinopterygians belonging to the superorders Chondrostei and Holostei are known as *ganoid fish*. They are all characterized by having scales covered with an enamel-like *ganoin* and heterocercal tail fin.

Polypterus. The bichirs, represented by species of *Polypterus* and *Calamoichthys*, are restricted to the rivers of Africa. These small (less than 1 meter) fishes probably are the most primitive living actinopterygians. Their pectoral fins with fleshy bases are used as supporting limbs. The caudal fin has secondarily become homocercal. Skeleton is well ossified and intestine has a spiral valve. Dorsal fin is divided into a series of separate finlets, each with a single supporting bony ray. Body surface is well armoured with thick, interlocking, multilayered ganoid scales. The paired ventral air bladders serve as lungs. The larva resembles the tadpole of Amphibia.

Acipenser. The chondrosteans or cartilaginous ganoids are represented by *sturgeons* and *paddle fishes* which are skeletally degenerate or specialized forms. The tail is elongate and heterocercal. The skeleton is largely cartiliginous and the intestine has a spiral valve. They have a fish like air bladder with a dorsal connection to oesophagus. Mouth is ventral and all species have sensory barbles on the undersurface of rostrum. Sturgeons (*Acipenser*) are probably the most successful chondrosteans because of their gigantic size (1 to 6 meters). About 23 species are found only in the Northern Hemisphere. They are either anadromous (ascending into fresh waters to breed) or entirely freshwater in habitat. Body surface is covered by five longitudinal rows of separate bony plates. The snout is greatly elongated into a shovel-like rostrum. Sturgeons are commercially important both for their rich flesh and as a source of the best caviar.

Polyodon. Paddle fishes or spoonbills (*Polyodon*) are large bizarre fishes (2 metres) with an intriguing geographical distribution. Of the two species, one occurs in the Yantze River valley of China, the other in Mississippi River valley of North America. Skin is naked. Bony scutes are absent and ganoid scales are present only on the upper lobe of the tail. The most outstanding feature is the great elongation of snout into a flat oar-like rostrum. Contrary to the common belief that this paddle or shovel-like rostrum is used to stir food from muddy river bottom, paddlefishes are planktivores.

Lepisosteus. The holosteans or bony ganoids are represented by only 2 genera, *Lepisosteus* and *Amia*, both confined to North America. Holosteans are closely related to the teleosts and are clearly transitional in some characters to higher fishes. They have complex scales covered with ganoin but lack all the layers of the chondrostean scale. The scales of trunk are arranged in oblique rows. Skeleton is more complex and completely ossified. Caudal fin is short but distinctly heterocercal. The dorsal and paired air bladder, functions as an effective lung. Seven species of gars (*Lepisosteus* or *Lepidosteus*) are medium to large (1 to 4 metres), powerful, predaceous fishes of fresh or estuarine waters, feeding on other fishes. The body has a solid covering of ganoid scales. Snout is elongated and the jaws bear needle-like teeth.

Amia. The single species of bowfin, *Amia calva*, is another large (0.5 to 1 metre), powerful, predatory freshwater fish of North America. It shows approach to the teleosts in many respects. The head skeleton and scales are simplified and tail is almost homocercal. Scales are cycloid. Air bladder is cellular. Intestine has spiral valve. Two peculiar comb like structures are found on the throat. It moves by undulations of body and the long dorsal fin. Like gars, it can breathe air through air bladder in oxygen-deficient water (Fig. 3).

[IV] Advanced ray-finned bony fishes

The superorder Teleostei is the largest and the most diverse group including advanced ray-finned bony fishes (Figs. 4 & 5).

Salmo. Commonly called *salmon* or *trout*, belongs to the family Salmonidae of the order Clupeiformes. A freshwater and marine fish found in temperate and arctic zones of Northern Hemisphere. Introduced in Kashmir and Nilgiris. A small adipose fin on back. Much prized for food and game.

Notopterus. Family Notopteridae, order Clupeiformes. *N. chitala* throughout India in rivers and tanks. 1.5 meters in length. Body much compressed. Scales very small. Lateral line distinct. Tail tapering. Anal fin long and united with caudal. Dorsal fin short.

Clarias. Family Claridae, Order Cypriniformes. Common name *magur. C. batrachus* in fresh and salt waters in India. Dorsal and anal fins long but separate from caudal. Pectoral fin with a pungent spine. Scales absent. 4 pairs of barbels. Dendritic accessory respiratory organs dorsal to gills. Highly nourishing and esteemed as food.

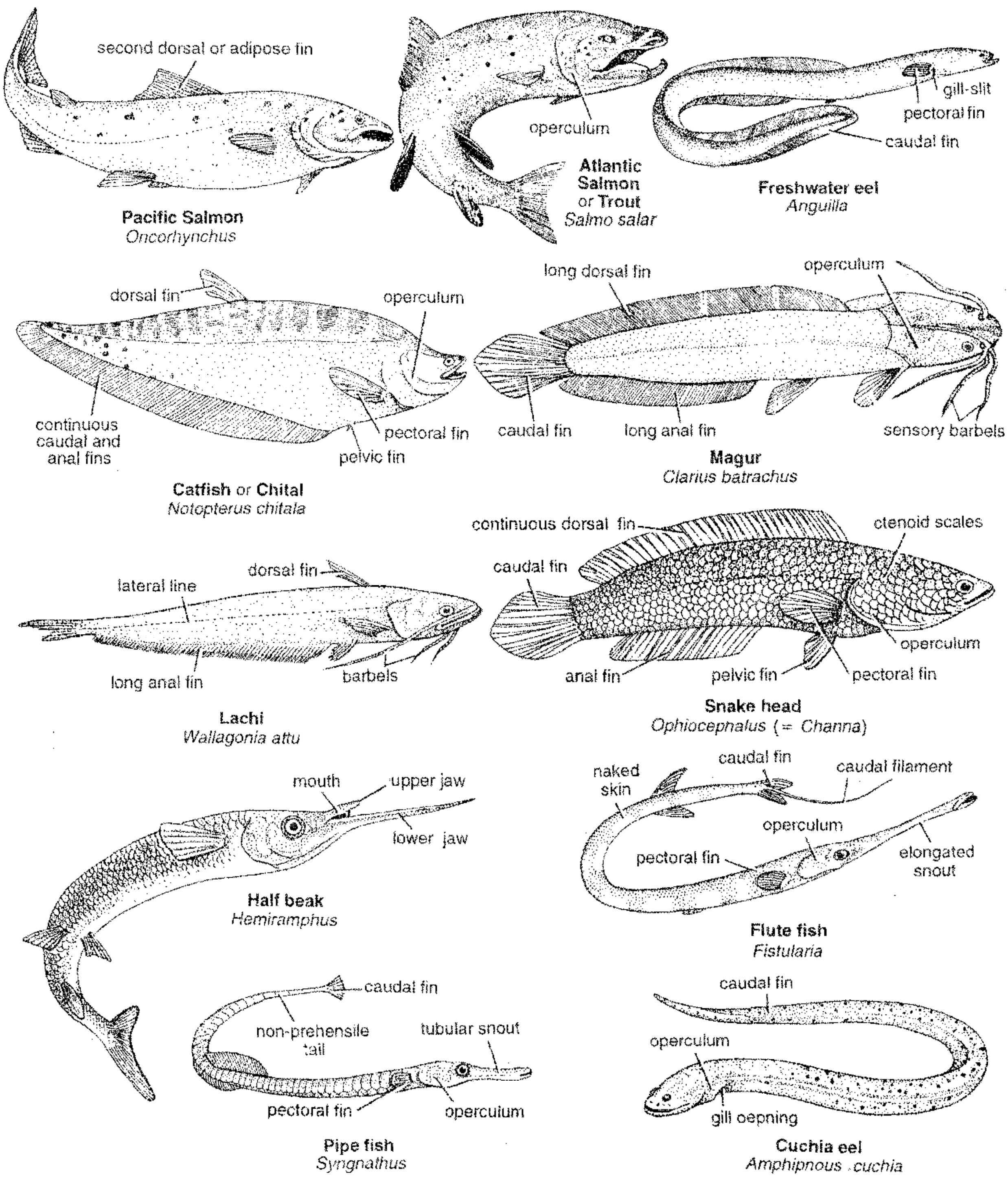

Fig. 4. Ray-finned fishes (Teleostei).

***Heteropneustes* (=*Soccobranchus*).** Family Heteropneustidae, order Cypriniformes. Common name *singhi*. *H. fossilis* found in India, Pakistan and Sri Lanka. Body elongated, grey and devoid of scales. Dorsal fin small, anal fin continuous with caudal. Pectoral fin with a spine. 8 barbels. Frequently breathe air from water surface with an accessory respiratory tube. Considered highly nutritious.

***Wallagonia* (=*Wallago*).** Family Siluridae, order Cypriniformes. *W. attu* common throughout India in fresh waters. Common names *lachi*, *mullee* or *boalli*. Skin scaleless, Dorsal fin small. Anal fin long but not joining caudal. Barbels 2 pairs.

***Anguilla*.** Family Muraenidae, order *Anguilliformes*, Common name *eel*. *A. bengalensis* common throughout India is similar to European (*A. vulgar*) and American (*A. rostratus*) eels. It lives in marshes and is a foul feeder. Body is slender, elongated (1.2 meters) and snake like. Skin has rudimentary scales. Pectoral fins present, pelvic fins absent. Dorsal and anal fins continuous with caudal. Adults migrate to sea in autumn, spawn in deep water and die. Delicate transparent pelagic larvae, called *leptocephali* or *glass fishes*, feed and grow in sea for 2 or 3 years, then enter the rivers and undergo metamorphosis to become adults.

***Amphipnous*.** Family Amphipnidae, order Synbranchiformes *A. cuchia*, also known as *eel*, lives in Bengal in marshes near coasts. Body elongated (1 meter), eel-like. Scales minute. Paired fins absent. Dorsal and anal fins continuous with caudal, rudimentary and without fin rays. Only one midventral gill slit. Scattered round black spots and short yellow lines on body which is dark green above and dirty pale red below. No swim bladder. A pneumatic sac on either side of branchial chamber functions as lung.

***Ophiocephalus* (=*Channa*).** Family Ophiocephalidae, order Ophiocephaliformes. *O. punctatus* and *O. striatus* common throughout India in freshwater ponds, ditches, etc. Common name *lata* in W. Bengal. Head snake-like, triangular with a pointed snout, hence called snake-headed fish. Dorsal and anal fins long but not continuous with caudal. Pelvic fins below pectorals. Lateral line interrupted. Body scales ctenoid. Fish migrates from one pond to another and breathes air by special suprabranchial cavities serving as lungs. Eaten mostly by poor classes.

***Hemirhamphus*.** Family Hemirhamphidae, order Beloniformes. Found in rivers and ponds of W. Bengal and Orissa. Length of the genus extends upto 30 cm. The colour of the body is greenish blue above with silvery band on the sides. Called half-beaked fish. Lower jaw (dentaries) projected beyond the upper jaw, both having pointed teeth.

***Exocoetus*.** Family Scombresocidae, order Beloniformes. *Exocoetus* and *Cyselurus* inhabit tropical and subtropical regions of Atlantic, Pacific and Indian Oceans. Commonly called *flying fish*. Size 30 to 45 cm. Scales large, cycloid. Eyes large. Dorsal fin opposite the anal fin. Large wing-like pectoral fins. Fish takes a leap with the powerful tail and glides for a few metres in air sustained by large pectoral fins. True flight not possible. Carnivorous. Excellent food fish.

***Hippocampus*.** Family Syngnathidae, order Syngnathiformes. Occurs in tropical and temperate seas including Indian Ocean. Size variable (5 to 20 cm). Head large at right angle to body and produced into a tubular snout, thus resembling the head of a horse, hence the common name *sea-horse*. Body enclosed in an armour of bony plates. Mouth toothless and suctorial. Pectoral fins just behind opercula, small and transparent. Pelvic, ventral and caudal fins lacking. Tail long, prehensile and coiled around sea-weeds, etc. for attachment. Gills lophobranchs made of several small rounded lobes. Operculum is large, plate like structure. Muscles are feebly developed. Swims feebly and vertically with the help of vertical fin. Sexual dimorphism displayed. On the belly of male is a brood pouch for incubating eggs. On the belly of female is a small anal fin.

***Syngnathus*.** Family Syngnathidae, order Syngnathiformes. Found in warm seas and called *pipe fish* because of eel-like elongated body about 45 cm long. Structure and habits similar to those

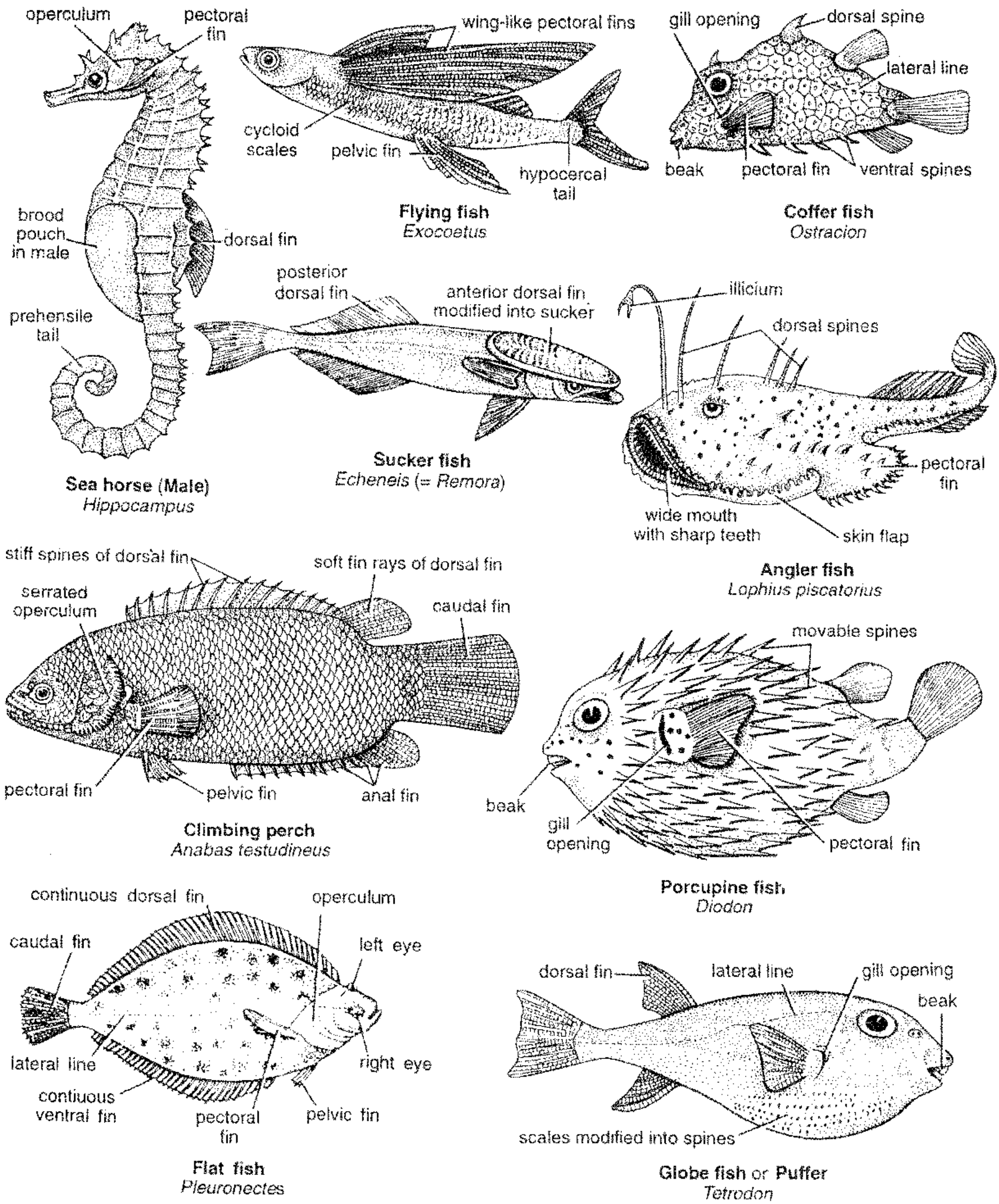

Fig. 5. (Continued). Ray-finned fishes (Teleostei).

of *Hippocampus*, except that tail is non-prehensile and carries a small caudal fin. Scales are transformed into ring like plates covering the body. Males possess brood pouch.

Fistularia. Found in tropical and temperate waters from Africa to China. Occurs in coastal waters of Channai. Commonly called *flute fish* because of slender elongated eel-like body and long tubular snout. Skin naked. Mouth small, narrow with minute teeth. Caudal fin present with middle caudal ray much elongated and supported by horny rays.

Anabas. Family Anabantidae, order Perciformes. Occurs in rivers of India and South-East Asia. Common name *climbing perch*, Koi fish in W. Bengal. Body laterally compressed, 20 cm long and covered with cycloid scales. Lateral line interrupted. Fins well-developed. Each of dorsal and anal fins made of a long anterior part supported by stiff spines and a small posterior part bearing soft fin-rays. Preorbitals and opercular serrated. Gill openings rather narrow. Accessory respiratory organs of thin laminae in supra-branchial chambers, for breathing atmospheric air. Travels on land by fins and opercular spines. Can live outside water for several days. Contrary to popular belief, it can not climb up the trees.

Pleuronectes **or** ***Synaptura.*** Family Pleuronectidae, order Pleuronectiformes. Marine, bottom-dwellers in which asymmetrical body is stronglly compressed laterally to become flat, hence the common name *flat fish*. Under surface usually right side and unpigmented, while upper surface or left side is pigmented. Both eyes present on upper side. Body covered with imbricate, ctenoid or cycloid scales. Dorsal and anal fins long, spineless and fringing the body. Caudal fin is well developed. Pectoral fins are small and placed high up laterally. Air bladder is lacking in adult. Mouth narrow. Swims by undulating movements and feeds on molluscs. Newly hatched young are symmetrical with pigmentation and eyes on both sides. Edible and commercially important.

Common flat fishes of Indian coasts are *Pleuronectes* or *Synaptura, Psettodes, Zebra* and *Solea*. In the primitive flat fish (*Psettodes*) some individuals have eyes on both sides. Solea has a small separate caudal fin. In *Zebra* flat fish body is banded and the small caudal fin is continuous with dorsal and anal fins.

Echeneis **or** ***Remora.*** Family Echeneidae, order Echeneiformes. Marine tropical fish commonly called *remora* or *sucker fish*. Size upto 50 cm. Scales minute, Head depressed and its upper surface bears a large, flat, oval adhesive disc or *sucker* made by two rows of transverse lamellae. Sucker represents modified anterior dorsal fin. Fish usually carried from place to place attached to body of larger fishes, whales, turtles, boats, etc. Natives capture sea turtles and fishes with a remora tied with a cord. Remora eats smaller fishes.

Tetrodon. Family Tetrodontidae, Order Tetraodontiformes. Coastal waters and estuaries of Indian rivers. Commonly called *globe fish* or *puffer*. Shape round or globose when taken out of water, it inflates suddenly with air like a balloon and a sound is emitted by forceful expulsion of air from oesophagus. Scales modified into small spines, especially on ventral side. Mouth narrow, Teeth fused to form beak. Eyes large and protruding. Pelvic fins lacking. Contains a powerful alkaloid poison called *tetrodotoxin*. Used in lung infection in Japan. *Tetradon cutcutia* and *T. patoca* are two typical Indian fishes.

Diodon. Family Diodontidae, order Tetraodontiformes. Similar to *Tetrodon* in structure and habit. Body uniformly covered by large movable spines for defence, as in a porcupine, hence the common name *porcupine fish*. Occurs from Red Sea through Indian seas to Pacific Ocean.

Ostracion. Family Ostraciontidae, order Tetraodontiformes. Shallow coastal waters of

Tropical seas including Indian Ocean. Body roughly triangular and encased in a carapace or armour of hexagonal bony plates, hence the common name *trunk fish* or *coffer fish*. Due to presence of two horn-like supraorbital spines also known as *cow fish*. Rest of structure and habits similar to other tetrodons (*Tetrodon, Diodon*).

Lophius. Family Lophiidae, order Lophiiformes. On bottom of Atlantic coasts of N. America and Europe. Commonly called *angler fish, frog fish, devil fish*, etc. *Lophuis piscatorius* grows to 1.5 meters. Body ugly-looking, dorso-ventrally compressed. Skin leathery, Scaleless. Head and anterior trunk portion large. Eyes dorsal. Mouth a wide gape with sharp recurved teeth covered by a pigmented skin fold for camouflage. Dorsal fin spinous with few long isolated flexible rays in front. First ray or spine on head with a fleshy mass or bait at tip (illicium) to lure prey into mouth. Small skin flaps fringing the body mimic leaves of aquatic plants. Broad pediculate pectoral fins used to move on bottom. In some deep sea species, a dwarf male remains permanently attached to the head of female.

Cave fishes. Some fishes can live even in caves there is neither light nor food. They are well adopted to their environment and modes of life. Besides fish, other animal species are also found in the caves but the fishes form the largest number of cave dwellers. Such fishes are *Grovias migrilabris, Cholagaster cornium Typhlichthyes subterraneus, Amblyopsis spalaeus* and *Amiturus nigrilabris*. Eyes in these fishes are either very much reduced or they are blind. The absence of eye is compensated by the presence of tectile organs. In *Amplyopsis spalaeus*, taste buds are found all over the head region. The sense of smell is also increased in cave fishes. Since they are not sensitive to light and sound waves but they respond to ordinary vibrations. Due to scarcity of food the organs of digestion and modified to utilize all the nutrients of food.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give characters and classification of the class Osteicthyes with important features of each group.

» *Short Answer Type Questions*

1. Give the zoological significance of Crossopterygii.
2. Write short notes on — (i) Climbing perch, (ii) *Anguilla*, (iii) Dipnoi, (iv) *Echeneis*, (v) Flying fish, (iv) *Hippocampus* (sea horse), (vii) *Latimeria*.

» *Multiple Choice Questions*

1. Tail in bony fishes is usually :
   (a) Homocercal (b) Heterocercal
   (c) Hypocercal (d) Hypercercal
2. Cloaca in bony fish is :
   (a) Single (b) Lacking (b) One pair (d) Two pairs
3. Aortic arches in Osteicthyes are :
   (a) 2 pairs (b) 3 pairs (c) 4 pairs (d) 5 pairs
4. Excretion in class Osteictheys is :
   (a) Ammonotelic (b) Aminotelic
   (c) Uricotelic (d) Ureotelic
5. Internal ears of bony fishes possess :
   (a) 3 semicircular canals
   (b) 2 semicircular canals
   (c) 1 semicircular canal
   (d) 0 semicircular canal
6. Subclass Sarcopterygii includes :
   (a) Cat fishes
   (b) Lobe finned fishes
   (c) Snake like fishes
   (d) Ray finned fishes

7. Lung fishes are included in the order :
   (a) Cropterygii (b) Polypteriformes
   (c) Dipnoi (d) Acipenseriformes
8. Members of super order Chondrostei possess
   (a) Placoid scales (b) Cycloid scales
   (c) Ctenoid scales (d) Ganoid scales
9. *Fistularia* is commonly known as :
   (a) Flute fish (b) Sword fish
   (c) Dog fish (d) Saw fish
10. Pipe fish is the common name of :
    (a) *Hippocampus* (b) *Syngnathus*
    (c) *Anabas* (d) Remora
11. *Tetrodon* is commonly known as :
    (a) Cow fish (b) Devil fish (c) Puffer (d) Cave fish
12. Cow fish is the common name given to :
    (a) *Lophius*
    (b) *Tetrodon*
    (c) *Diodon* (d) *Ostracion*

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d)

18

Superclass Pisces and Fish : General

The superclass *Pisces* (L., *piscis*, fish) of the truly jawed vertebrates (Gnathostomata) includes all the fishes which are essential aquatic forms with paired fins for swimming and gills for respiration.

General Characters of Superclass Pisces

1. Aquatic, marine or freshwater, herbivorous or carnivorous, cold-blooded, oviparous or ovoviviparous vertebrates.
2. Body usually spindle-shaped, streamlined and differentiated into head, trunk and tail. A neck is absent.
3. Locomotion by paired pectoral and pelvic fins along with median dorsal and caudal fins, supported by true dermal fin rays. Muscular tail used in propulsion.
4. Exoskeleton of dermal scales, denticles or bony plates covering body surface.
5. Endoskeleton cartilaginous or bony. Jaws are hinged. Notochord more or less replaced by true vertebrae.
6. Muscles arranged into segments called myotomes, with separate dorsal and ventral parts.
7. Alimentary canal with definite stomach and pancreas and terminates into cloaca or anus.
8. Respiration by gills. Gill-slits 5 to 7 pairs, naked or covered by an operculum.
9. Heart 2-chambered (1 auricle, 1 ventricle) and venous or single circuit. Sinus venosus and renal and portal systems present. Erythrocytes nucleated. Poikilothermous.
10. Kidneys mesonephric. Excretion ureotelic.
11. Brain with usual 5 parts. Cranial nerves 10 pairs.
12. Paired nasal sacs do not open into mouth. Tympanic cavity and ear ossicles lacking. Internal ear with 3 semicircular canals. Lateral line system well developed.
13. Sexes separate. Gonads typically paired. Gonoducts open into cloaca or independently.
14. Fertilization internal or external. Female oviparous or ovoviviparous. Eggs large with much yolk. Extraembryonic membranes absent. Development usually direct without or with little metamorphosis.

Classification of Superclass Pisces

About 40,000 species of fishes are known. Various workers have provided different schemes of their classification. However, no classification has been universally accepted because of the confusion due to staggering numbers of fishes and great diversity in their shape, size, habits and habitat. Mueller (1844) was pioneer who gave first scientific classification of lower vertebrates. He divided fishes into six subclasses viz., 1. Dipnoi, 2. Teleostei, 3. Ganoidae, 4. Elasmobranchi 5. Marshipobranchi and 6. Leptocardii. He included cyclostomes in Marshipobranchi and

Table 1. **Comparison of Chondrichthyes and Osteichthyes.**

Characteristic	Chondrichthyes (cartilaginous fishes)	Osteichthyes (bony fishes)
1. Habitat	Mostly marine	Both marine and freshwater
2. Shape	Usually dorso-ventrally flattened	Usually bilaterally flattened
3. Caudal fin	Heterocercal	Homocercal or diphycercal
4. Pelvic fins	Usually posterior. In male form claspers for transferring sperms into genital tract of female	Usually anterior, sometimes posterior. Claspers absent. Whenever present not formed by pelvic fins
5. Mouth opening	Ventral on head. Large and crescentic	Terminal on head. Variable in shape and size
6. Gill openings	Usually 5 pairs of naked gill slits. No operculum	5 pairs of gill-slits covered by a lateral flap of skin called operculum, so that a single gill opening on either side
7. Spiracles	Usually 1st gill slit become spiracles which open just behind eyes	Spiracles are lacking
8. Cloaca	Between two pelvic fins lies midventrally common cloacal opening for alimentary, urinary and genital products	Cloaca absent. Anus and urinary and genital apertures open separately
9. Exoskeleton	Separate dermal placoid scales	Overlapping dermal cosmoid, ganoid, cycloid or ctenoid scales
10. Endoskeleton	Wholly cartilaginous	Mostly bony
11. Jaw suspension	Hyostylic	Hyostylic and autostylic
12. Stomach	Typically J-shaped	Shape variable. Absent in some
13. Intestine	Short and with an internal fold or scroll valve in lumen	Long and without scroll valve
14. Rectal gland	Present	Absent
15. Liver	Generally has 2 lobes	Generally has 3 lobes
16. Type of gills	Lamellibranch with long interbranchial septum	Filiform with reduced interbranchial septum
17. Air (swim) bladder	Absent	Usually present
18. Conus arteriosus	Present in hert	Absent
19. Afferent branchial vessels	5 pairs from ventral aorta to gills	Only 4 pairs
20. Efferent branchial vessels	9 pairs	4 pairs
21. Brain	Primitive with larger olfactory lobes & cerbrum and smaller optic lobes and cerebellum	Advanced with smaller olfactory lobes and cerbrum and larger optic lobes and cerebellum
22. Restiform bodies	Present in brain	Absent
23. Ductus endolymphaticus	Open on top of head	Do not open to exterior
24. Retina	Lacks cones	Cones present
25. Accommodation of eye	Lens moved forward by protractor lentis muscle	Lens moved back by retractor lentis muscle
26. Ampullae of Lorenzini	Present	Absent
27. Male genital duct	Connected to anerior genital part of kidney	Not connected with kidney
28. Oviducts	Not connected to ovaries	Connected to ovaries
29. Urinary and genital apertures	United and urinogenital apertures lead into common cloaca	Separate and open independently to exterior
30. Fertilization	Internal	External in water
31. Eggs	Few, large with much yolk	Numerous, small with less yolk
32. Development	Internal in ovoviviparous types. Externally inside egg cases in oviparous types	Usually external without an egg case

Cephalochordates in Leptocardii. Subsequently, cyclostomes were separated and placed in a class Myzontes by Agassiz. Later, noteworthy additions were made by workers like Boulenger (1904), Regan (1906), Jordan (1923) and Goodrich (1930). Perhaps the earliest best known scheme of classification was provided by Berg (1940) who recognized seven classes of fishes as follows :

Class 1. Pterichthys	
Class 2. Coccostei	Extinct
Class 3. Acanthodii	fishes
Class 4. Elasmobranchii	
Class 5. Holocephali	
Class 6. Dipnoi	Living
Class 7. Teleostomi	fishes
Subclass 1. Crossopterygii	
Subclass 2. Actinopterygii	

Romer (1959) included Elasmobranchii and Holocephali as subclasses into a single class *Chondrichthyes* for all cartilaginous fishes. Similarly he put all bony fishes (Dipnoi, Teleostomi) under a single class *Osteichthyes*, which he divided into two subclasses : Sarcopterygii and Actinopterygii. Parker and Haswell (1960) have further combined all the extinct jawed fishes under a single class : *Placodermi* or *Aphetohyoidea*. This simple division of superclass Pisces only into three classes—Placodermi, Chondrichthyes and Osteichthyes—has been followed more or less by all the eminent authors. In our text we have also adopted this scheme with slight modifications because of its simple and direct approach to our readers, while ignoring its other merits and demerits.

Dipnoi

The dipnoans, belonging to the order Dipnoi of the subclass Sorcopterygii of Osteichthyes, are generally called "lung fishes". The name Dipnoi (Gr., *di*, two + *pnoe*, breathing) means double breathers", as they respire through gills as well as lungs.

[I] Distribution

Fossil dipnoans appeared in mid-Devonian, probably as an offshot of the crossopterygian stem. They flourished moderately in Permian and Triassic and later became rare. The earliest recorded fossil lungfish is *Dipterus* of mid-Devonian. From this genus, dipnoan evolution led directly to the Triassic form *Ceratodus*, having a wide distribution over earth. Dipnoans have remained conservative and changed very little since that time (Fig. 1).

There are only 3 living genera of lung fishes, one in each of the 3 continents of the Southern Hemisphere.

1. ***Neoceratodus*** **(=*Epiceratodus*).** Single species *N. forsteri* found in Burnett and Marry rivers in Queensland (Australia). A direct descendant of ancient lungfish. Attains a length of 1.5 meters and a weight of 45 kg.

2. ***Protopterus*****.** 4 or so species in certain lakes and rivers of tropical africa (rivers Senegal, White Nile and Zambesi and take Tanganayika). Grow up to 1 or 2 metres and weigh about 40 kg.

3. ***Lepidosiren*****.** Single species *L. paradoxa* in river Amazon and its tributaries of tropical South America.

[II] Habits and habitat

Lungfishes are large, bizarre fishes, inhabiting semipermanent freshwaters and swamps in Africa, S. America and Australia. They probably survive because they live in habitats where no actinopterygians can successfully compete. All can survive extremely stagnant waters, periodically coming to the surface and gulping air into their lungs. *Neoceratodus* respires exclusively via gills and uses its single lung only under stress. *Lepidosiren* and *Protopterus* have weakly developed gills and will drown if prevented from reaching the surface to use their paired lungs. All are sluggish bottom dwellers and predaceous carnivores feeding on worms, molluscs, crustaceans, frogs, small fishes and even members

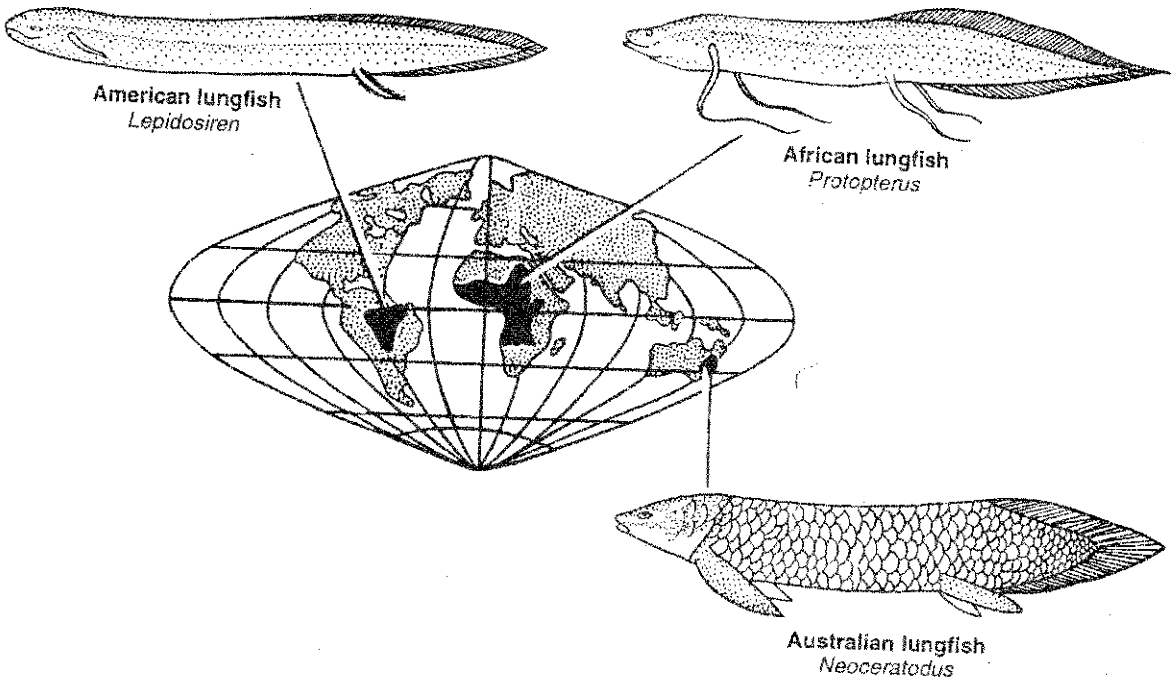

Fig. 1. Discontinuous distribution of three living genera of lung fishes (Dipnoi).

of their own species. Besides swimming in water by undulating body movements, they also crawl on the bottom using their paired fins like legs. South American *Lepidosiren* and African *Protopterus* species survive drought by aestivating in a mucous cocoon buried in the bottom mud of their dried-up habitats. During aestivation the air bladder is constantly used as a lung. When mud softens again during rains, they resume their normal life like fish. Male *Protopterus* vigorously guards eggs laid by female in an oval muddy pit or nest, after fertilizing them. Parental care is even more pronounced in male *Lepidosiren* whose pelvic fins develop vascular tufts during breeding season. The male periodically leaves the nest to engulp atmospheric air and O_2 diffuses from freshly aerated blood of pelvic fins to the vicinity of eggs or young for respiration and growth.

[III] Peculiarities

1. External features. Lung fishes are slender fish-like or eel-like creatures, 1 to 2 meters in length. Paired pectoral and pelvic fins, often designated as limbs, are narrow lobe-like or filamentous, with a central axis of flesh and bone. Dorsal, anal and caudal fins are fused into a continuous, symmetrical, diphycercal tail, supported by partly calcified fin rays. Snout is depressed bearing external nostrils enclosed within upper lip. Mouth is substerminal or ventral. Gills are covered on either side by an operculum leaving a single slit-like gill slit. Spiracles are absent. Anus, urinary and genital apertures and one or two abdominal pores lie within a small mid-ventral cloaca. Eyes are small. Lateral line system is well developed, especially on head. Skin is covered by an exoskeleton of thin, bony, overlapping cycloid scales.

2. Internal features. Endoskeleton is mostly cartilaginous. Notochord is persistent with cartilaginous vertebral arches but lacking vertebral centra. Anterior vertebrae are fused with skull. Primary cranium persists with little ossification and with or without fontanelles. Premaxillae and maxillae absent and teeth modified as crushing plates. There are 4 to 6 cartilaginous branchial arches. Jaw suspension is autostylic. Pectoral girdle is a stout cartilage with a pair of investing bones on either side. Pelvic girdle is well-developed and cartilaginous. Intestine has a spiral valve. Glottis may be protected by an epiglottis. Internal nares may open into mouth cavity much like those of Amphibia. Air bladder (swim bladder) forms a single or double lung with internal alveoli as in higher vertebrates. Gills may be well developed or reduced. Auricle and ventricle of heart and sinus venosus are imperfectly divided. The large atrioventricular opening is filled by a fibrous plug, there being no true valves. Ventral aorta is very small. Conus arteriosus is partly or fully partitioned. A spiral valve is present. A pulmonary artery is given off on either side from efferent branchial system. A pulmonary vein opens into left side of auricle. There are two precavals (ductus Cuvieri) and a large posterior vena cava (posterior cardinal vein), as in tetrapods. Mid-brain is almost undivided into optic lobes. Pallium of cerebral hemispheres has a layer of nerve cells. Paired oviducts open anteriorly into coelom in female. Vasa efferentia carry sperms through excretory part of kidney in male. Fertilization is external. Development includes metamorphosis. Larvae may develop suckers and external gills.

[IV] Classification

Order Dipnoi is divided into 2 suborders.

Suborder 1. Monopneumona

Lung single. Lateral jointed rays of archipterygium (paired fins) well developed.

Examples : Living Australian *Neoceratodus forsteri* and extinct Triassic *Ceratodus*.

Suborder 2. Dipneumona

Lung double. Lateral rays of archipterygium (paired fins) vestigial or absent.

Examples : African *Protopterus* and Australian *Lepidosiren paradoxa*.

[V] Affinities of Dipnoi

With special features of their own, the Dipnoi combine characteristics in which they resemble different groups of fishes as well as Amphibia.

1. Affinities with fishes (general). Lung fishes are true fishes beyond doubt as they resemble them in general in the following features :

1. Body spindle-shaped and streamlined.
2. Locomotory appendages fins.
3. Diphycercal caudal fin.
4. Largely ossified, slender dermal fin rays.
5. Body covered by overlapping cycloid scales.
6. Notochord persistent.
7. Vertebrae without centra.
8. Skull with little ossification and with several investing bones.
9. Branchial arches 4 to 6 pairs present.
10. Aquatic respiration by gills.
11. Lateral line sensory system.

2. Affinities with Elasmobranchii. Lung fishes resemble cartilaginous fishes in the following primitive characters :

1. Intestine with a spiral valve.
2. Nephrostomes lacking in kidney tubules.
3. Similar diencephalon.
4. Similar female reproductive system.
5. Each gill arch with 2 efferent arteries.
6. Similar conus arteriosus.

The main differences from elasmobranchs are presence of diphycercal tail, opercula and lungs, absence of claspers and external fertilization.

3. Affinities with Holocephali. According to Jarvick (1964, 1967), dipnoans and holocephalians resemble remarkably with each other as follows :

1. Teeth fused into dental plates on jaws.
2. Gills covered by operculum.
3. Operculo-gular membranes of both sides fused.
4. Intestine with a spiral valve.
5. Jaw suspension autostylic.
6. Excurrent nostrils opening into mouth cavity.
7. Similar kidneys, gonads and ducts.
8. Similar cranial nerves.
9. Each gill arch with 2 efferent arteries.

Main differences from holocephalians are presence of lungs, absence of claspers and external fertilization.

4. Affinities with Actinopterygii. Lung fishes resemble subclass Actinopterygii in the following characters :

1. Blunt snout.
2. Body covered with cycloid scales.
3. Paired inferior jugular veins.
4. Powerful palatine and splenial teeth.

5. Presence of swim bladder.
6. Presence of operculum over gills.

However, the Actinopterygii belong to a separate evolutionary line. They have thin, broad fins modified for swimming, and the external nostrils never penetrate into the mouth. Most of them are small in size, have reduced snout, large eyes, single separate dorsal fin and a homocercal caudal fin.

5. Affinities with Crossopterygii. The two orders, Dipnoi and Crossopterygii were included under the subclass Sarcopterygii by Romer (1959). Instead of specializing for aquatic habitats (as did the Actinopterygii), they have adapted for a semiaquatic existence. They show many close similarities as follows :

1. Powerful leg-like lobate fins.
2. Caudal fin diphycercal.
3. Internal nostrils piercing roof of mouth cavity in some cases.
4. Similar skull bones.
5. Vertebral column reaching upto the end of caudal fin.
6. Air bladder modified as a lung with good pulmonary circulation.
7. Contractile conus arteriosus.
8. Larval forms in some cases with external gills as accessory respiratory organs.

Besides, the fossil crossopterygians (rhipidistians such as Devonian *Osteolepis*) and fossil dipnoans (such as Devonian *Dipterus*) show even closer affinity in :

1. Similar body shapes and sizes (20 to 70 cm).
2. Separate 2 dorsal, 1 anal and 1 heterocercal caudal fin, supported by dermal bony rays.
3. Paired fins somewhat lobate with a fleshy scaly central axis. Pectoral fins placed high.
4. Presence of internal nares in some.
5. Cycloid scales modified from cosmoid type.
6. Similar number and disposition of dermal bones on skull and pectoral girdle.
7. No vertebral centra.
8. Similar opercular and gular bones.
9. Similar lateral line sensory system.
10. Comparable lower jaw.

This led to the belief that the dipnoans are degenerate descendants of the crossopterygians, which the early dipnoans closely resembled. But Jarvik (1968) and others throw doubt upon this belief. According to them, certain structures are more specialized in dipnoans than in crossopterygians. Their basic *differences* are in structural organisation of food crushing apparatus, fin skeleton, vertebral column, visceral skeleton, neural endocranium, snout, division of heart, atrium, blood supply of swim bladder, etc.

6. Affinities with Amphibia. Dipnoans resemble amphibians in several features, such as :

1. Semiaquatic or marshy habitat.
2. Internal nostrils piercing roof of mouth cavity.
3. Multicellular skin glands.
4. Dermal scales present in Gymnophiona.
5. Lungs capable of pulmonary respiration.
6. Spiracles lacking.
7. Vomerine teeth present.
8. Auricle and sinus venosus partially divided into right and left halves.
9. Conus arteriosus spirally twisted and longitudinally partitioned.
10. Ventral aorta short.
11. Presence of anterior abdominal vein, posterior vena cava, pulmonary artery and vein.
12. Pericardium is thin-walled.
13. Jaw suspension autostylic.
14. Brain similar in structure of cerebrum and cerebellum.
15. Sperms carried through excretory part of mesonephric kidney.
16. Similar structure of egg and development.
17. Larval stages having suckers and external gills.

This close similarity led early workers to conclude that lung fishes gave rise to amphibians, a view no longer held now-a-days. According to Dolo, these similarities probably were due to convergent evolution on account of similar habits and habitat. On the other hand, the lung fishes have the following special features by which they *differ* from amphibians.

1. Lobate fins instead of limbs for locomotion.
2. Fin skeleton not like that of primitive tetrapods.
3. Peculiar crushing plates instead of teeth.
4. Skull mainly cartilaginous with little ossification.
5. Few anterior vertebrae fused with skull.
6. Lungs located dorsal to gut.
7. Urinary bladder develops from dorsal wall of cloaca in Dipnoi but from ventral wall in Amphibia.

[VI] Phylogency and significance

The origin and evolution of Dipnoi remains problematic due to diverse opinions. They combine characteristics in which they resemble almost all the other groups of fishes as well as Amphibia. Fossil primitive Dipnoi (e.g. *Dipterus*), shows geater similarity with fossil crossopterygians (e.g. *Osteolepis*), than do their living members. During the course of their evolution, the modern Dipnoi have undergone several changes or specializations such as :

1. Anterior dorsal fin was reduced and eventually lost.
2. Remaining median fins elongated and fused so that originally heterocercal tail became symmetrically diphycercal.
3. Reduction in number of dermal bones of skull and operculum.
4. Thick bony cosmoid scales modified into thin cycloid scales.
5. Extensive sheet of cosmine covering head and body was lost.
6. Fusion of conical teeth into crushing tooth plates to feed effectively upon shell fish.
7. Air bladders became functional lungs not unlike those of higher vertebrates.

Evidence indicates that Dipnoi are degenerate descendants of Crossopterygii which early dipnoans closely resembled. Romer (1945) thought that Dipnoi and rhipidistian Crossopterygii had a common ancestor. On the other hand close similarity between Dipnoi and Amphibia led early workers to conclude that dipnoans gave rise to amphibians, a view no longer held now. However, it is universally accepted that Amphibia have originated either directly from rhipidistian Crossopterygii or from some common ancestor.

Types of Fins

Fishes swim with their fins which are thin, broad folds of integument internally supported by fin rays which may be bony, cartilaginous, fibrous or horny. Fins of adult fish are always of two kinds : (1) *unpaired median* fins and (2) *paired lateral* fins.

1. Unpaired median fins. These include 1 or 2 *dorsal fins* along mid-dorsal line, a ventral *anal fin* behind anus or vent (cloaca) and a tail or *caudal fin* around the tip of tail. Dorsal fins may be in a series or reduced or absent. Anal fin may be absent especially in bottom dwellers.

2. Paired lateral fins. These include *pectoral fins* anteriorly and *pelvic fins* posteriorly. Pelvic fins are called thoracic when placed below the pectoral fins and abdominal when situated just in front of anus. In some cases they are absent.

Uses of fins. Fish swim mainly by lateral movements of tail and tail fin. Other fins are principally used as steering devices and rudders. When the body is at rest, the paired lateral fins serve to maintain equilibrium. Fins are also modified to serve other purposes. Lungfishes use them as legs in walking. The flying fish use their large and extended pectoral fins for gliding. Pelvic fins in some male, Chondrichthyes become modified as claspers. In remoras, anterior dorsal fin forms an adhesive disc or sucker on head. In some teleosts the anal fin forms on intromittent organ or ovipositor.

Origin of Fins

The first chordates lacked paired appendages but it is universally accepted that tetrapod limbs arose during evolution from the fins of fishes. However, clues to the origin of fins themselves have remained obscurre and unresolved. Median and unpaired fins in fishes are believed to have originated from a continuous fold of tissue. This fold extends from the posterior region of head and continues posteriorly around the tail and extends

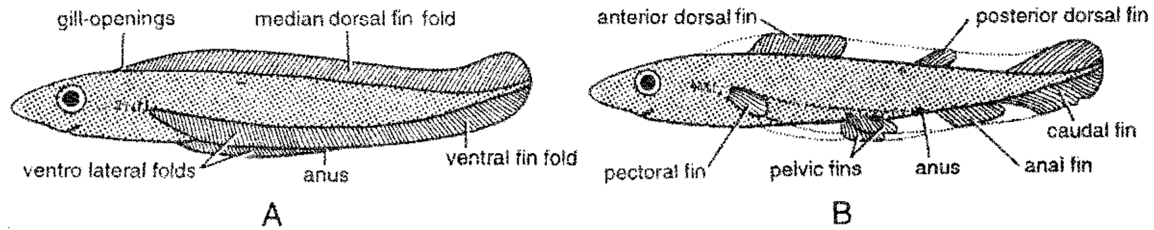

Fig. 2. Diagrams illustrating the origin of fins according to Balfour's fin-fold theory.

up to anus. This fold of skin is supported by a series of parallel cartilaginous rods. During the course of development each of these supporting rods divides into a lower basal piece, embedded in the body wall and upper radial piece, lying in the fin fold. Several theories have been advanced to explain the source and manner of origin of fins (Figs. 2 & 3).

1. Gill arch theory. According to this theory proposed by Gegenbaur in the nineteenth century, the paired fins and fin skeleton are the modified flaps of skin and skeleton of last gill arches, while the gill bars themselves became the girdles. However, the theory is not tenable due to lack of any morphological or embryological support.

2. External gill theory. According to Graham Kerr, paired fins and their skeleton are derived from external gills which occur temporarily in some larval forms. However, this theory has no supporting evidence.

3. Fin-fold theory. According to this theory by Balfour and Thatcher was later supported by workers like- Wiedershiem, Parker, Goodrich etc., continuous median and lateral folds of bodywall, similar to those of *Branchiostoma*, were present in some ancestral fish. These folds became interrupted at intervals resulting in separate dorsal, caudal, anal, pelvic and pectoral fins. Evidences in support of this idea are also quoted. (i) Basic skeletal structures of paired and unpaired fins are similar indicating a common mode of origin. (ii) In the embryos of certain elasmobranchs, early stages show continuous series of muscle bands which disappear, except those forming the isolated paired and unpaired fins. (iii) In some extinct Devonian acanthodian sharks, a row of numerous small accessory spiny fins on either side between

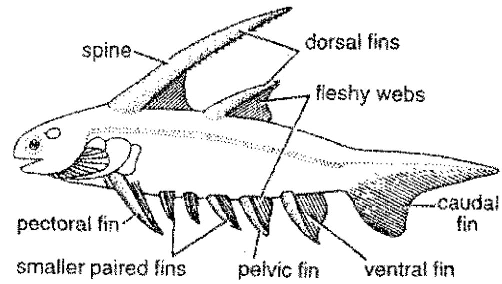

Fig. 3. Schematic derivation of fins according to the fin-spines theory.

pectoral and pelvic fins, have been interpreted as remnants of fin folds. (iv) In the extinct shark *Cladoselache*, the pectoral and pelvic fins are broad, without basal notches and supported by parallel cartilaginous rods (pterygiophores), suggesting a primitive fin fold-like origin. Though seemingly plausible, the theory is no longer widely accepted. Any primitive fossil fish having continuous fin folds is still unknown.

4. Fin spines theory. According to this theory, probably the first fins consisted of metamerically arranged spines with fleshy webs, like those of some extinct acanthodian sharks. Subsequently all spines and webs may have been lost except one anterior and one posterior pair which later evolved into pectoral and pelvic fins.

5. Ostracoderm theory. Some ostracoderms possessed lateral fleshy lobes, projecting from either lateral side. They may have been the precursors of pectoral fins. Other ostracoderms had ventro-lateral rows of dermal spines similar to extra fins of acanthodians. Most of these spines were lost while some were retained in the pectoral and pelvic regions, thus accounting for the origin of paired fins (and limbs) from ostracoderm ancestors.

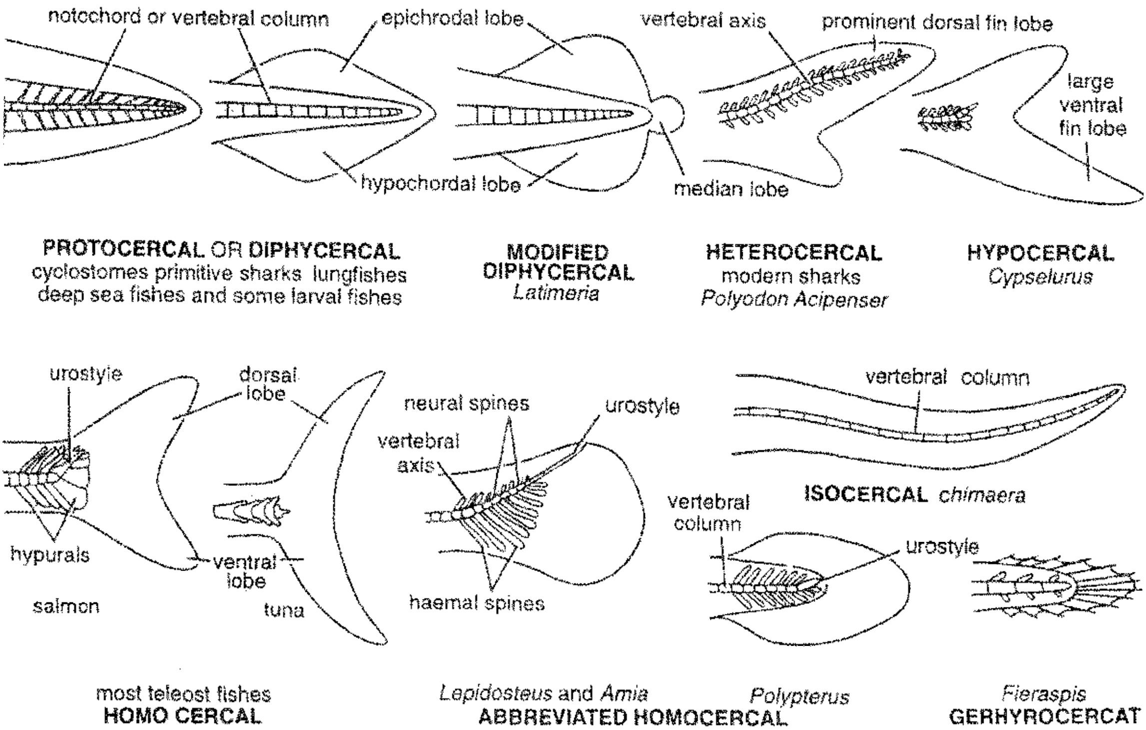

Fig. 4. Different types of caudal fins or tails in fishes.

Types of Caudal Fins or Tails

Caudal fin is well developed in most fishes because it is an important contributor to forward propulsion during swimming. The caudal fin in most of the fishes is highly developed, with few exceptions like- in *Hippocampus* and some of the eels. In sea horse, the tail is prehensile. In bottom dwelling rays, it tends to be reduced and in sting rays caudal fin is lacking. It has different shapes in different groups of fishes correlated with their habits, so that it is of great importance in classification of fishes. Three main, types of tails or caudal fins are found in fishes : diphycercal, heterocercal and homocercal (Fig. 4).

1. Diphycercal. Most primitive kind of tail or caudal fin is called *diphycercal* (*diphus*, double) or *protocercal* (*protos*, first or primary). It is not exhibited by many living fish. The vertebral column extends straight back to the tip of tail dividing the fin symmetrically and equally into the dorsal or *epichordal* and ventral or *hypochordal lobes*. Diphycercal caudal fin occurs in modern cyclostomes, primitive sharks, Holocephali (*Chimaera*), living Dipnoi (lung fishes), living Crossopterygii (*Latimeria*), many larval teleosts and deep sea fishes. *Latemeria* and extinct coelacanths have unique symmetrical 3-lobed tail with a marked median lobe. In *Chimaera* and some deep sea fishes, the fin is called *isocercal* (Gr., *ios*, equal) which is very much elongated and symmetrical. Presence of protocercal tail in some highly developed fishes is due to its secondary modifications.

2. Heterocercal. It is the intermediate type in which are vertebral column bends upwards and reaches upto the tip of the more prominent dorsal lobe, thus making the caudal fin strongly asymmetrical (Gr., *heteros*, other, different). It is typical of modern elasmobranchs, extinct osteolepid crossopterygians (*Osteolepis*), extinct dipnoans (*Dipterus*), and living holosteans (*Acipenser, Polyodon*). Heterocercal caudal fin is characteristic of bottom feeders, with ventral mouth and without swim bladder. The strokes of larger dorsal lobe in swimming serve to direct fish towards bottom.

The opposite of heterocercal condition, in which the vertebral column terminates into a larger ventral lobe, is known as *hypocercal* (Gr., *hypos*, under, beneath) type. It is peculiar to flying fish, some primitive fishes and (fossil agnatha) ostracoderms. Larger ventral lobe enables the flying fish (*Cypselurus*) to attain maximum speed for gliding as it leaves the water.

3. Homocercal. This is the advanced and most common type (Gr., *homos*, common, alike), characteristic of the large majority of higher bony fishes (teleosts). It is externally symmetrical but internally it is asymmetrical. In this type the original dorsal lobe or epichordal is suppressed. Only the originally ventral lobe or hypochordal is greatly developed into a single or two equal and symmetrical lobes. Vertebral column is short and its terminal part, the *urostyle*, is slightly upturned into the dorsal lobe (e.g. salmon). Homocercal caudal fin is characteristic of fishes with a terminal mouth, and its strokes force the fish straight forward.

Homocercal type has several variations. In cod and tuna, the upturned urostyle of vertebral column is reduced or absent. In some deep sea fishes, the terminal part of vertebral column is straight and greatly elongated to form *isocercal tail*. In *Fieraspis*, vertebral column and fin itself become reduced and vestigial forming a *gephyrocercal* tail. In chondrosteans (*Polypterus, Amia, Lepidosteus*), the urostyle is a bit elongated and upturned, also with or without an upturned fleshy lobe. This is called *abbreviated homocercal* type. Most of these variations represent an intermediate stage between heterocercal and homocercal types. The protocercal or diphycercal type of caudal fin is considered as the most primitive type, heterocercal as the intermediate stage and homocercal represents the most advanced stage. During the development of many teleosts, it is seen that caudal fin starts as diphycercal; subsequently it becomes heterocercal and finally assumes homocercal condition. The transition between three types of caudal fins in the developmental history of fishes is significant from the phylogenetic point of view.

Scales of Fishes

In many vertebrates, the exoskeletal covering of body is made of two types of scales: epidermal and dermal. *Epidermal scales* are cornified derivatives of the Malpighian layer of epidermis. They are well developed in terrestrial vertebrates such as reptiles, birds and mammals. *Dermal scales* are mesenchymal in origin and especially

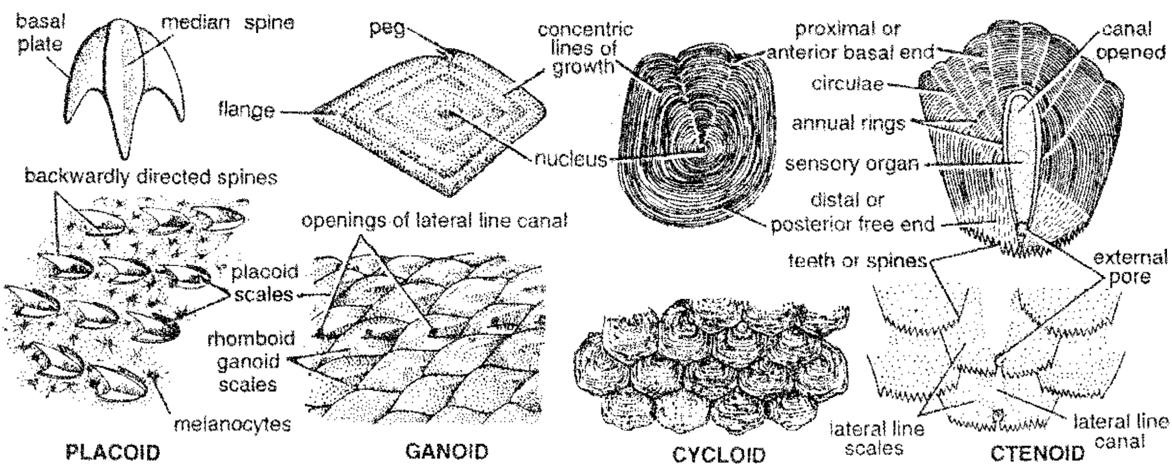

Fig. 5. Different types of dermal scales found in fishes. Lower row shows parts of skin with numerous scales. Upper row shows single scales.

developed in the fishes. They are small, thin, cornified, calcareous or horny plates which fit closely together or overlap. As regards the arrangement of scales on piscine body is concerned, they are most often imbricated and thus, overlap like shingles on the roof, with their free margins directed towards the tail, so as to minimize the friction of water. But some times total reversal of the pattern of arrangement is seen in some fishes. Among barbot (*Lota*) and freshwater eel (*Anguilla*) the pattern is mosaic rather than overlapping one another, they are separted minutely or meet their neighbours only at their margins. Scales vary in size and shape in different species. The body of all fishes except members of family Siluridae and a few bottom dwellers is covered by scales. Scales are usually found covering entire body surface, but in some fishes like— *Chimaeras*, *Polydon* and *Acipenser*, the scales are present in some localized areas.

Primitive fossil fishes possess exoskeleton in the form of plates and scales which consist of three distinct layers. The innermost layer of *isopedine*, the intermediate one is *spongy* layer and outer layer is of *dentine*. Five types of dermal scales have been identified in fishes : *cosmoid, placoid, ganoid, cycloid* and *ctenoid* (Fig. 5).

1. Cosmoid scales. These do not occur in living fishes. These were characteristic of certain ostracoderms, placoderms, and extinct sarcopterygians (lobe finned fishes and lung fishes). These consisted of 4 distinct layers : an outermost thin enamel-like *ganoine*, thick dentine-like *cosmine*, *spongy bone* and innermost *compact bone*.

2. Placoid scales. These are characteristic of elasmobranch fishes only. Each placoid scale consists of a backwardly directed *spine* arising from a rounded or rhomboidal *basal plate* embedded in dermis. Spine is made of enamel-like and basal plate of dentine-like bony material. A pulp cavity inside spine opens through basal plate. Placoid scales are closely set together in skin giving it a sandpaper like quality.

3. Ganoid scales. Ganoid or rhomboid scales are thick, usually rhomboid or diamond-shaped plates closely fitted side by side, like tiles, providing a bony armour to the fish. In some cases they may overlap. Ganoid scales are characteristic of chondrosteans (*Polypterus, Acipencer*) and holosteans (*Leipidosteus*) so that these are often called *ganoid fishes*. *Polypterus* has *palaeoniscoid* ganoid scales composed of 3 layers : outer enamel-like ganoine, middle dentine-like cosmine and inner bony isopedine. *Lepidosteus* has *lepidosteoid* ganoid scales with only two layers : outer ganoine and inner isopedine.

4. Cycloid scales. Cycloid scales are thin flexible translucent plates, rather circular in outline, thicker in the centre and marked with several concentric lines of growth which can be used for determining the age of the fish. They are composed of a thin upper layer of bone and a lower layer of fibrous connective tissue. They overlap each other, each scale embedded in a small pocket of dermis. Cycloid scales are found in lung fishes, surviving dipnoans some holosteans (*Amia*) and the lower teleosteans such as carps, cods, etc.

5. Ctenoid scales. These are characteristic of modern higher teleosteans such as perch, sunfish, etc. In form, structure and arrangement they are similar to cycloid scales. They are more firmly attached and their exposed free hind parts which are not overlapped, bear numerous small comblike teeth or spines (Gr., *ctenos*, comb). Intermediate types between cycloid and ctenoid scales also occur. Certain fishes, such as flounders, may bear both types, ctenoid scales dorsally and cycloid ventrally.

Modifications of scales. Some fishes are totally scaleless or naked, such as *Torpedo* (electric ray) and catfishes. In eels, they are minute and deeply embedded in dermis. In some fishes (chimaeras) they become localized. In globe fish (*Tetrodon*) and porcupine fish (*Diodon*), they develop into large protective spines making it difficult to be swallowed. In trunk fish (*Ostracion*) they form a complete bony box. In sturgeon (*Acipenser*) stout bony plates or scutes form a bony armour. Shark teeth are modified large placoid scales. Sting (barb) of a sting ray is a modified placoid scale. The lateral teeth on the elongated rostrum of sawfish (*Pristis*) are formed by placoid scales. In basking shark (*Cetorhinus*) myriads of placoid scales become gill rakers. In *Hippocampus* (Sea horse and *Syngnathus* (Pipe fish) the scales become fused to form a protective bony ring around the body.

Uses of scales. Scales form a protective covering of exoskeleton on the body. Scales grow throughout life in size with the fish. Growth results in concentric lines which make age determination possible in salmon, trout, bass and several other species. For every species, its scale pattern is rather constant. Thus arrangement, number, form and structure of scales play important role in identification and classification of fish species.

Air Bladder or Swim Bladder

A characteristic organ of bony fishes is a gas-filled pneumatic sac, called *air bladder* or *swim bladder*, lying dorsal to the digestive tract, directly beneath the vertebral column and mesonephric kidneys but outside coelom. Swim bladder does not occur in elasmobranchs. However, it is found in all bony fishes except a few bottom dwellers (*Lophius*, *Pleuronectes*, etc.). It is vestigial in *Latimeria*, the only living crossopteygian.

Generally speaking, the air bladder arises as an outgrowth from the oesophageal region of the alimentary canal. It shows a great diversity in mode of development, structure and function in different fishes. It lies ventral to alimentary canal in *Polypterus*, laterally in Dipnoi, and dorsally or dorsoventrally in teleosts (Fig. 6).

1. Condition in ganoids and dipnoi. In most primitive fishes, the air bladder serves as an accessory respiratory organ or lung, which seems to have been its original function. In *Polypterus* (Chondrostei), one of the most primitive bony fishes living today, it is a smooth-walled bilobed sac, with a short left and long right lobe, opening ventrally into oesophagus by a single duct. In the lung fishes *Protopterus* and *Lepidosiren*, the condition is similar but the two lobes are equal in

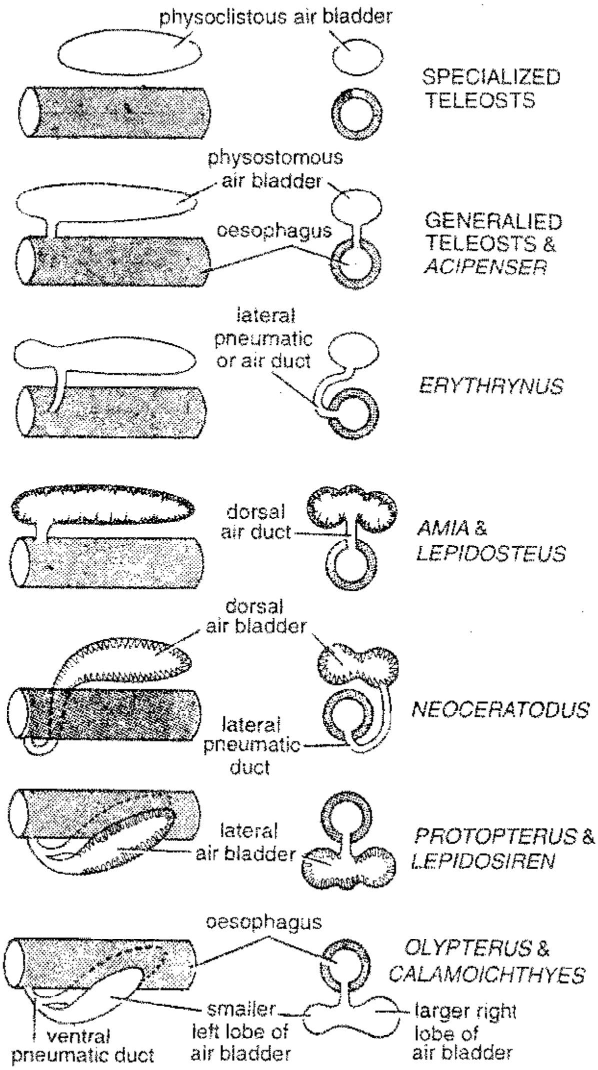

Fig. 6. Various types of swim bladders and lungs in fishes shown in L.S. (left side) and T.S. (right side).

size and have thick, vascular walls with alveoli and septa. In the Australian lung fish *Neoceratodus*, air bladder consists of a single lobe lying dorsal to gut, but still connected ventrally to oesophagus by a narrow *pneumatic duct,* passing down along the right side of gut. In the holosteans *Amia* and *Lepidosteus*, air bladder is a single large and highly vascular lobe, lying dorsal to oesophagus and its pneumatic duct also opening dorsally into oesophagus. Thus, in *Amia* and *Lepidosteus*, the air bladder serves as both a respiratory organ (lung) and a hydrostatic organ.

2. Condition in teleosts. Air bladder in higher bony fishes or teleosts is the most specialized, playing little or no part in respiration, and primarily serving as a hydrostatic organ. Two types o air bla ers are known. In the more generalized groups of teleosts, (salmon, eel) the air bladder retains connection with the gut via a pneumatic duct, just as in a ganoids and dipnoi. Such an open air bladder is called *physostomous*. In the teleost *Erythrinus* the air bladder has a lateral attachment to gut. In the more specialized teleosts (perch, cod), the duct becomes atrophied or lost. Such a closed or ductless air bladder is called *physoclistous*.

3. Structure of teleostean air bladder. A typical teleostean air bladder is a thin-walled gas-filled sac lying dorsal to alimentary canal extending the entire length of body cavity. The gases are similar to those dissolved in water (O_2, CO_2, N_2). In higher physoclistic teleosts, the air bladder tends to be divided into two chambers, demarcated by a constriction with a sphincter. Essentially air bladder is tough sac-like structure with an overlying capillary network. Just beneath the capillary protocercal there is a layer of connective tissue called *tunica externa*. Below this layer lies the *tunica interna*, made up of chiefly smooth muscle fibers and epithelial gas glands. The wall of anterior chamber has a remarkable *red body* or *red gland* so called because of its colour. It contains a compact mass of interlacing fine capillaries called *rete mirabile* (pleural *retia mirabilia*). The red gland receives blood from coeliaco-mesenteric artery and empties into the hepatic portal vein. Gases in the bladder come from blood secreted by the red gland. The posterior chamber is thin-walled and forms the oval gland which permits reabsorption of gases by the blood. Secretion and resorption are under the control of autonomic nervous system. In physostome fishes with air bladder connected to pharynx by a duct, air can also be gulped or bubbled through the mouth (Fig. 7).

4. Functions of air bladder. Air bladders or swim bladders in fishes are associated with several functions.

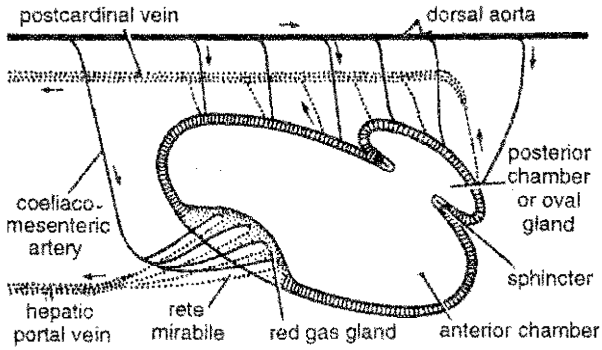

Fig. 7. Structure and blood supply of a ductless teleostean swim bladder in section.

*(a) **Respiration.*** In lower or intermediate fishes, such as ganoids and lung fishes, the air bladder serves as a lung. These fishes come to water surface regularly to gulp air. In physostomous (with duct) teleosts, which also gulp air, the bladder serves as an accessory respiratory organ. Even in physoclistous (ductless) teleosts, the bladder is said to store oxygen to be utilized during deficiency.

*(b) **Hydrostasis.*** Air bladder in teleosts functions chiefly as a hydrostatic organ and helps to keep the weight of piscine body equal to the volume of water displaced by fish. Secretion of more gases means lower specific gravity so that fish rises in water. Resorption of gases means increased specific gravity and the fish sinks. Thus, the fish is able to rise or sink and maintain its equilibrium or position in water without any muscular effort.

*(c) **Sound production.*** Some fishes are able to produce sounds with the gases inside air bladder by the use of special muscles attached to the air bladder. But the actual mechanism is not understood. However, some fishes (*Doras*, *Platystoma*, and *Malapterurus*) can produce grunting, hissing or drumming sound. The circulation of air inside the bladder causes the vibration of incomplete septa, which in turn, produces sound. Sound may also be produced by compression of extrinsic and intrinsic musculature of the swim bladder *Polypterus*, *Protopterus* and *Lapidosiren* produce sound by forceful expulsion of gases from the swim bladder. In *Cynoscion*

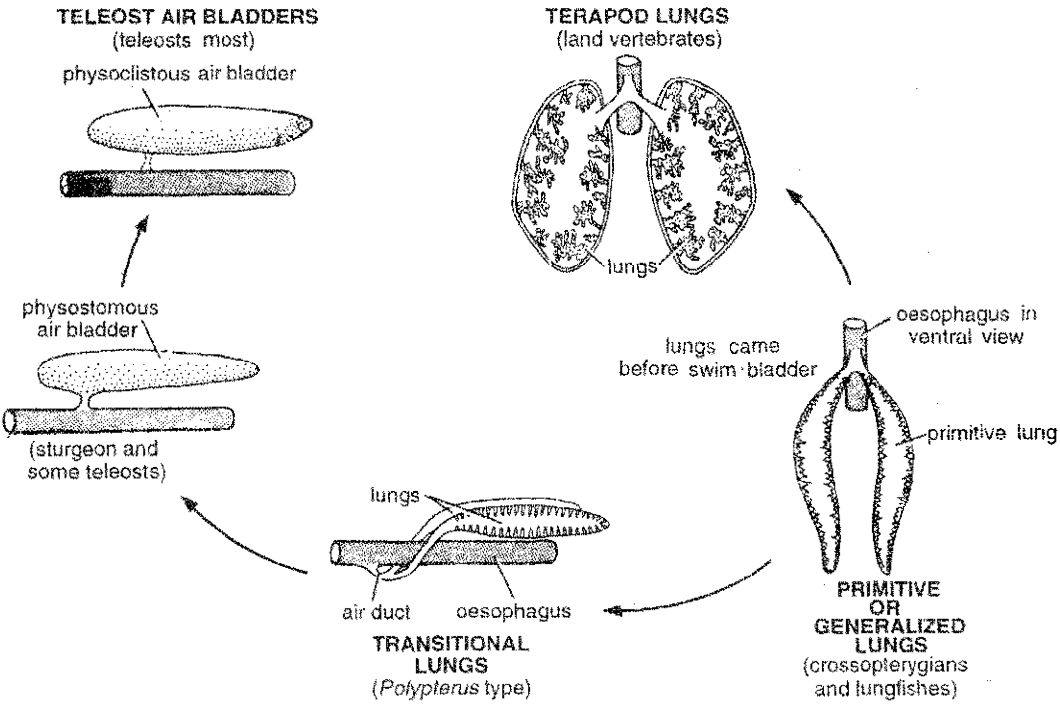

Fig. 8. Evolution of air bladders and lungs.

males, compression of the bladder is achieved by contraction of specialized muscles, *musculus sonorificus*. The sound production is meant to startle the enemies or to attract mates.

(d) Audition. In Cypriniformes, a series of small bones, the weberian ossicles, connects the air bladder and perilymph cavity containing internal ear. Low-frequency vibrations of the contained gas, induced by noises in water, are transmitted by the ossicles to the membranous labyrinth. Thus, these fish can hear.

5. Phylogenetic relationship with tetrapod lungs. There is a striking similarity between the swim bladders in fishes and lungs of tetrapods in origin, structure and development. This suggests a positive phylogenetic relationship between the two. Probably both arose phylogenetically as pharyngeal pouches. No vertebrate exhibits both a swim bladder and a lung. While swim bladders are characteristic of fish, lungs are characteristic of tetrapods. This led to the previous view that both are *homologous* and that the swim bladder was the *precursor* or forerunner of the lungs of higher forms. But this is not supported by any geological evidence. According to the present view, lungs are more primitive since they are present in the most primitive fishes (dipnoi and ganoids), while the swim bladder of higher fishes (teleosts) is a specialized modification of lungs. Further, there are basic *differences* between the two. The lungs function primarily as respiratory organs, arise from ventral pharyngeal wall and get blood supply from sixth aortic arches. On the other hand, swim bladders are primarily hydrostatic organs, arise from dorsal or dorso-lateral oesophageal wall and get blood supply from the dorsal aorta.

6. Evolution of air bladders and lungs. Fossil record indicates that early bony fishes (placoderms, crossopterygians) evolved lungs as an adaptation to the unreliable freshwater conditions of the Devonian period. Their lungs were similar to those of the living African lung fish, *Protopterus* and originated as a pair of ventral sac-like pouches connected to pharynx (or oesophagus) by single duct. From this generalized condition three lines of evolution emerged. (i) One line led to the air bladder or swim bladder of most modern teleosts by a gradual shift of origin from and connection with gut from ventral to dorsal side. The lateral attachment to gut of air bladder in the teleost *Erythrinus* and other transitional or intermediate stages seen in certain species support this view. Thus, the dorsal swim bladder became a hydrostatic organ for floatation, instead of breathing. (ii) Second line of evolution without change in position but with extensive internal foldings, led to lungs for respiration found in land vertebrates. (iii) They were lost in elasmobranchs and a few teleosts (Fig. 8).

Accessory Respiratory Organs

Adult fishes depend chiefly on pharyngeal gills for aquatic respiration. However, other devices also occur to supplement or replace gill respiration. All such additional respiratory organs, other than gills, are known as *accessory respiratory organs*. These are found mostly in fishes of tropical fresh waters and hill streams and develop as adaptation to the particular environmental condition. Accessory respiratory organs enable the fishes to live in oxygen-deficient water, to aestivate over prolonged droughts in dry summer, to take short excursions on land or simply to meet extra demand for oxygen. Some accessory organs subserve aquatic respiration while others aerial respiration (Fig. 9).

1. Skin or integument. Common eels (*Anguilla anguilla, Amphipnous cuchia*) often make overland journeys through damp vegetation. They can respire cutaneously both in air and in water. Mudskippers (*Periophthalmus*), fish larvae and embryos can also subserve cutaneous respiration through thin, moist and permeable skin before the emergence of gills. Median fin folds of many fishes are supplied with numerous blood vessels that help in cutaneous respiration. Besides this, highly vascular opercular folds of *Stergeons* and many cat fishes serve as accessory respiratory structure.

2. Bucco-pharyngeal epithelium. In most of the fishes, the epithelial lining of buccal cavity and pharynx is usually highly vascular and permeable to gases in water. But, the South American fish, *Symbranchus* and the mud skippers (*Periophthalmus*), can fill their oral and pharyngeal cavities with air and thus take oxygen directly

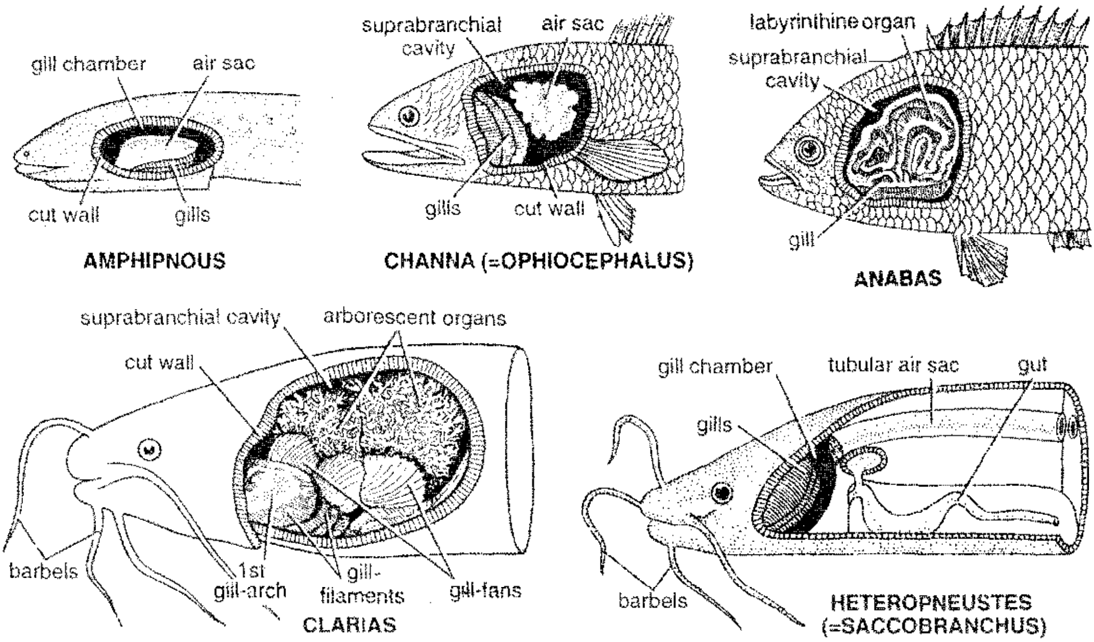

Fig. 9. Accessory respiratory organs dissected on the left side in some air-breathing teleost fishes.

from atmosphere. The old idea that the mudskippers use the vascular tail as respiratory organ is not supported by icthyologists.

3. Gut epithelium. In several fishes epithelial lining of certain parts of alimentary canal becomes vascular and modified to serve as a respiratory organ. It may be just behind stomach (*Misgurus fossilis*), or intestine (*Lepidocephalus guntea, Gobitus*) or rectum (*Callichthyes*). Fresh air is drawn through mouth or anus and after gaseous exchange voided through anus. In these fishes the wall of gut is modified to perform the respiratory function. The walls of the gut in these areas become thin, due to reduction of muscular layer.

4. Pelvic fins. In American lung fish, *Lepidosiren*, during breeding time, the pelvic fins of male become enlarged and grow filamentous vascular outgrowths which provide fresh oxygen to the guarded eggs.

5. Pharyngeal diverticula. These are a pair of simple sac-like outgrowths of pharynx, lined by thickened vascular epithelium and extending above the gills. These are very small in *Periophthalmus*, small and smooth in *Amphipnous* and somewhat folded in *Channa* (=*Ophiocephalus*). The fishes have poorly developed gill-filaments and the accessory respiratory sacs or chambers serve to breathe atmospheric air during aestivation or while coming out of water for sometime. The diverticula of *Amphipnous* open anteriorly through the mid-ventral gill slit. Moreover, the third gill-arch is found to bear fleshy vascular epithelium which also serves as an accessory respiratory organ.

6. Branchial diverticula. The outgrowths from gill chambers form more complicated aerial accessory respiratory organs than the *simpler* pharyngeal outgrowths in other fishes. Three well known examples are :

(a) Heteropneustes (=Saccobranchus). This Indian catfish has a pair of long, tubular and dorsally situated *air sacs*, arising posteriorly from gill chambers and extending almost upto the tail. They are highly vascular. The air is drawn in and expelled out through pharynx.

(b) Anabas. This Indian climbing perch has two, spacious, suprabranchial cavities as dorsal outgrowths of the two gill chambers. Each cavity contains a special *labyrinthinie organ* formed by much folded, concentric bony plates developed from the first epibranchial bone and covered with thin vascular mucous membrane. Margins of these plates are wavy and the plates are covered with vascular gill-like epithelium. Each branchial outgrowth communicates freely not only with the opercular cavity but also with buccopharyngeal cavity. Air is drawn through mouth into suprabranchial cavities and expelled through opercular opening. The fish is so dependent on atmospheric oxygen that it will drown if denied access to surface to gulp air. Accessory respiratory organs of *Trichogaster fasciatus* are also similar but simpler.

(c) Clarias. The Indian catfish, *Clarias batrachus* has the most complicated accessory respiratory organs. These are in the form of two much branched tree-like *dendritic* or *arborescent organs* developed inside suprabranchial cavities one on either side above gill chambers. The cavities and the organs are covered by vascular, mucous epithelium and function as lungs. The fish periodically reaches water surface to renew air.

7. Air bladders. Swim bladder of higher bony fishes (teleosts) is essentially a hydrostatic organ. But, in lower bony fishes (dipnoans and ganoids), the air bladder acts like a lung to breathe air and is truly an accessory respiratory organ. The wall of bladder is vascular and sacculated with alveoli. In *Amia* and *Lepidosteus* bladder is single, dorsal, and opens dorsally into pharynx. In *Neoceratodus* also it is single and dorsal but opens ventrally into pharynx. However, in *Lepidosiren* and *Protopterus*, it is bilobed, ventral and opens ventrally into pharynx. The gills in these fishes are poorly developed so that they will die due to asphyxiation if not allowed to reach surface to take in fresh air. The swim bladder of feather tail, *Notopterus notopterus* has a wide pneumatic duct and a network of blood capillaries covered by a thin epithelium in its wall. This helps in exchange of gases.

Parental Care in Fishes

Fish as a group pay little parental care to their eggs and young. Most of them are content to

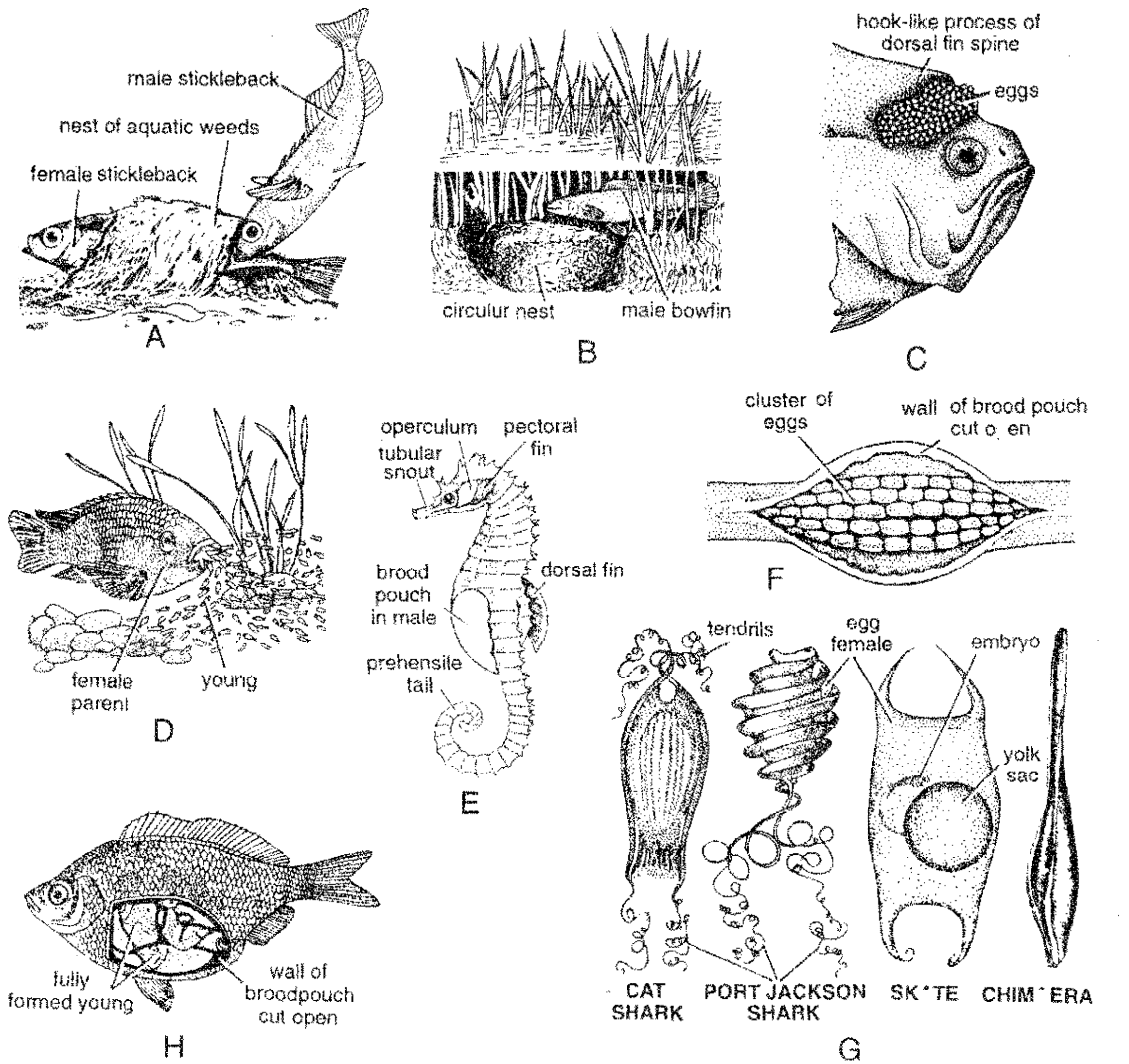

Fig. 10. Some interesting examples of parental care in fishes. A—Male stickleback (*Gasterosteus aculeatus*) muzzles female at the base of tail to stimulate her to lay eggs in a nest of dead aquatic plants. B—Male bowfin (*Amia calva*) guarding over circular nest. C—The male Australian *Kurtus* incubates eggs on its forehead. D—Very young of *Tilapia mossambica* take refuge in female parent's buccal cavity in times of danger. E—A male *Hippocampus* carrying brood pouch. F—Brood pouch of male *Syngnathus* opened to show eggs. G—Mermaid's purses for eggs. H—Body cavity of *Cymatogaster aggregatus* cut open to shown fully formed young ready for hatching.

ensure fertilization of their eggs but bestow little attention on them. This lack of parental behaviour is correlated with production of great numbers of eggs and sperm. There are, however, some notable exceptions in which the eggs and young are guarded with great solicitude mostly by the male parent (Fig. 10).

1. Nest building. Most interesting example is provided by the male stickleback (*Gasterosteus aculeatus*), a small freshwater fish of North American lakes and ponds. The male fish actually builds a nest of dead aquatic plants making use of a sticky secretion from his kidneys. When the nest assumes a considerable size, the male makes a small tunnel. By an elaborate courtship ritual, he induces several females to lay eggs in a tunnel in the nest. Then he guards over the fertilized eggs, keeping away all intruders in a fierce manner, till they are hatched. The bowfin (*Amia calva*) of the great lakes of North America, builds a crude circular nest among aquatic plants. The male keeps guard until the eggs hatch and then keeps the young fish with him for some time afterwards. The male of African lung fish (*Protopterus*), digs oval pits or holes at the base of tall swamp grasses. As many as 5000 eggs may be laid in a single hole or nest by several females. The male vigorously guards them and even thrashes surface to aerate water around the eggs. The male of American lungfish (*Lepidosiren*) leaves the nest, a tunnel-like burrow, periodically to gulp atmospheric air so that oxygen diffuses from the freshly aerated blood of its modified pelvic fins near the eggs and young. In *Betta, Macropodus* and several other fishes, the eggs collected by the males in their mouths are thrown to adhere to floating nests of mucous and air bubbles.

2. Coiling round eggs. In *Pholis*, one of the parents possibly the male guards by coiling round the eggs, rolled into a ball or sphere until they hatch.

3. Attachment to body. The male of the New Guinea fish, *Kurtus* entangles the egg mass on a hook like process on head until they are hatched.

4. Integumentary cups. In the siluroids, *Aspredo* and *Platystacus*, the fertilized eggs are pressed into the soft spongy skin of belly of the female. Each egg becomes attached by a stalk into a cup-like depression of integument and carried until hatching.

5. Shelter in mouth. There are several species of mouth-brooding fishes. The fertilized eggs are carried in the mouth cavity by males in the catfish *Arius* and by females in the Cichlid, *Tilapia*. The very small young also take refuge in the parental buccal cavity in times of danger.

6. Brood pouches. In the sea horse, *Hippocampus* and pipe fish *Syngnathus*, the female transfers eggs into a brood pouch on the belly of male to be kept until hatching takes place.

7. Mermaid's purses. Oviparous sharks (e.g. *Scyllium*) lay fertilized eggs inside protective horny egg capsules or mermaid's purses, which remain anchored to see weeds by their long tendrils. The young hatch out after rupturing the egg case.

8. Viviparity. A few species of fishes are viviparous, such as the dogfish, *Scoliodon* and the surf fish *Cyamatogaster aggregatus*. Both fertilization and development are internal. Developing embroys are nourished mostly by a yolk sac placenta and the young are born with the characteristics of the adult. Viviparity provides maximum protection and represents the highest degree of parental care.

Migration in Fishes

Many fishes, like birds, perform seasonal migrations. The barracudas (*Sphyraena*) and swordfish (*Xiphius gladus*) of the warm tropical seas perform *latitudinal migration*, moving north in spring and south in autumn. Some deepwater fishes perform daily vertical migration. Migration is sometimes limited to freshwaters only, it is called *potamodromy* or *limnodromy* and some times limited within the sea called *oceanodromy*. However, migration between the two is called *diadromy*, which is classified into two categories. Movement from fresh water to salt-water (sea) for spawning is called *catadromous migration*. The most famous example of catadromous fish is the freshwater eel, *Anguilla*. The reverse movement, that is, from salt-water to fresh, is termed *anadromous migration*. Examples of anadromous fishes are salmon, shad, striped bass, sturgeon, *Alosa, Hilsa* and some trout. Completely free movement between fresh and marine water without the purpose of breeding is called *amphidromous* migration, exhibited by fishes like *Megalopa, Chanos* etc. (Fig. 11).

1. Eels. The best example of *catadromous migration* is furnished by two common species of eels, *Anguilla rostrata* of European freshwater rivers and *Anguilla vulgaris* of America. With the advent of autumn, their colour changes from yellow to metallic silver. Feeding stops with the

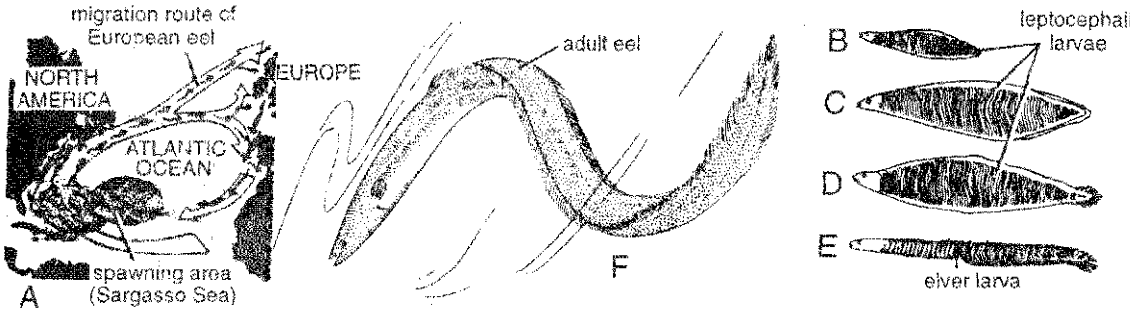

Fig. 11. Migration of fresh water eel, *Anguilla*. A—Migration route and breeding place. B,C,D—Leptocephali larvae. E—Elver or glass eel. F—Adult eel.

shrinking of their digestive tract. Eyes become larger, snout becomes sharper with thinner lips and the gonads are fully mature. The silvery eels then enter sea and migrate about 4500 kilometers westwards from Europe or eastwards from America. Reaching their breeding place in the Sargasso Sea off Bermuda, the adults die immediately after spawning in deep waters. The eggs hatch into little transparent, leaf-like flattened pelagic larvae, called *leptocephalia*, less than 6 mm long. They have sharp needle-like teeth for feeding. During their long return journey towards homes of their parents, they grow into *elvers* or *glass eels* about 8 cm long, with cylindrical bodies. On reaching land, the males remain behind in brackish waters near coasts, while the females ascend freshwater streams and rivers. The elvers feed and grow to become yellow eels in some years. How the elvers without parents are able to find their way across the sea towards homes of their parents remains an unsolved mystery. Until their real identity was discovered, the leptocephali larvae were called *glass fishes* and placed in the genus *Leptocephalus*. The biggest larva of some unknown species was 184 cm long which was captured in 1930 by Dana Expedition west of the Cape of Good Hope (Africa).

2. Salmon. There is a single species of Atlantic salmon (*Salmo salar*) and 5 species of Pacific salmon (*Oncorhynchus*). They furnish the best example of *anadromous migration*. In winter, both the sexes leave their feeding grounds at sea to ascend the freshwater mountain streams, reaching the identical spot where they originally grew some years before. They stop feeding, change to a dull reddish brown from silver, and excavate shallow saucer-like pits in bottom gravel. After spawning the adults die, but some of the Atlantic species (*Salmo*) may survive, return to sea and spawn for a second or third time in life. After hatching, the larval fish feed and grow for some time in the streams before going out to sea. The young salmons grow faster in the ocean because of abundant food there. Experimental evidence shows that strong olfactory sense of salmon determines its homing into the original birth place, for different streams have different odours.

Economic Importance of Fish

Fish have considerable economic importance. They are useful as well as harmful to man.

[I] Useful fishes

1. As food. Nearly all fish, freshwater and marine, are edible and have been an important source of protein food since time immemorial. In most fishes, the flesh is white, contains 13 to 20% of protein and has a food value of 300 to 1600 calories per pound. According to Pottinger and Baldwin, fish meat contains at least 5 of the essential amino acids. Besides this, it contains vitamin A and D together with large amount of phosphorus present in it. Important marine food fishes include salmon, cod, halibut, herring, eels, tuna, mackerel and sardines. Important freshwater food fishes are catfish, trout, bass, perch and mullet. Even eggs of certain fishes, such as Russian sturgeon, are eaten as cavier. The major food fishes of India include species of *Labeo, Catla, Cirrhina, Mystus, Wallago, Notopterus, Ophiocephalus*, etc. The cartilaginous sharks, skates and rays are also used as human food in several countries. They are eaten by poorer classes of people along the sea coasts of India and Sri Lanka. The canned meat of sharks is sold commercially under the name of gray fish. In south-east Asian countries, shark fins are dried and boiled to get a gelatinous material used in soups.

Fresh fish meat is usually cooked for human consumption. However, large quantities are refrigerated, salted, smoked, canned or pickled. Today, fisheries of the world carry on business worth several hundred thousand rupees annually and also provide employment to thousands of people.

2. Fish oils. Fishes provide vast supplies of commercial oil. Oils are extracted from liver and body of several fishes like sharks, rays, cod, salmons, sardines, herrings, mackerels, etc. Liver oil is good source of vitamin A and D. The body oil is of two types. The oil having higher iodine value is called *drying oil*. And oil having lesser iodine value is called *semidrying oil*. Large quantity of crude fish oil is used in the manufacture of paints, insecticides, soaps, medicines and other purposes.

3. Fish skin and leather. Shark skin leather is of some commercial importance in the manufacture of many useful articles such as shoes and handbags. In Japan, lanterns are prepared from the skin of puffer fishes (e.g. *Tetrodon*). Some tribal people used skins of puffer and porcupine fishes (e.g. *Diodon*) for war helmets. Crude skins of sharks and rays are used by carpenters and metal workers. Shark skin tanned with placoid scale on it, is called *shagreen*. It has been used as an abrasive for polishing wood and ivory and also for covering jewel-boxes, fine books and sword handles.

4. Fish meal and fish manure. Suitable scraps from canneries as well as unpalatable and unmarketable fishes are ground, dried and prepared into fish meal used to feed poultry, pigs, cattle and pet animals. Sharks mixed with other unpalatable fishes, crushed and ground bones and refuse of no other use, make good fertilizer for tea, coffee and rubber plantation. It is rich in nitrogen and calcium phosphate.

5. Fish glue. Liquid glues are prepared from skin, heads and other trimmings of certain fishes. It has adhesiveness of great power.

6. Isinglass. It is a gelatinous product obtained from the air bladders of certain fishes such as sturgeons, carps, perches, salmons, catfishes, cods, etc. It is variously used for making certain cements, jellies and for clarification of wines and beers. The finest quality of isinglass is obtained from Russia.

7. Medicines and disease control. Refined oils extracted from livers of cods and sharks are rich in vitamins A and D. Pituitary glands yield important extracts for medicines. Fishes like top minnows (*Gambusia affinis*), *Trichogaster, Esomus, Barbus, Panchax*, etc., feed voraciously on mosquito larvae. These larvicidal fishes are propagated and distributed widely into ponds, lakes and tanks to destroy mosquito that transmit malaria, yellow fever and other dreadful diseases of tropical countries. Certain fishes and their bye-products contribute to useful Ayurvedic and Unani medicines for the treatment of duodenal ulcers, skin diseases, night blindness, general weakness, loss of appetite, colds, coughs, bronchitis, ashthma, tuberculosis, etc.

8. Sport and recreation. Sport fishing by individuals and fishing parties is a popular recreation for million of people, as well as a source of food, all over the world. Most commonly hunted fishes are the freshwater perch and trout and the marine tarpon. However, some of the best game fish are not taken as food. The *Tarpon*, for example is most famous for the sport that it provides, but its flesh is not palatable. Many people's hobby is to cultivate certain tropical fishes as pets. Both native as well as foreign fishes are displayed in home aquaria for their beauty and graceful movements. Common aquarium fishes are gold fish (*Carassius auratus*), angel fish (*Pterophyllum*), sword tail guppy (*Xiphophorus*), minnow (*Gambusia affinis*), siamese fighter (*Betta splendens*), paradise fish (*Macropodus*), *Hemigrammus*, *Aphyocharax*, loach (*Botia*), *Trichogaster, Tilapia*, etc. Goldfish are cultured and not found in nature and the Japanese have produced their several curious artificial varieties. Petshops now-a-days stock many kinds of fishes for hobbyists and scientists.

9. Fancy articles. Scales of garpike (*Lepidosteus*) are used for jewelry and novelties. From scales of some fish is secured a pigment whose water suspension is known as *pearl essence*. It is used in the manufacture of artificial pearls in Europe, especially in France.

10. Scientific study. Fishes have considerable use as experimental animals, especially in the fields of Genetics, Embryology, Animal Behaviour and Pharmacology. Certain fishes such as *Latimeria* and dipnoans have anatomical features of great zoological interest. Fishes like dogfish (*Scoliodon*), perch (*Perca*) and carp (*Labeo*), etc., are dissected for study in zoological laboratories. Researches in Ichthyology are conducted for the benefit of fisheries and mankind.

[II] Harmful fishes

1. Destructive. All cartilaginous fishes are predaceous and feed chiefly on large quantities of crabs, lobsters, squids and other valuable marine animals. They cause great harm by destroying eggs, young and even adults of our food fishes. Sharks are particularly a big nuisance to fishermen because they tear nets, steal baits, devour captured fish and drive away squids and fishes to be netted. The damage done by these sharks amounts to several hundred thousand rupees.

2. Injurious. Larger sharks and sword fish may capsize small boats and injure or even kill fishermen. All sharks, small or big, are a menace to bathers and skin divers in shallow waters. The pirhanas of Central and South America have very strong teeth and are dangerous even to men.

Some fishes like cartilaginous electric ray (*Torpedo*) have electric organs which give powerful shocks to swimmers and fishermen. An extreme case of specialization is the bony electric eel (*Electrophorus electricus*) of the Amazon. It is

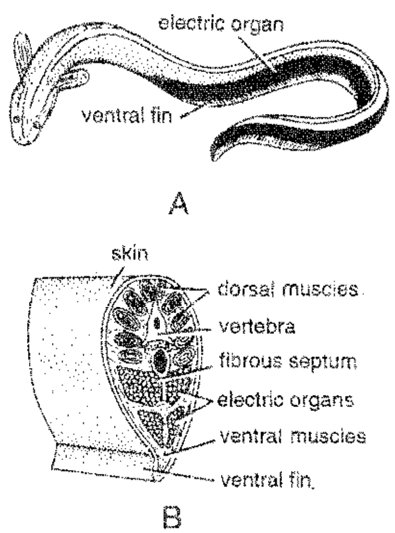

Fig. 12. Bony electric eel, *Electrophorus electricus*. A—Adult showing the extent of electric organ. B—Section of tail showing internal position of electric organ.

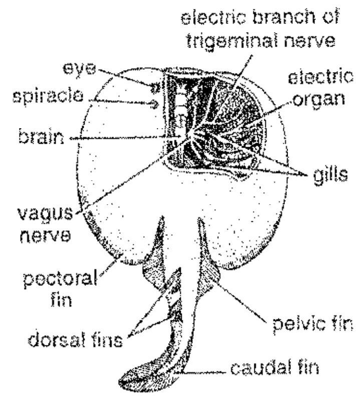

Fig. 13. Electric ray *Torpedo*, partially dissected on the right side to show the electric organ and its nerve supply.

nearly 1.5 meters long and the postero-ventral four-fifth part of its body is occupied by the electric organ. It can generate electricity upto 600 volts in potential with a maximum output of 1000 watts (Figs. 12 & 13).

3. Poisonous. Poisonous glands are found in many cartilaginous fishes such as stingray (*Trygon*), and eagle ray (*Myliobatis*). They can inflict painful wounds, sometimes fatal by their poisonous stings or spines. Poison glands are also found in *Squalus* (dogfish), *Heterodontos, Chimaera, Diodon* (porcupine fish), *Tetrodon* (globe fish), scorpion, fish, etc. These are also capable of causing wounds by their spines or spiny opercula. Flesh of some tropical fishes (e.g. *Tetrodon*) is also poisonous.

[III] Breeding of fishes

Since fish form an important food and a large population in most of Asian countries eat fish, techniques are being developed for increased fish production. Techniques used for breeding of fishes are described in short in the following account :

Major edible fish species like *Labeo rohita*, *Cirrhina mrigala* and *Catla catla* etc. (major carps) breed naturally in rivers in the monsoon months. They show local migration and go to shallow marginal waters to breed. Fertilization is external. Female lays eggs in water and the male sprinkles its sperm in the form of milt over them. One gravid female fish may contain 4-20 lakhs eggs in the ovary depending on the species. Eggs hatchout within 18-36 hours. Major carps attain maturity when they are three years old and the environmental conditions are favourable. They show sexual diamorphism. Females are generally larger than the males.

1. Bundh breeding of Indian major carps. Major carps do not naturally breed in confined waters though they attain sexual maturity. They breed in rivers, reservoirs and artificial bundh type tanks where favourable conditions stimulate them for spawning. By this method of induced breeding in confined waters large number of eggs can be procured which can be transferred to larger tanks to grow. Bundhs are of two types :

(a) Dry bundh. It is a shallow depression enclosed by earthen walls on three sides and an extensive catchment area on the fourth side. Bundh gets flooded during the south-west monsoon, but remains comparatively dry for a considerable period of the year.

(b) Wet bundh. It is a perennial pond located on the slope of a vast catchment area. It has inlets towards the upland and outlets towards the low land. During summer months the deeper portion of the pond retains water containing breeders. The remaining portion is dry and is used for agriculture. In monsoon the water fills in the large part of the bundh. The fish gets almost natural conditions and spawns. The wet bundhs are much bigger than the dry bundhs. For more successful results, the breeders are collected from perennial reservoirs just before the onset of monsoon and males and females are kept in separate tanks. With the onset of monsoon, the breeders are introduced into the bundhs to spawn.

After lowering the water level, eggs are collected by dragging a piece of mosquito net cloth and are carried to cement hatcheries measuring $2.4 \times 1.2 \times 0.3$ m.

2. Fish seed production by induced breeding. Fish eggs collected from the natural waters are generally a mixture of more than one species of fishes and it is very difficult to sort them out. Also since the fish seed collection centres are located at remote places, difficulties are encountered in transporting the eggs as a number of eggs die during transport. Also it is expensive to transport the eggs. For this reason a technique known as induced breeding has been developed which is giving very good results in India and other Asian countries. This is also known as hormone injection technique.

3. Hormone injection technique. Sex stimulating hormones of the pituitary gland are follicle stimulating hormone (FSH) and luitinizing hormone (LH). FSH helps in the development and maturity of sex organs and LH largely helps in spawning. Environmental factors like light intensity, temperature, rain etc. regulate the seasonal cycle of the fish. Pituitary gland of fully mature fish is rich in the gonadotropins (FSH and LH) and pituitary glands collected from such fishes are put in absolute alcohol. After 24 hours the absolute alcohol is changed and the glands are then transferred to small phials with fresh alcohol and kept in refrigerator until required. The hormones of pituitary are soluble in water and insoluble in alcohol. When required, the preserved pituitary glands are taken from the phial and kept on a filter paper to allow alcohol to evaporated. It is then weighed and is macerated in a tissue homogeniser. 0.3% salt solution is used for making a homogenate which is further diluted with the salt solution. A total quantity of 5 to 10 mg of pituitary gland per kg body weight of the female and 2 to 6 mg/kg body weight of males in a single or double doses gives successful results. After injection of the hormones the males and females called brooders are put together. After 8-10 hours stripping of females and males is done for good results. HCG (Human Chorionic Gonadotropin) is also administered to the breeders. HCG doșe is prepared by dissolving 01 mg HCG powder in 12 ml distilled water. Female breeders are given 3-4 mg per kg body weight, 3-4 months prior to breeding. It is also administered to the breeders at the dose of 5-6 mg per kg body weight at the time of breeding in addition to the pituitary extract. A 3 ml graduated syringe is used for injection. For injecting, the breeders are weighed and kept on wet sponge and held by one person. The other person injects the dose on the caudal peduncle. Soon after injection the breeders are left in a breeding hapa measuring $3.5 \times 1 \times 1$ metre and the top of the hapa is also covered. The hapa is fixed to bomboo poles in pond, river or canal water. Injections are given in the evening and the hapa is left undisturbed. The fish spawns within 6-8 hours after the injection. In this way large quantity of eggs can be collected which can be suitably handled economically.

4. Preservation of food fishes. Fish and other sea foods are perishable, therefore, they have to be carefully handled after the harvest as it has to be transported to distant places. Immediately after the catch is received the fish is given a thorough wash with chlorinated sea water to eliminate the bacteria. Preservation is done by the following methods :

(a) Preservation by ice. This is cheapest and reasonably efficient method of preservation. By this method fish can be kept in good condition upto 15 days depending on the species. Fatty fishes can be stored for only 2-5 days due to oxidation of fatty acids. Fishes are packed in boxes covered from all sides by crushed ice layers. In place of ordinary ice, ice containing antibiotics like chelotetracycline and oxytetracycline in low concentration gives better preservation for longer duration.

(b) Preservation by refrigerated sea water. This method is good for nonfatty fishes. Fatty fishes develop black spots. This method is more commonly used by the bigger vessels and trawlers which go to distant off-shore areas. Sea water contains 3-4% salt, hence, freezing point of water is lower than ice i.e., 1.5°C.

(c) Freezing. For this method suitable freezing cabinets or rooms are used. Liquified nitrogen, carbon-dioxide or air is used for freezing. For transport of frozen fish by air, solid carbon dioxide (dry ice) is used. Quick freezing methods are more advantageous.

(d) Canning. The principle of canning process is the destruction of microorganisms present in fish by heat application. The canned food is then packed in cans and sealed airtight so that no more microorganism can enter the fish. Canned food can be kept at room temperature for years. Apart from this, sometimes on small scale are preserved by pasting, pickling and spicing.

(e) Dehydration. Moisture helps the growth of bacteria. By drying of fish microbial spoilage can be prevented to a good extent. Sundrying is a traditional process of fish preservation. Since it is a slow process the fish lose some of the nutrients due to exposure to sunlight. Also some bacterial contamination may occur. By vacuum drying moisture is removed by application of low temperature in vacuum. Heat is then given by conduction or radiation.

(f) Salting (salt curing). Salting is infact drying of fish by using salt. Salt absorbs moisture of the cells. It also brings about plasmolysis of the bacterial cells. The enzymes of the tissue are also destroyed so that decomposition is also prevented. Small fish can be salted as such while bigger fish has to be dressed (removal of gills and internal organs) and they are split open along the vertebral column. In still larger fishes many incisions are made after dressing. In this method the fishes are either immersed in concentrated salt solution or are kept in boxes with alternate layers of salt and fish. Salting is done in fish preservation earlier to drying, smoking and canning processes.

(g) ***Smoking.*** The flesh of smoked fish is tender and delicious and can be consumed without further cooking but it has short shelf life. Smoking is an intermediate step in the preparation of canned smoked fish. The phenolic content of smoke has preservative action. Smoking methods are of four major types :

(i) Hot smoking. This is carried out in kilns. Fresh, frozen or chilled fish of good quality can be hot smoked. The frozen fish is defrosted and washed. It is then salted, the excess salt rinsed and the fishes are tied in bundles. These bundles are arranged in layers in cages, fried, cooked and subjected to hot smoking inside the kiln.

(ii) Cold smoking. In this method the fish is dressed and salt dried. The dried fish is stacked in bundles and subjected to smoking at 40°C for about 3 to 4 days.

(iii) Electrostatic smoking. In this process fish is first smoked and then cooked. Smoking is done in big containers under high voltage electric field. Smoke is provided by generators. This is a comparatively quick method.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Classify the superclass Pisces giving characters and examples of its main groups.
2. Give a general account of Dipnoi and discuss their affinities.
3. Describe the different types of scales found in fishes.
4. Discuss the various theories concerning the origin of paired fins in fishes.

» *Short Answer Type Questions*

1. Draw a comparison between Chondricthyes and Osteicthyes in a tabular form.
2. Write an essay on — (i) Accessory respiratory organs of teleosts, (ii) Air bladder of fishes, (iii) Economic importance of fishes, (iv) Migration in fishes, (v) Parental care in fishes.
3. Write short notes on — (i) Cycloid and ctenoid scales, (ii) Dipnoi, (iii) Hetrocercal tail, (iv) *Neoceratodus*, (v) *Protopterus*, (vi) Swim bladder, (vii) Salmon.

» *Multiple Choice Questions*

1. Super class Pisces includes organisms which are essentially aquatic and use :
   (a) Paired fins for swimming and gills for respiration
   (b) Paired fins for respiration and gills for swimming
   (c) Paired fins for locomotion and gills for sound production
   (d) Paired fins for sound production and gills for respiration
2. The fish body is divided into :
   (a) Head and trunk (b) Head, trunk and tail
   (c) Head, neck trunk and tail (d) Head, neck and tail
3. In fishes, the paired nasal sacs
   (a) open into mouth (b) open into pharynx
   (c) Do not open into mouth
   (d) Open into internal ear
4. The eggs of fishes are :
   (a) Micro lecithal, extra embryonic membranes absent
   (b) Meso lecithal, extra embryonic membranes absent
   (c) Mega lecithal, extra embryonic membranes present
   (d) Mega lecithal, extra embryonic membranes absent
5. The super class Pisces is divided into three subclasses :
   (a) Placodermi, Chondricthyes and Osteicthyes
   (b) Actinopterygii, Chondricthyes and Osteicthyes
   (c) Elasmobranchi, Chondricthyes and Osteicthyes
   (d) Ptericthyes, Coccostei and Acanthodi
6. Rectal glands are present in :
   (a) Both Chondricthyes and Osteicthyes
   (b) Only Chondricthyes (c) Only Osteicthyes
   (d) Neither chondricthyes nor Osteicthyes
7. Liver in Osteicthyes is :
   (a) 1 lobed (b) 2 lobed (c) 3 lobed (d) 4 lobed
8. Members of order Dipnoi are commonly known as :
   (a) Pipe fishes (b) Cow fishes
   (c) Cat fishes (d) Lung fishes
9. *Neoceratodus* is found in :
   (a) Australia (b) Asia
   (c) South Africa (d) South America
10. *Protopterus* is commonly known as :
    (a) Australian lung fish (b) African lung fish
    (c) American lung fish (d) Asian lung fish

11. The accessory organ of respiration in Lung fishes is :
(a) Swim bladder (b) Gills
(c) Lungs (d) Urinary bladder
12. The centrum in vertebrae in Lung fishes is :
(a) Procoelous (b) Amphicoelous
(c) Acoelous (d) Absent
13. The body of Lung fishes is covered with :
(a) Cycloid scales (b) Ctenoid scales
(c) Ganoid scales (d) Placoid scales
14. The internal nostrils in lung fishes :
(a) Open into lungs (b) Open into mouth cavity
(c) Do not open into mouth (d) Open into pharynx
15. Pelvic fins in fishes are called thoracic when :
(a) They are situated anterior to pectoral fins
(b) They are situated just above the pectoral fins
(c) They are situated just below the pectoral fins
(d) They are situated just in front of anus
16. Lateral and median fins are used as :
(a) Swimming organs (b) Defensive organs
(c) Sound producing organs
(d) Steering devices
17. The caudal fin in *Latimeria* is :
(a) Single lobed (b) Bilobed
(c) 3 lobed (d) 4 lobed
18. Swim bladder is absent in :
(a) Teleosts (b) Acanthodians
(c) Placoderms (d) Elasmobranchs
19. Which of the following is not a function of air bladder :
(a) Reproduction (b) Respiration
(c) Hydrostasis (d) Sound production
20. Which of the following is not an accessory respiratory organ in fishes :
(a) Skin or integument (b) Pectoral fins
(c) Pelvic fins (d) Gut epithelium
21. Brood pouches are developed in *Hippocampus* :
(a) On the back of female (b) On the belly of female
(c) On the belly of male (d) On the back of male
22. Catadromous migration refers to movement of fishes :
(a) From freshwater to freshwater
(b) From saltwater to saltwater
(c) From saltwater to freshwater
(d) From freshwater to salt water

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d) 13. (a) 14. (b) 15. (c) 16. (d) 17. (c) 18. (d) 19. (a) 20. (b) 21. (c) 22. (d).

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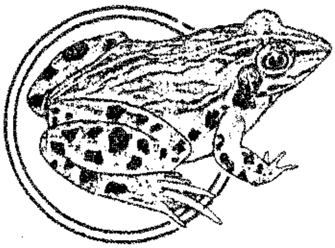


Type 7. *Rana tigrina** : Common Indian Bull Frog

In early Carboniferous period, some crossopterygian fishes developed into the first land vertebrates. These were primitive stem Amphibia called *Labyrinthodontia*. Some of them gave rise to modern amphibians, such as frogs, toads and salamanders. Although credited to be first land vertebrates, they are not fully adapted for a terrestrial existence like higher tetrapods. The name of the class *Amphibia* (Gr., *amphi*, dual or both + *bios*, life) indicates that these animals live at different times in their life cycle in two environments—water and air or land. Thus, the class Amphibia represents a transitional group between the strictly aquatic earlier vertebrates and strictly terrestrial later vertebrates. The animal widely studied as the representative of the class is the familiar frog, although toad is substituted in some cases.

Suitability for Study

Frog is selected because of several reasons in its favour. It is better known than toad. It is non-poisonous, easy to procure and inexpensive. Its size is convenient for dissection. It is a nice clean animal, admirably suited for physiological experiments. Its internal anatomy can be demonstrated merely by opening its body cavity. It does not give foul smell and can be kept alive without food for several days. Its physiology is well known and easily demonstrated. Its natural history is simple and easily observed. Its form and functions are similar to those of higher vertebrates, including man. It is convenient to make comparisons between lower and higher vertebrate types. In fact, frog is widely used even as a type of vertebrates in Introductory Zoology for beginners.

* Now called *Hoplobatrachus tigrinas*

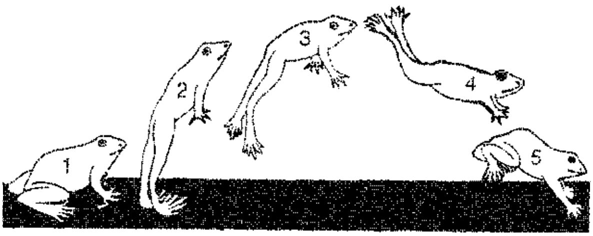


Fig. 1. Frog. Stages of leaping on land.

Most frogs are similar in external appearance and internal morphology, differing only in colour, size and special features. The following description is based mainly on the common Indian bull frog *Rana tigrina*, but in general it applies equally well to ot' er species.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Division	Gnathostomata
Superclass	Tetrapoda
Class	Amphibia
Order	Anura (=Salientia)
Suborder	Diplasiocoela
Family	Ranidae
Type	*Rana tigrina** (Common Indian bull frog)

Habitat

Frogs in general are found in or near water and in very damp places on land. The common Indian bull frog, *Rana tigrina* lives in or near permanent freshwater lakes, ponds and streams. It is in the water most of the time. It lives near water mainly for two reasons : (i) To keep skin moist to carry on cutaneous respiration, and (ii) To immediately jump or slip into water to escape from enemies.

Habits

Frogs are non-poisonous, harmless and normally silent animals. The presence of a frog is difficult to detect unless it is disturbed. It is very agile and an excellent jumper.

1. Locomotion. Frog moves in two ways, by *leaping* on land and by *swimming* in water. Its muscular and endoskeletal systems have become well specialized to do so.

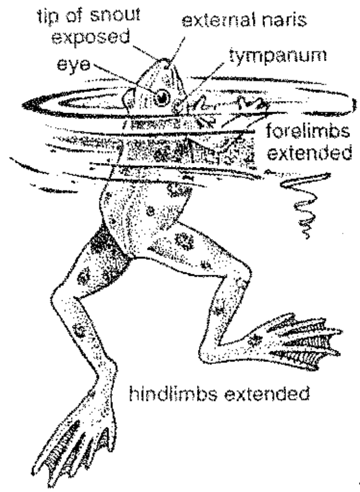


Fig. 2. Frog floating in water.

(a) Leaping. A frog rests on land with its short forelimbs upright and the very long and powerful hind limbs or legs flexed or folded in the manner of 'Z'. During ordinary resting position front part is inclined upwards and is called *squatting posture*. It jumps or leaps by suddenly extending the hind limbs which act like springs throwing the body up into air. A frog may leap a distance of 1.5 to 2 metres in a single jump. On landing back the forelimbs act like shock absorbers. The forelimbs also manipulate and adjust the direction of the jump (Fig. 1).

(b) Swimming. The frog swims in water by powerful backwards thrusts of its hind limbs which act like propellers. During their backward strokes, the toes are spread apart and the broad webs push against water, moving the body forward. Forelimbs usually take no part in swimming. However, the right and left forelimbs are moved alternately when the frog is paddling around leisurely. Forelimbs basically perform two functions, they help in propelling the animal to some extent and in guiding the direction of movement. When frog comes to surface to breathe, or simply to float, only the tip of snout carrying nostrils is exposed, with fore and hind limbs extended in water. When disturbed in this position, it immediately dives under water (Fig. 2).

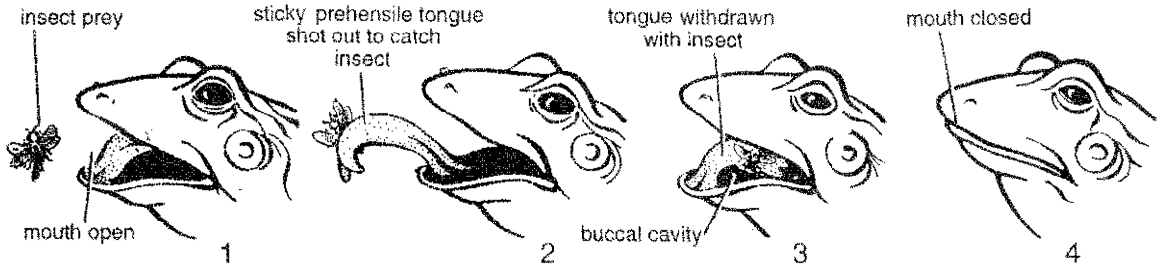


Fig. 3. Frog. Mechanism of capturing prey with sticky prehensile tongue.

2. Feeding. Frogs are carnivorous and food consists mainly of living insects, worms, molluscs and tadpoles, which are caught by a sudden flip of its large protrusible sticky tongue attached at the front end and free behind. Any motionless object or food is simply ignored. The food is not chewed but swallowed whole (Fig. 3).

3. Croaking. The characteristic noise or sound made by frogs is known as *croaking*. It is commonly heard is breeding season during rains and is a mating call. It is produced by forcing air from lungs over vocal cords into mouth cavity and back again. Frogs can croak under water as well as on land. It is louder in males due to presence of a pair of distensible balloon-like loose skin folds on throat, called *vocal sacs*. These act as resonators.

4. Hibernation and aestivation. Being *cold-blooded* or *poikilothermous* animals, the body temperature of frog fluctuates with that of the environment. During adverse environmental conditions in cold winter or dry hot summer days, frogs burry in the soft damp bottom mud for protection. They become metabolically inactive and stop feeding, living only on the glycogen and fat stored in their bodies. Lung respiration is suspended and cutaneous respiration through damp skin alone is sufficient. This state of dormancy or suspended animation is called *hibernation* or 'winter sleep' during winter and *aestivation* or 'summer sleep' in summer. With the end of cold winter or hot summer season, the frogs come out to lead a normal active life once again. According to Fischer-Sigwarts, frogs do not undergo aestivation (Fig. 4).

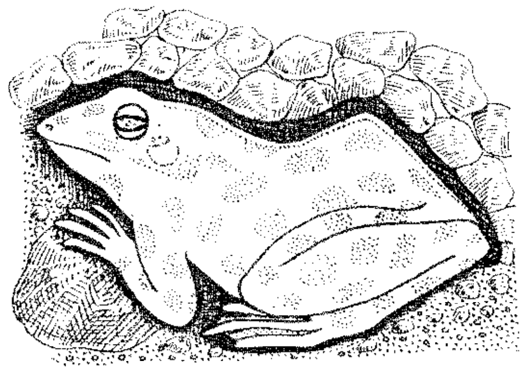


Fig. 4. Frog in hibernation or aestivation.

5. Camouflage. Frogs are not easily noticeable by their enemies as they can change the colour of their skin to match with that of the surroundings. This type of protective colouration is known as *camouflage*. Changes in colour are possible by dispersion or concentration of special amoeboid pigment cells in their skin.

6. Breeding. With the onset of rainy season, frogs emerge out of aestivation and immediately start breeding which lasts from July to September. Males gather in appropriate shallow waters and start croaking justly to attract females for mating or copulation. The male mounts upon the back of the female and grasps firmly around her thorax by his forelegs. The roughened *nuptial pads* on the bases of inner fingers of male are fully developed during breeding season and help him in holding the slippery female. This sexual embrace, called *amplexus*, may continue for several days until the female deposits several hundred ova or eggs through her cloaca into water. The male also discharges milt or seminal fluid containing spermatozoa over eggs to fertilize them. Thus, fertilization is external. The male now releases his grip and leaves the female. Mass of eggs, called frog's *spawn*, is embedded in a gelatinous material which on contact with water swells into a protective transparent jelly. Within two weeks fertilized eggs or zygotes develop into free-swimming aquatic larvae, called *tadpoles*, which undergo metamorphosis to become adult terrestrial frogs (Fig. 5).

7. Enemies. Several natural enemies eat adult frogs and tadpoles thus reducing their numbers. The chief enemies are snakes, turtles, mongooses, racoons, crows, vultures, aquatic birds, fishes, other amphibians and man. Frogs also serve as hosts for different kinds of parasites, such as protozoans (*Opalina, Nyctotherus, Balantidium, Trichomonas, Entamoeba*), lung flukes (*Haematoloechus, Pneumobites*) and nematodes (*Rhabdias*).

8. Economic importance. Frog is used for laboratory study more often than any other animal as a vertebrate type. It is also used for researches in Physiology, Pharmacology and human pregnancy tests and as a fish-bait. It is a good friend of farmers as it feeds on insects harmful to crops. The muscular hindlegs of frogs are used as food by men. They are even reared at farms in some parts of the world.

External Features

1. Shape and size. Body of a frog is somewhat spindle-shaped, pointed anteriorly and rounded posteriorly. It is slightly flattened dorsoventrally and streamlined to swim through water. It is divisible into distinct head, trunk and limbs, there being neither a neck nor a tail. Size of adult *Rana tigrina* varies from 12 to 18 cm in length and 5 to 8 cm in width.

2. Skin and colour. Skin of frog is thin, moist, slimy, smooth and fitting loosely on the body. Unlike the skin of dogfish, there are no placoid scales or any other hard exoskeletal parts. Skin of back has dorso-lateral folds or thickenings

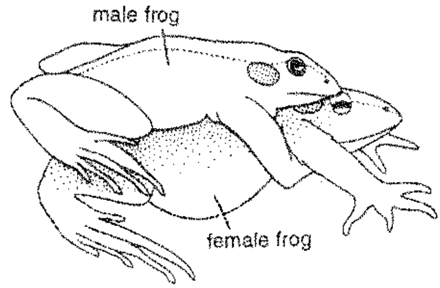


Fig. 5. Frogs in amplexus.

called *dermal plicae*. Colour of skin is green with black or brown spots dorsally but lighter pale-yellow ventrally. Indian bull frog is called *Rana tigrina* due to its mottled colouration like that of a tiger. A light yellow mid-dorsal line runs from tip of snout to the cloacal opening on the back. The colour of the skin is basically due to three layers of pigment cells. The melanophores lie in the deepest layer, guanophores lies in the intermediate layers and lipophores over lying these. The guanophores are full of granules which by diffraction produce green colour, while the lipophores filter out b ie. Change in colour of skin is produced by expansion of pigment in the melanophores under the influence of secretions of pituitary gland.

3. Head. Head of frog is more clearly demarcated from trunk than the head of dogfish. It is flat, roughly triangular in outline and with a short blunt anterior *snout* terminating in a wide transverse *mouth*. Two small openings, the *external nares* or *external nostrils*, lie dorsally above the mouth, at the tip of snout and serve in respiration. Two very large, spherical and protruding *eyes* are situated dorsolaterally on top of head. When pressed downwards, they make marked prominences on the roof of buccal cavity. Unlike higher animals, eyes do not rest on any bone. Each eye has a thick, pigmented and almost immovable *upper eyelid* and a thin semi-transparent and freely movable *lower eyelid*. From the lower eyelid arises a transparent third eyelid or *nictitating membrane*, which covers and protects the eye during swimming and keeps it

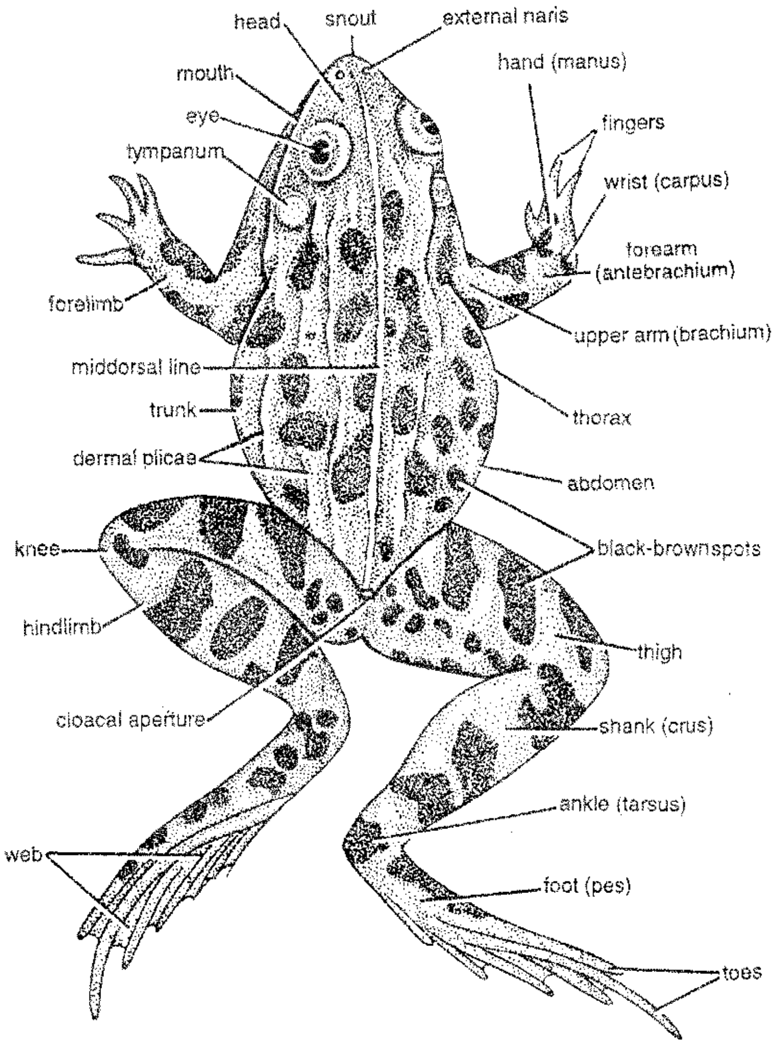


Fig. 6. *Rana tigrina*. External features in dorsal view.

moist in air. A median light-coloured patch or *brow spot* just in front of eyes represents the vestigial pineal eye. Behind and below each eye is a conspicuous, flat and deeply pigmented circular patch of skin, the *eardrum* or *tympanum*, that receives sound waves. An external ear is lacking. In male frog, the throat bears two bluish patches of skin, the *vocal sacs*, which act as resonators to intensify sound of croaking during breeding season (Figs. 6–8).

4. Trunk. Head is broadly joined behind with the flat ovoid trunk. Its back is raised in the middle in a characteristic sacral prominence of *hump*, especially conspicuous when the frog is squatting. At the posterior end of trunk is a small circular *cloacal aperture* or *vent* for the discharge of faecal and urinary wastes as well as reproductive products (ova or sperm).

5. Limbs. Laterally, the trunk bears two pairs of limbs or appendages. The short *forelimbs* arise anteriorly from trunk just behind the head. Each forelimb consists of the upper arm (*brachium*), forearm (*antebrachium*), wrist (*carpus*) and hand (*manus*) bearing 4 digits without web. Thumb or pollex is vestigial. In male frog, the base of first inner finger is thickened, especially in breeding

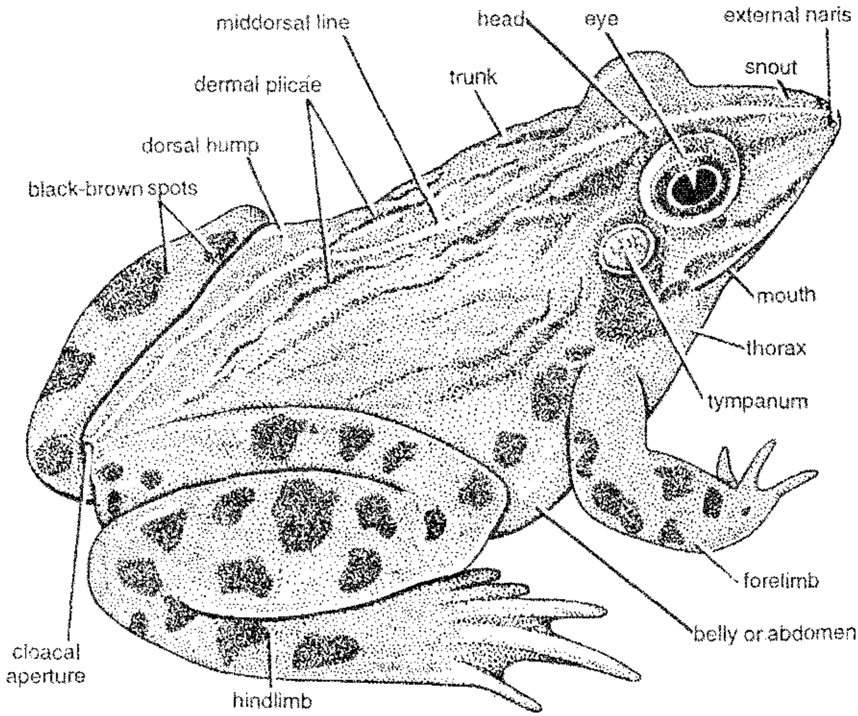


Fig. 7. *Rana tigrina* in sitting posture.

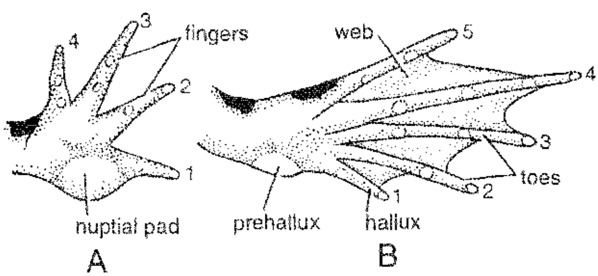


Fig. 8. Frog. A—Underside of right hand of male in breeding season showing nuptial pad. B—Foot showing web.

season, forming the *nuptial pad* for clasping the female during amplexus. The much elongated and powerful *hind limbs* or *legs* arise close together posteriorly from trunk. Each hind limb consists of the thigh, shank (*crus*), much lengthened ankle (*tarsus*) and large foot (*pes*) having 5 slender clawless toes connected by broad thin webs of skin which assist in swimming. In addition there is rudimentary sixth digit called *prehaullex* which is enclosed within the skin and is not seen as sixt digit.

Sexual Dimorphism

There are some differences in external characters by which male and female frogs can be distinguished.

(1) Males are generally smaller and darker in colour than females.

(2) Males are slimmer while females stouter, especially when they contain eggs.

(3) Males croak loudly as they have vocal sacs which are absent in females. The eardrum is larger in male.

(4) Males have swollen copulatory or nuptial pads on inner fingers, especially developed in breeding season for grasping the female during mating. Nuptial pads are lacking in females.

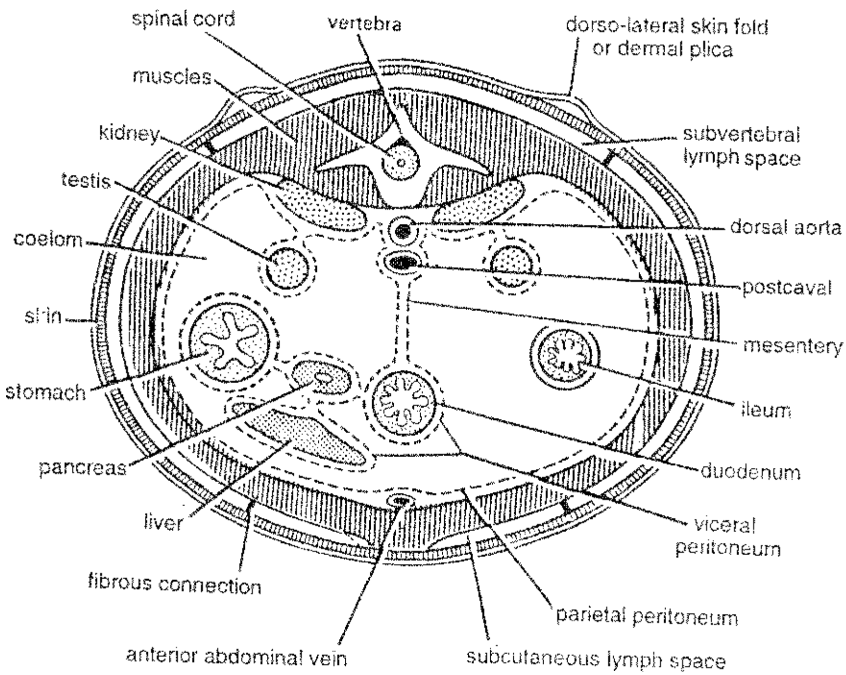


Fig. 9. Frog. Diagrammatic T.S. of trunk showing coelom, peritoneum (broken lines) and viscera.

(5) In copulating frogs in amplexus, the upper one is male, the lower one female.

Coelom and Viscera

Inside the trunk of frog, is a large *body cavity* or *coelom*. It contains most of the *internal organs* or *viscera*. A thin, transparent membrane of mesodermal origin, the *peritoneum*, lines the body cavity (parietal peritoneum) and also covers the internal organs (visceral peritoneum). Most digestive and reproductive organs are suspended from mid-dorsal bodywall by double layers of peritoneum, called *mesenteries*, through which nerves and blood vessels connect to the organs. Body cavity is filled with a watery coelomic fluid which lubricates the viscera and protects them from friction. Heart is enclosed within a special coelomic cavity, the *pericardium*. The remaining coelom is known as *perivisceral* or *abdominal cavity*. There is no *pericardio-peritoneal canal* as found in dogfish (Fig. 9).

Endoskeleton

There is practically no *exoskeleton* in modern Amphibia. The *endoskeleton* of frog is well developed and consists largely of bone and cartilage. It has been described in Chapter 37 in the Section on "Vertebrate Osteology".

Muscular System

Three types of muscle fibres occur in a vertebrate—smooth, cardiac and striated—which differ in microscopic structure and physiology. Smooth or *involuntory muscles* occur in visceral organs. *Cardiac muscles* found in heart are involuntary and striated. External muscular system consists of striated *skeletal* or *voluntary muscles*, which work at will. A frog has about 200 voluntary muscles. Two opposite ends of a voluntary muscle are usually connected to bones directly or by means of a *tendon* which is an elastic band of connective tissue. The less movable end of a muscle is called the *origin* ; the more

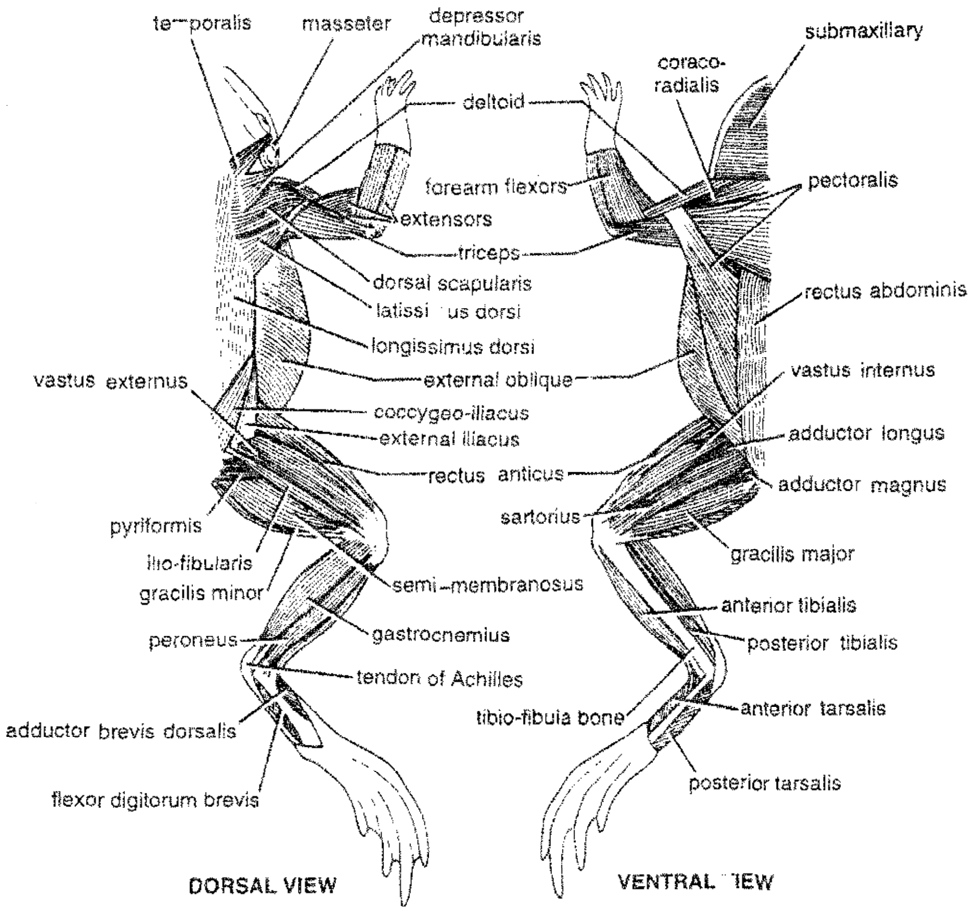


Fig. 10. Frog. Superficial skeletal muscles.

movable end, the *insertion*. A muscle usually causes movement only when it contracts. There are several types of muscles according to their action. Principal superficial skeletal or voluntary muscles of frog have been depicted in the Fig. 10.

The muscles possess power of contraction and relaxation. The muscles are mostly arranged in opposing groups, in such a way, that when one set contracts, the opposing set remains in a relaxed state. This co-ordination of opposing sets of muscles is controlled by the nervous system. Depending upon the mode of action, the muscles in frog are grouped into the following general types :

1. Flexor muscles. This type of muscles bends one part on another. Example : *biceps* flexes forearm over the upper arm.

2. Extensor muscles. This muscle straightens or extends a part. Example : *Triceps* extend forearm on upper arm.

3. Abducter muscles. These muscles draw a part away from the axis of body or limb. Example : *Deltoid muscle* draws arm forward.

4. Adductor muscle. These muscles draw a part towards the axis of body or of a limb. Example : *Latissimus dorsi* muscles draws arm up and back.

5. Depressor muscle. This muscle lowers a part. Example : *Depressor mandibular* muscle moves lower jaw down to open the mouth.

6. Levator muscle. These muscles raise or elevate a part. Example : *Masseter muscle* raises lower jaw to close the mouth.

7. Rotator muscle. These muscles rotate a part. Example : *Pyriformis muscles* raises and rotates the femur.

Table 1. **Important Muscles of Frog and their Functions.**

Muscle	Origin	Insertion	Function
Pterygoid muscle	Frontal region of skull	Mandible	Elevates mandible
Temporal muscle	Tympanic bone of skull	Mandible	Flexes mandible
Masseter muscle	Zygomatic process of tympanic bone of skull	Mandible	Elevates mandible
Depressor mandibular muscle	Junction of neck and skull	Mandible	Lowers mandible to open mouth
Adductor mandibular muscle	Junction of neck and skull	Mandible	Raises mandible to close mouth
Mandibular muscle	Tympanum	Mandible	Lowers mandible to open mouth
Trapezius muscle	Otic region of skull	Anterior edge of scapula	Rotates head and bends neck
Mylohyoid muscle	Medial (upper) surface of mandible	Middle line of mandible	Raises floor of mouth cavity
Submental muscle	Mandible	Mandible	Approximates two rami of lower jaw
Hypoglossus muscle	Hyoid	Tongue	Retracts tongue
Geniohyoid muscle	Midline of mandible	Posterior end of Hyoid	Elevates hyoid and lowers mandible
Pterohyoid muscle	Otic region	Wall of hyoid as well as pharynx	Elevates hyoid and constricts pharynx
Omohyoid muscle	Scapula	Lateral margin of hyoid	Draws hyoid backwards
Sternohyoid muscle	Dorsal side of sternum, coracoid and clavicle	Hyoid	Draws shoulder forward
Genioglossus muscle	Mandible	Tongue	Protracts tongue
External oblique muscle	Dorsal fascia and ilium	Xiphisternum and posterior border of scapula	Supports and tenses abdomen. Depresses or retracts scapula
Cutaneous abdominus muscle	Pubic symphysis	Fascia of skin near ilium	Tensor of skin near back
Coccygeo iliacus muscle	Urostyle	Ilium	Approximates urostyle to ilium
Iliolumber muscle	Sacrum and ilium	Transverse processes of middle vertebrae	Flexes and extends vertebral column
Longissimus dorsi muscle	Urostyle	Back part of vertebrae and skull	Elevates head and extends back.
Latissimus dorsi muscle	Ventral face of dorsal fascia	Humerus	Elevates retracts and rotates humerus
Dorsalis scapulae muscle	Dorsal side of scapula and suprascapula	Humerus	Rotates and elevates humerus
Anal sphincter muscle	Urostyle	Around cloaca	Constricts vent Constricts vent
Rhomboideus muscle	Anteroposterior part of skull and neural spine of third and fourth vertebrae	Ventral part of suprascapula	Protracts and rotates suprascapula
Levator scapulae muscle	Exoccipital bone of skulls	Ventral part of suprascapula	Elevates and protracts suprascapula
Serratus muscle	Transverse processes of third and fourth vertebrae	Middle border of suprascapula and posterior margin of scapula	Retracts suprascapula and elevates scapula

Muscle	Origin	Insertion	Function
Internal oblique muscle	Ilium and vertebrae	Xiphisternum	Tenses abdominal wall
Sternoradialis muscle	Sternum	Radioulna	Draws arm forward
Cutaneous pectoralis muscle	Xiphisternum	Ventral skin	Tenses skin
Pectoralis muscle	Coracoid and border of epicoracoid	Crest of humerus	Flexes, adducts and rotates the arm
Rectus abdominis muscle	Pubic joint	Dorsal surface of xiphisternum	Depresses sternum
Transversus muscle	Ilium and vertebrae	Linea alba	Supports abdominal viscera
Coracoideus muscle	Posterior margin of coracoid	Humerus	Retracts humerus
Supracoracoideus muscle	Ventral side of coracoid	Radius	Flexes elbow
Deltrideus	Coracoid, clavicle and scapula	Crest of humerus	Protracts and retracts humerus
Triceps brachii muscle	Posterior edge of scapula and anterior half of humerus	Radio-ulna	Adducts arm
Extensor digitorum communis muscle	Lateral surface of humerus	II, IV and V digits	Extends fingers
Anoconeus muscle	Humerus	Ulna	Extends forearm
Flexor digitorum muscle	Humerus	Fascia of fingers	Flexes hand and fingers
Flexor carpi ulnaris	Humerus	Wrist and ventral fingers	Flexes hand and fingers
Iliacus internus muscle	Pubic symphysis and ilium	Femur	Flexes and rotates thigh
Biceps femoris muscle	Posterior part of ilium	Proximal end of tibiofibula	Extends thigh and flexes leg
Triceps femoris muscle	Ilium and acetabulum	Proximal end of tibiofibula	Flexes thigh and extends leg
Gastroenemius muscle	Distal end of femur	Sole of foot	Extends ankle and foot and flexes shank
Semimembranosus muscle	Dorsal surface of ischium	Proximal end of tibiofibula	Flexes knee and extends thigh
Pyriformis muscle	Tip of urostyle	Femur (near head)	Draws urostyle down and femur dorsally
Adductor magnus muscle	Ischium and pubis	Femur	Adducts leg and thigh
Iliac externus muscle	Ilium outer, dorsal surface	Femur, posterior end of its head	Rotates thigh
Peroneus muscle	Distal end of femur	Tibiofibula and calcaneum	Extends foot and draws shank against thigh
Semitendinosus muscle	Ischium	Tibiofibula	Flexes knee joints
Obturator internus muscle	Acetabulum	Dorsal surface of femur	Rotates femur
Pectineus muscle	Ilium and pubis	Femur	Adducts and flexes thigh
Adductor brevis muscle	Pubis and ischium	Distal end of femur	Flexes and adducts thigh
Adductor longus muscle	Ilium	Femur	Adducts thigh
Sartorius muscle	Pubic joints and ilium	Tibiofibula	Flexes thigh at hip
Extensor cruris muscle	Femur	Tibiofibula	Protracts femur and extends leg
Tibialis anticus longus muscle	Femur	Astragalus and calcaneum	Flexes tarsus and extends foot
Tibialis anticus brevis muscle	Tibiofibula	Astragalus	Flexes foot
Gracialis major muscle	Ischium	Tibiofibula	Flexes knee and extends thigh
Gracialis minor muscle	Ischium	Tibiofibula	Flexes knee and extends thigh
Tibialis posticus muscle	Tibiofibula	Astragalus	Extends foot

Three general structural forms have been observed in case of voluntary muscles —

- Broad, thin sheet muscles like external oblique and transverse that form a flexible wall of the abdomen.
- Slender ribbon-like muscles like biceps or deltoid.
- Sphincters with circular arrangement of fibers that constricts to close the anus.

During body movements several muscles act together. Some of them contract more than others and this co-ordination is directed by the nervous system.

Digestive System

Digestive system includes the *digestive tract* or *alimentary canal* and the associated *digestive glands* (Figs. 11–13).

[I] Alimentary canal

Alimentary canal of frog is complete. It is a long and coiled tube of varying diameter extending between mouth and cloaca. It comprises buccal cavity, pharynx, oesophagus, stomach, small intestine, large intestine and cloaca.

1. Mouth. Alimentary canal begins at the mouth opening. It is a very wide gap, extending from one side of the snout to the other. It is bounded by two bony jaws covered by immovable lips. Upper jaw is fixed while the lower jaw can move up and down to close or open the mouth.

2. Buccal cavity. Mouth opens into a large, wide and shallow *oral* or *buccal cavity*. Its ciliated columnar epithelial lining contains mucous glands which secrete mucus for lubricating food. There are no salivary glands in frog.

(a) Teeth. The lower jaw lacks teeth, but small conical and backwardly pointed teeth occur in a row on either side on the *premaxillae* and *maxillae* bones of the upper jaw. Besides, two small bones in the roof of mouth, called *vomers*, also bear two groups of vomerine teeth. The teeth are not meant for chewing, they simply hold the prey and prevent it from slipping out.

Teeth are similar (*homodont*), not set in a socket (*acrodont*), but each attached to the jaw

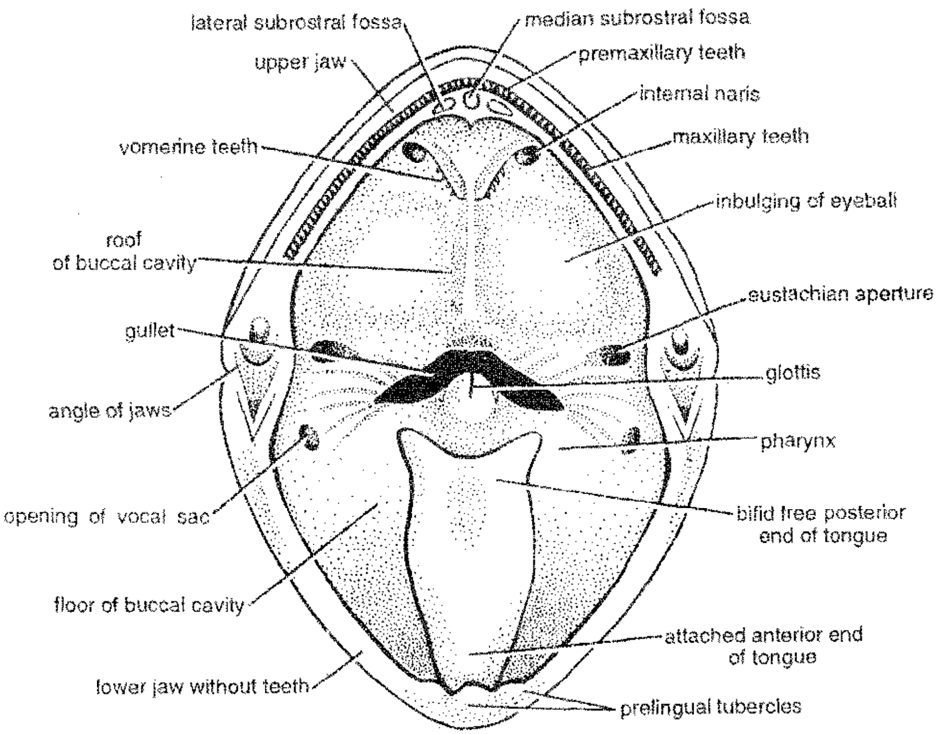


Fig. 11. Frog. Bucco-pharyngeal cavity of male.

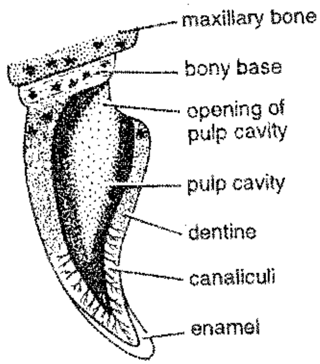


Fig. 12. Frog. A maxillary tooth in V.S.

bone by a broad *base* made of a bone-like substance. The free part or *crown* of tooth is made of a hard ivory-like substance, the *dentine*, which is traversed by numerous fine canals or *canaliculi*. Tip of the crown is covered by a very hard, resistant and glistening substance, the *enamel*. Tooth contains a central *pulp cavity* open at the side and filled with a soft nourishing *pulp* containing connective tissue, blood vessels, nerve and *odontoblast cells* that produce new material for the growth of tooth. In life, teeth of frog are replaced several times (*polyphyodont*) by the growth of new teeth when worn out or lost.

(b) Tongue. On the floor of mouth cavity lies a large, muscular sticky protrusible tongue. Its anterior end is attached to the inner border of lower jaw. Its posterior end is free and bifid which can be flicked out and retracted suddenly after capturing the prey with its slimy surface. The protrusion of the tongue is brought about by the change of pressure in large sublingual lymph sac. Hartog was of the opinion that the contraction of mylohyoid muscles forces the lymph from subhyoid space into the tongue which causes the protrusion of tongue.

(c) Internal nostrils. The roof of buccal cavity contains anteriorly, just in front of vomerine teeth, a pair of small openings of *internal nares*, by which the nasal cavities open into buccal cavity. These aid in respiration.

(d) Bulgings of orbits. Behind the vomerine teeth, roof of buccal cavity shows two large oval and somewhat pale areas, the bulgings of eyeballs. While swallowing food, frog depresses the eyes causing the orbits to bulge inwards and push the food towards the pharynx.

3. Pharynx. Posteriorly, the buccal cavity passes without demarcation into a short pharynx. Hence, the two sometimes are described as a single *bucco-pharyngeal cavity*. Various apertures open into pharynx. A median elevation on the floor carries a longitudinal slit-like aperture, the *glottis*, leading into the laryngo-tracheal chamber. In the roof on either lateral side is a wide *eustachian aperture* which opens into the middle ear. In male frog, on the floor of pharynx on either side near the angle of two jaws, is present the small opening of a *vocal sac*. As already mentioned the vocal sacs act as resonators during croaking. Pharynx abruptly tapers behind to lead into oesophagus through a wide opening, the *gullet*.

4. Oesophagus. Oesophagus is a short, wide, muscular and highly distensible tube. Its mucous epithelial lining is folded longitudinally and contains some mucous glands. Longitudinal foldings of the oesophagus allow its expansion during the passage of food into stomach. The glandular lining of oesophagus secretes an alkaline digestive fluid. In the peritoneal cavity, oesophagus enlarges to merge imperceptibly with stomach.

5. Stomach. Stomach lies on the left side in the body cavity, attached to the dorsal bodywall by a mesentery called *mesogaster*. It is a large (4 cm long), broad and slightly curved bag or tube with thick muscular walls. Its large broader anterior part is called *cardiac stomach*, while the short narrower posterior part, the *pyloric stomach*. The inner surface of stomach has several prominent longitudinal folds which allow its distension when food is received. Its mucous epithelium contains multicellular *gastric glands* secreting the enzyme pepsinogen, and unicellular *oxyntic glands*, secreting hydrochloric acid. The posterior or pyloric end of stomach is slightly constricted and its opening into small intestine is guarded by a circular ring-like sphincter muscle, called *pyloric valve*. Stomach serves for storage and digestion of food.

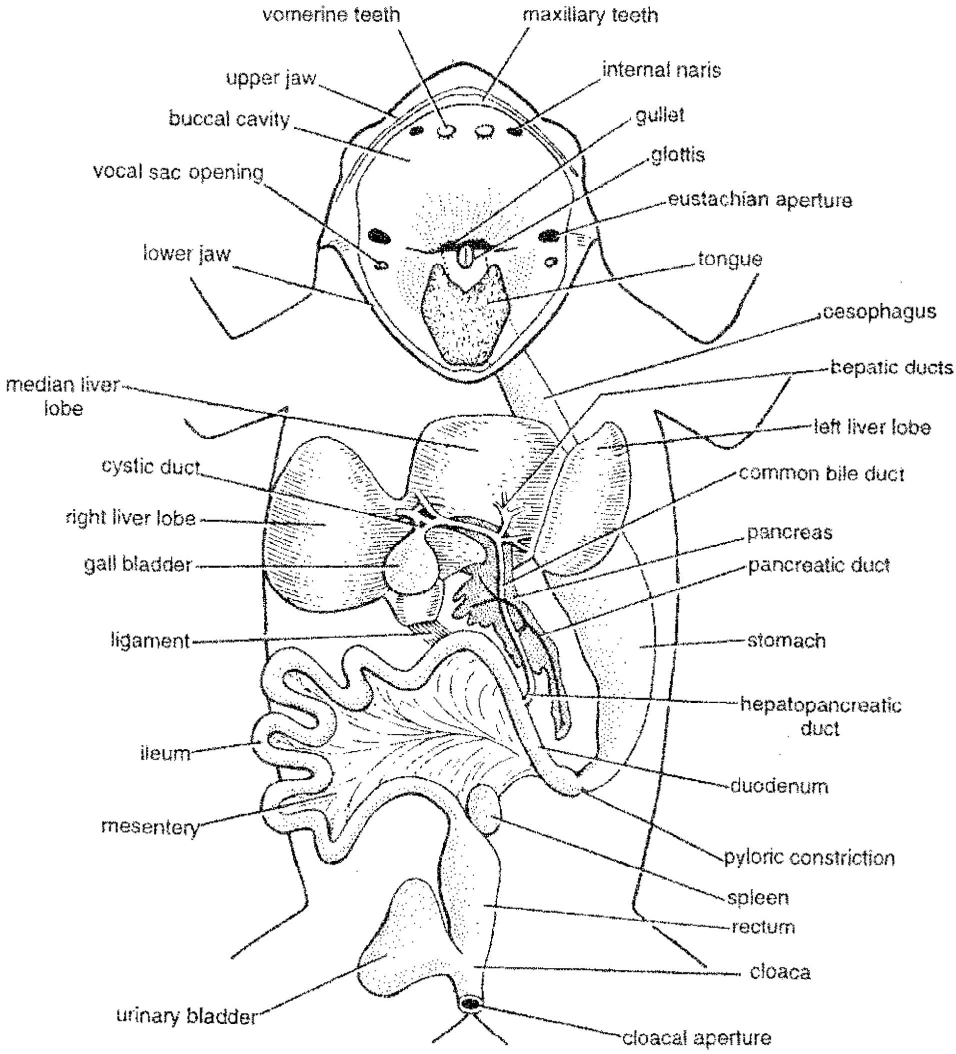


Fig. 13. Frog. Digestive system in ventral view.

6. Small intestine. Small intestine is a long, coiled and narrow tube, about 30 cm long, and attached mid-dorsally to bodywall by mesenteries. It is made up of two parts; a small anterior *duodenum*, and a much longer posterior *ileum*. The mucosal lining of the small intestine consists of two types of cells besides intestinal glands, large *goblet cell* containing oval vacuoles and granular substances which possibly produces mucous. The nucleus is situated near the base of the cell. The small *absorbing cells* with oval nuclei near the base.

(a) Duodenum. It runs ahead parallel to stomach forming a U. It receives a common *hepatopancreatic duct* from liver and pancreas bringing bile and pancreatic juice. The internal mucous lining forms low transverse folds.

(b) Ileum. It is the longest part of alimentary canal and makes several loops before enlarging posteriorly to join rectum. The internal mucous lining forms many longitudinal folds, but there are no true villi and definite glands and crypts as in higher vertebrates. Digestion of food and absorption of digested food occur in the small intestine.

7. Large intestine or rectum. It is a short, wide tube, about 4 cm long, running straight behind to open into cloaca by anus guarded by an *anal sphincter*. Its inner lining forms numerous low longitudinal folds. Its function is the re-absorption of water and the preparation and storage of faeces.

8. Cloaca. It is the small terminal sac-like part into which open the anus and the urinogenital apertures. Cloaca opens to outside by the *vent* or *cloacal aperture*, lying at the hind end of body.

[II] Digestive glands

Besides *gastric glands* (stomach) and *intestinal glands* (small intestine), two large glands associated with the alimentary canal of frog are the *liver* and the *pancreas*.

1. Liver. Liver is the largest gland found in the body of a vertebrate. It is a reddish-brown, mutilobed gland located close to the heart and lungs. Liver of frog consists of 3 lobes—right, left and median. The innumerable polygonal cells of liver secrete a greenish alkaline fluid, the *bile*. It is stored in a large, spherical, greenish and thin-walled sac, the *gall bladder*, which lies between the lobes of liver. *Cystic ducts* from gall bladder and *hepatic ducts* from liver lobes combine to form a *common bile duct*. It runs through pancreas and joins the *pancreatic duct* to form a hepatopancreatic duct which ultimately opens into duodenum. Bile has no digestive ferments; it only emulsifies fats so that liver is not truly a digestive gland.

2. Pancreas. Pancreas of frog is a much branched, irregular, flattened and yellow-coloured gland lying in the mesentery between stomach and duodenum. Its function is both endocrine as well as exocrine. Its endocrine part is formed by scattered *islets* of *Langerhans* manufacturing the hormone *insulin* concerned with sugar metabolism. The exocrine part secretes pancreatic juice containing several digestive enzymes. Pancreas has no independent duct and its pancreatic juice is conveyed into duodenum through the hepatopancreatic duct.

[III] Physiology of digestion

Frog is strictly carnivorous. If feeds on insects, worms, crustaceans, molluscs, small fish and even small frogs and tadpoles. The prey is captured by rapid flicking action of its prehensile tongue and swallowed whole, without mastication, passing down the oesophagus into stomach. No salivary glands are present but mucus for lubricating food is secreted from the lining of bucco-pharyngeal cavity and oesophagus. Food is pushed down the oesophagus by a wave of contraction of its muscular wall, called *peristalsis*.

1. Gastric digestion. Food stays in stomach for sufficient time (2 to 3 hours). Gastric glands of stomach wall secrete the gastric juice containing hydrochloric acid and an inactive pre-enzyme *pepsinogen*. In the presence of hydrochloric acid pepsinogen changes into the active enzyme *pepsin* which catalyzes the hydrolysis of proteins, breaking them into *peptones* and *proteoses*. Acid not only provides acidic medium, but also kills bacteria and fungi present in food and makes it soft. Muscular contractions of stomach wall also aid in disintegration and mixing of digestive enzymes with food. With presence of food, stomach also produces a hormone, *gastrin*, which activates cells secreting hydrochloric acid. When the liquified semidigested acidic food, now called *chyme*, reaches the proper state, the pyloric sphincter relaxes allowing the chyme to enter duodenum.

2. Intestinal digestion. Presence of acidic chyme in duodenum causes production of several intestinal hormones with specific functions. (i) *Enterogastrone* reaches stomach through blood to stop production of more gastric juice with HCl. (ii) *Cholecystokinin* causes gall bladder to contract and release bile into duodenum through hepatopancreatic duct. (iii) *Secretin* and (iv) *Pancreozymin* working together stimulate pancreas to secrete pancreatic juices into duodenum. (v) *Enterocrinin* activates secretion of intestinal juice, the succus entericus.

Thus, three important substances mix up with food in intestine, necessary for completion of digestion and derived from three different sources : bile, pancreatic juice and intestinal juice.

(a) Bile. It is a greenish alkaline fluid secreted by liver. It does not contain digestive enzymes but the *bile salts* such as sodium bicarbonate, sodium glycocholate, sodium torocholate, etc. Alkaline bile, neutralizes the acidity of chyme, emulsifies fats, stimulates peristaltic action of intestine and activates pancreatic lipase.

(b) Pancreatic juice. The watery alkaline juice from pancreas contains various types of enzymes all of which act best in an alkaline medium and hydrolyze all 3 classes of food stuffs. (i) Inactive *trypsinogen* is changed by intestinal *enterokinase* into the active proteolytic enzyme *trypsin* which converts proteoses, peptones and polypeptides into simple amino acids. (ii) *Amylopsin* or *amylase* reduces starches (polysaccharides) into maltose (disaccharide) (iii) *Lipase*, formerly called *steapsin*, converts emulsified fats into fatty acids and glycerol.

(c) Succus entericus. Intestinal juice or succus entericus contains several enzymes, besides enterokinase, that act upon all classes of food stuffs. (i) *Erepsin* (collective name for all proteolytic enzymes or peptidases) changes polypeptides into amino acids. (ii) *Maltase* converts maltose to glucose, *sucrase* or *invertage* converts sucrose to glucose and fructose, and *lactase* converts lactose to glucose and galactose. (iii) *Lipase* splits fats into fatty acids and glycerol.

[IV] Egestion, absorption and assimilation

1. Egestion. Digestion is completed in the small intestine. Undigested part of food is slowly moved by peristalsis into rectum for storage and preparation of faeces. At intervals the faecal matter passes into cloaca and egested through cloacal aperture.

2. Absorption. Absorption of final products of digestion occurs through the walls of small intestine. Folds with villi—like processes increase the internal absorptive surface. Little is known about the actual mechanism of absorption. Osmotic forces and other factors seem to play a part. Water, mineral salts and other nutrients in solution are directly absorbed through the epithelial lining. Carbohydrates are absorbed as glucose and fructose, and proteins as amino acids. These pass into blood capillaries in the folds, then into hepatic portal system and so into the liver. Fatty acids and glycerol pass into lymphatic capillaries or lacteals in the folds and so into the veins.

3. Assimilation. Absorbed foodstuffs may be used for two basic purposes of nutrition : (i) *liberation of energy* during respiration, or (ii) *assimilation* as part of intimate structure of the animal. Surplus glucose may be either stored as glycogen in liver and skeletal muscles, or converted to fat or incorporated in living protoplasm. Fatty acids and glycerol are converted into fats which are deposited in adipose tissues. Amino acids may form proteins for growth and repair or undergo deamination resulting in the formation of urea to be excreted by kidneys with urine.

Respiratory System

Organs which help in the intake and supply of oxygen to the tissues (body) and get rid of excess carbon dioxide, from the *respiratory system*. Respiration in tadpole or larval stage is by means of external gills (*branchial respiration*) as in fishes. Respiration in adult frog is effected either (i) through moist surface of outer skin (*cutaneous respiration*), or (ii) through lining of bucco-pharyngeal cavity (*buccal respiration*), or (iii) through the lungs (*pulmonary respiration*). In each case there are numerous blood capillaries lying close to the moist epithelium through which the two gases readily diffuse, O_2 going in and CO_2 coming out (Figs. 14–19).

[I] Cutaneous respiration

Cutaneous respiration goes on all the time whether frog is in or out of water. It is practically the only mode of respiration when the frog is under water or hibernating. Skin is richly supplied with blood and is permeable to gases. Before oxygen can diffuse into blood, it must first dissolve in a moist surface. That is why frogs always stay near water

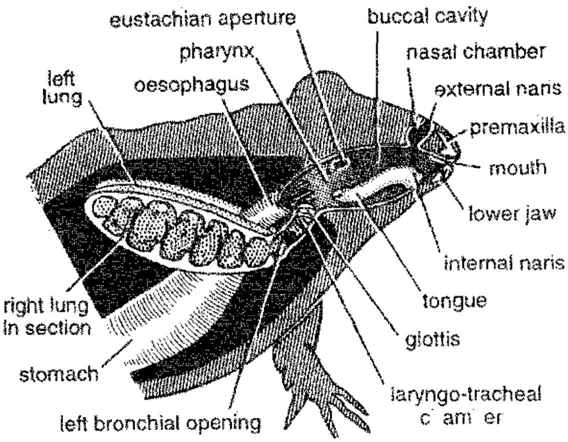


Fig. 14. Frog. Diagrammatic L.S. of respiratory system.

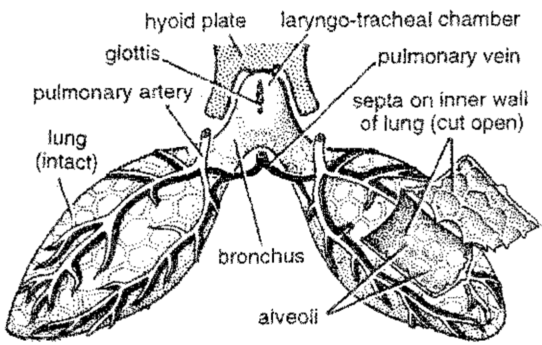


Fig. 15. Frog. Respiratory organs in dorsal view. Right lung partly cut open to show inner partitions and alveoli.

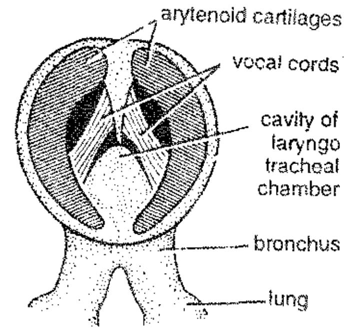


Fig. 16. Frog. Laryngo-tracheal chamber opened to show vocal cords.

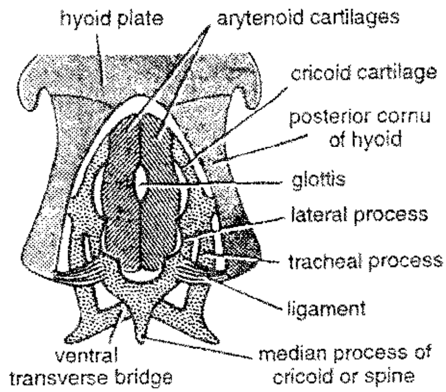


Fig. 17. Frog. Skeletal cartilages of laryngo-tracheal chamber.

to keep their skin moist. It is further kept moist by secretion of mucus from its glands, and does not become dry out of water. Since the skin remains exposed to air or water, no movements are needed in cutaneous respiration.

[II] Buccal respiration

In buccal respiration on land, the mouth remains permanently closed while the nostrils remain open. The floor of the buccal cavity is alternately raised and lowered, so that air is drawn into and expelled out of the buccal cavity repeatedly through the open nostrils. During buccal respiration, the glottis remains closed so that no air enters or leaves the lungs into buccal cavity. As the mucous epithelial lining of buccal cavity is richly supplied with blood capillaries, O_2 in the air is absorbed by blood while CO_2 is given out.

[III] Pulmonary respiration and sound production

Breathing on land in atmospheric air with the help of lungs is called *pulmonary respiration*. As lungs are poorly developed in frog, the inadequate supply of O_2 obtained through lungs is supplemented through moist skin and buccal cavity.

1. Organs of respiration. Chief organs for aerial respiration are the two *lungs*. The passage through which air enters and leaves the lungs, is called *respiratory tract*.

(a) Respiratory tract. It consists of external nostrils, nasal chambers, internal nostrils, bucco-pharyngeal cavity, glottis, laryngo-tracheal chamber, and two bronchi. The median slit-like *glottis* on the floor of pharynx opens into a small thin-walled chamber, called *larynx* or *laryngo-tracheal chamber.* Its walls are supported by cartilages (2 *arytenoid* + 1 *cricoid*). Its internal lining forms a pair of elastic horizontal bands, the *vocal cords,* for sound production so that larynx is also known as *voice box.* When air from lungs is forced out between vocal cords, they start vibrating and making the characteristic croaking sound. Special muscles can change the tension of the cords and hence the pitch of the sound. Vocal sacs are found only in the male frog to amplify the croaking sound. From larynx a very small tube, the *bronchus,* leads to each lung.

(b) Lungs. The two lungs are ovoid, thin-walled and highly elastic sacs suspended freely inside the peritoneal body cavity, one on either side of the heart. They are covered externally by peritoneum. The inner surface of each lung is divided by a network of folds or septa into many small air sacs or *alveoli,* while leaving a clear large central cavity. The *alveoli* are lined with thin epithelium richly supplied with blood capillaries containing deoxygenated blood for gaseous exchange. O_2 of the inhaled air diffuses into blood while CO_2 is released into alveoli.

2. Respiratory mechanism. Pulmonary respiration takes place in between buccal respiration, in which the buccal cavity acts like a *force pump.* The rhythmic up and down movements of the floor of buccal cavity are brought about by the action of two special sets of muscles. (i) *Sternohyal muscles* are attached at the lower end to sternum and at the upper end to the undersurface of cartilaginous hyoid apparatus embedded in the floor of buccal cavity. (ii) *Petrohyal muscles* are attached below to the upper surface of hyoid apparatus and above to the squamosal bone of skull. The whole mechanism involves two steps or phases : *inspiration* and *expiration.*

(a) Inspiration. To draw air into the lungs, the frog closes its glottis and mouth while the nostrils remain open. Now the sternohyal muscles contract so that the hyoid apparatus and the floor of buccal cavity are lowered. This enlargement of buccal cavity draws air through the nostrils into buccal cavity. The glottis now opens and the mentomeckelian bones of lower jaw push upwards the premaxillae bones of upper jaw so that the nostrils are closed. Now the petrohyal muscles contract raising the hyoid apparatus and the floor of buccal cavity. This reduction in volume of buccal cavity forces the compressed air through opened glottis into the two lungs, this process by which lungs are filled with air is called *inspiration.*

(b) Expiration. When lungs are filled the glottis closes and air is held in lungs for some time during which buccal floor is repeatedly raised and lowered to carry on buccal respiration. Soon, the glottis is opened and the air in the lungs driven out into the buccal cavity by lowering its

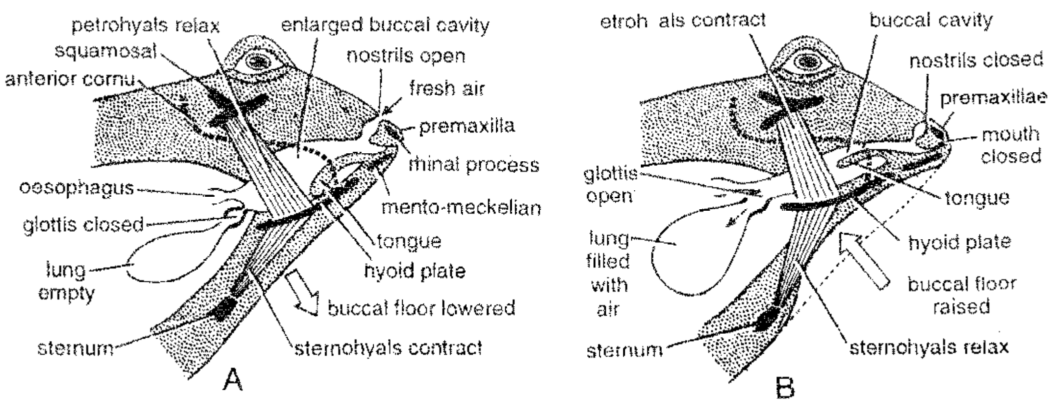


Fig. 18. Frog. Diagrammatic representation of respiratory mechanism involving two sets of muscles. The two stages bring inspiration. Reverse sequence will result in expiration.

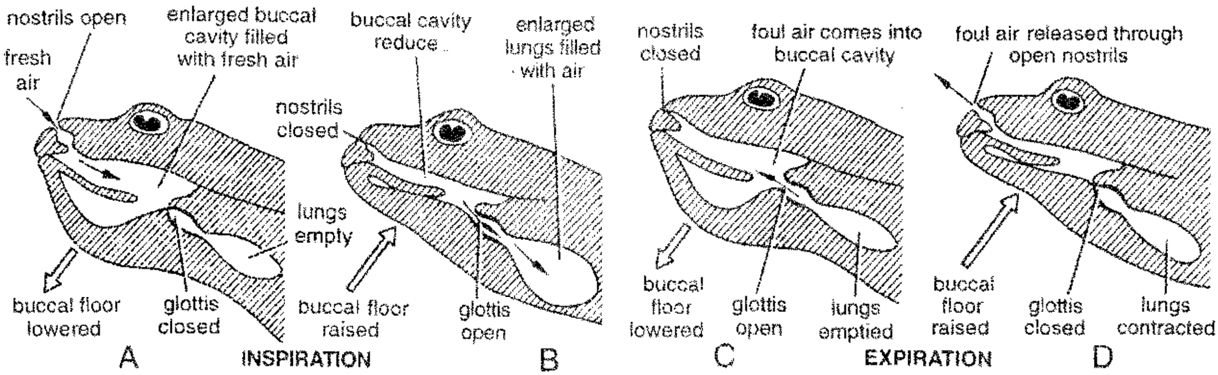


Fig. 19. Frog. Breathing movements during ventilation of lungs. Black arrows indicate path way of air in and out of lungs. White arrows show up and down movements of buccal floor.

floor and also aided by the elasticity of lungs and contractions of the body muscles. When the buccal floor is raised again, the glottis closes and the air is expelled through the opened nostrils to outside. This process by which the lungs are emptied is called *expiration*.

According to recent findings, the nostrils of frog remain open throughout and only mixed air of buccal cavity, not rich enough in oxygen, moves into and out of lungs several times. This accounts for the inefficiency of lungs for respiration in frog.

Blood-Vascular System

The blood vascular or circulatory system of frog is closed and includes : (i) heart, (ii) arterial system, (iii) venous system, (iv) blood, and (v) lymphatic system. Its chief function is to transport all necessary liquid and gaseous materials to the living tissues and also to bring away from them the liquid and gaseous wastes of metabolism to organs of elimination.

[I] Heart

The muscular heart is the central pumping station driving blood through the closed circulatory system (Fig. 20).

1. External features. The heart lies mid-ventrally inside the anterior trunk region protected by the pectoral girdle. It is reddish in colour and somewhat conical or triangular in shape with the broad base directed anteriorly and the narrow apex, posteriorly.

(a) Pericardium. The heart lies enclosed by a thin, transparent, two-layered sac, the *pericardium*. The outer wall of pericardium, *parietal pericardium* and inner one which closely invests the heart, called *visceral pericardium*. The narrow cavity between two pericardial layers contains a watery *pericardial fluid* which protects the heart from friction or mechanical shocks, keeps it moist and permits its movements.

(b) Chambers of heart. Frog's heart is a 3-chambered structure, made of two anterior dark-coloured *atria* or *auricles*, right and left, and a single posterior conical and pink-coloured *ventricle*. The two auricles are externally demarcated by a very faint longitudinal *inter-auricular groove*. However, the two auricles are clearly marked off from ventricle by a narrow transverse auriculo-ventricular groove or *coronary sulcus*.

The heart of frog has two *additional chambers* : *sinus venosus* and *truncus arteriosus*. *Sinus venosus* is a dark-coloured, thin-walled and triangular chamber attached dorsally to heart. It is formed by the union of three large caval veins, two anterior precavals and one posterior postcaval. *Truncus arteriosus* arising anteriorly from the right ventral side of ventricle, is a tubular chamber. It immediately bifurcates anteriorly into two branches or trunks, each further breaking into three arches : carotid, systemic and pulmocutaneous.

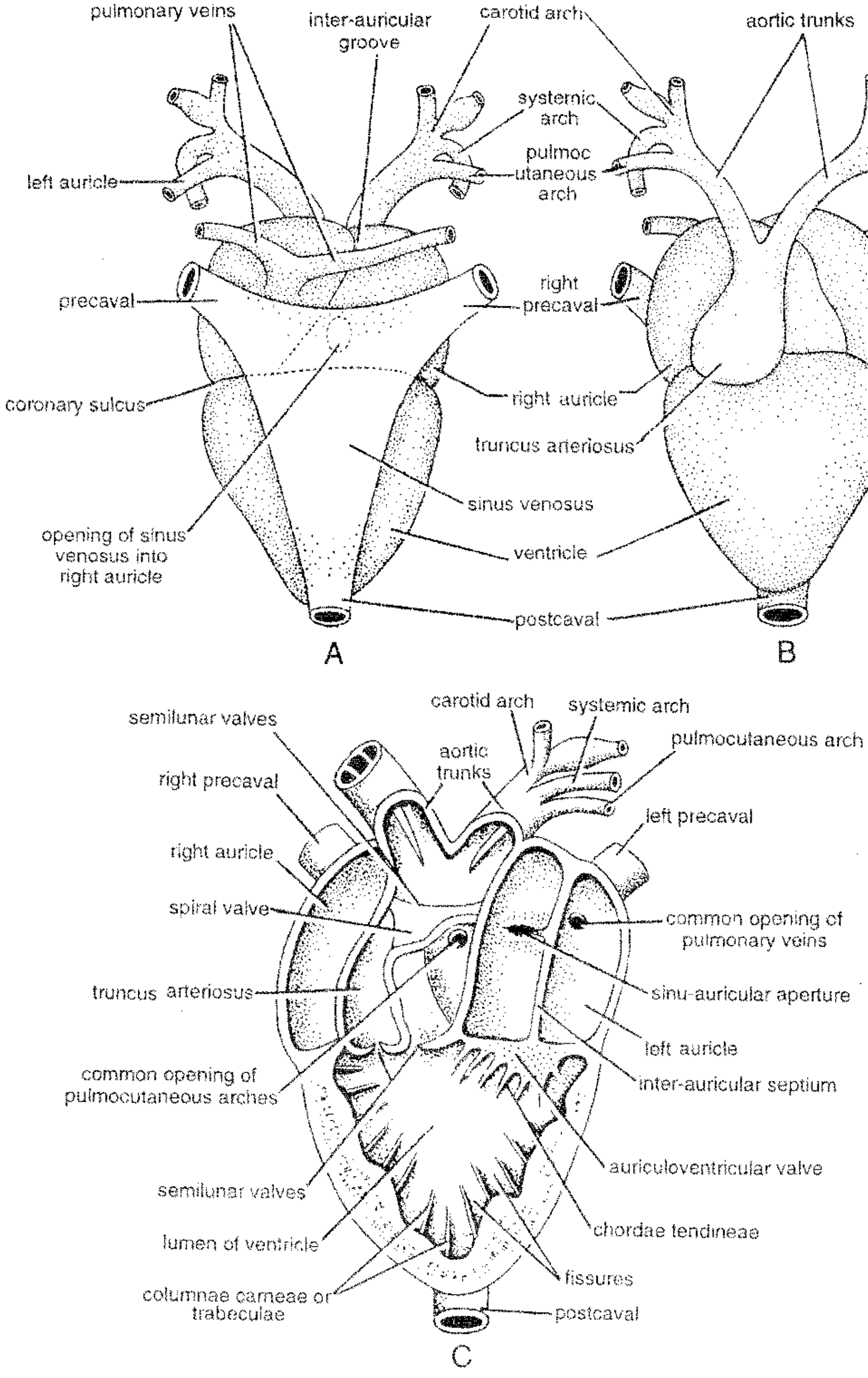


Fig. 20. Frog. Strucuture of heart. A—Dorsal view. B—Ventral view. C— Internal structure after removal of ventral wall.

2. Internal structure. The internal structure of heart is seen in its section. It is hollow and muscular. The various chambers are separated by valves to keep the blood flowing in one direction.

(a) Auricles. The two auricles, right and left, are thin-walled and completely separated from each other by a thin vertical *inter-auricular septum*. Right auricle is larger than the left. Sinus venosus opens into dorsal wall of right auricle through a large transverse oval aperture, the *sinu-auricular aperture*. It lies medially close to the interauricular septum and guarded by a pair of flap-like valves. Similarly, the common pulmonary vein opens into left auricle, near septum, by a small opening without valves. Both auricles open into single ventricle by a common large *auriculo-ventricular aperture* guarded by two pairs of flap-like *auriculo-ventricular valves*.

(b) Ventricle. The ventricle has thick muscular and spongy wall. Its inner surface has irregular strands or ridges, the *columnae carneae* or *trabeculae*, with depressions called *fissures*. These greatly reduce the cavity of ventricle. The flaps of auriculo-ventricular valves are connected to the wall of ventricle by thread-like *chordae tendineae*.

(c) Truncus arteriosus. The opening of ventricle into truncus arteriosus is guarded by 3 semilunar valves (4 according to Sharma, 1957) which prevent back flow of blood from truncus into ventricle. The spirally twisted cavity of truncus arteriosus is divided unequally by another set of 3 semilunar valves into a long basal thick-walled *conus arteriosus* or *pylangium* and a short distal thin-walled *bulbous aorta* or *synangium*. A large twisted longitudinal *spiral valve* further divides incompletely the cavity of conus or pylangium into a left dorsal *cavum pulmocutaneum* and a right ventral *cavum aorticum*. The spiral valve is attached dorsally while its ventral edge is free. The common opening of two pulmocutaneous arches lies in cavum pulmocutaneum, while separate openings of carotid and systemic arches lie in synangium. However, in *Rana tigrina*, Sharma (1957) describes a joint opening for systemic and carotid arches. All these openings are guarded by valves.

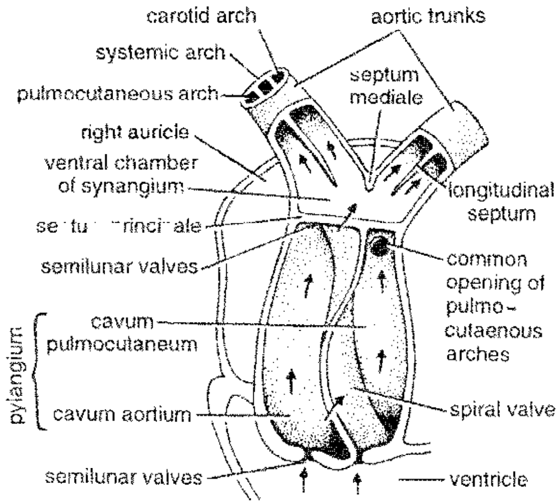


Fig. 21. Frog. Detailed internal structure of truncus arteriosus in ventral view.

The distal right and left branches or trunks appear externally to be single vessels but internally, each is made of 3 channels which eventually form three separate arches on either side (Fig. 21).

3. Working of heart. Heart is a muscular organ which constantly beats during life under nervous control to pump blood into the circulatory system. Contraction of heart is called *systole*, while its relaxation is termed *diastole*. Different chambers of heart contract in a regular sequence and the valves present, prevent the back flow of blood. When sinus venosus contracts, its nonoxygenated venous blood is forced into the right auricle through sinuauricular aperture. Mean while the oxygenated blood from lungs is poured into left auricle through common pulmonary vein. The two auricles now contract almost simultaneously forcing their blood into ventricle through the single auriculo-ventricular aperture.

(a) Old view. According to the conventional *older view* (Brucke, 1858), the ventricle contained only deoxygenated blood in its right side received from right auricle, and only oxygenated blood in its left side received from left auricle, with some mixed blood in the middle region. The two kinds of blood could not mix to any great extent because of their viscous nature and also because of the spongy nature of ventricle due to the presence of the network of columnae carneae. When ventricle starts contraction, first the deoxygenated blood from the right side being nearer, flows into the truncus arteriosus and directed by the spiral valve into the common opening of pulmocutaneous arches and carried to lungs and skin for oxygenation. Spiral valve now closes the opening of pulmocutaneous arches. Next follows the mixed blood which is pushed through cavum aorticum into the systemic arches and sent to the body and limbs. Finally enters the oxygenated blood of left side and directed through carotid arches to the head. Thus, spiral valve in truncus plays an important role in directing blood into different arches.

(b) Modern view. Recent experimental studies conducted mostly by Vandervael (1933) and Foxon (1953) show that it is actually completely mixed blood in ventricle and truncus which flows simultaneously through the three pairs of arches to all parts of the body. The blood received from skin and buccal cavity into sinus venosus and right auricle is in fact more oxygenated than that received from lungs into left auricle. According to this view the interauricular septum and spiral valve in truncus have become functionless in frogs. However, findings of Foxon do not seem to apply equally well to all kinds of frogs. On the other hand, studies by DeLong (1962) indicate that the carotid arches receive highly oxygenated blood, the pulmocutaneous arches with least oxygen, and the systemic arches mixed blood. The precise mechanism is not understood.

The blood flow and pressure is regulated by the extrinsic nerves of the heart. Nerve fibers from the vagus, slow down the speed of beat, whereas, fibers from sympathetic nerves accelerate the speed of beat.

[II] Arterial system

Aortic arches. Arteries carry blood away from the heart. The arterial system in frog begins with the truncus arteriosus. As already mentioned, the truncus divides into left and right branches or *trunks*, each of which subdivides into three major vessels or aortic arches : (i) *Common carotid* to head, (ii) *systemic* to body and viscera, and (iii) *pulmocutaneous* to lung and skin (Fig. 22).

1. Common carotid arch. It is a short vessel running forward and outward, but soon divides into 2 branches : external and internal carotids.

(a) External carotid. Also called *lingual*, it is the smaller inner branch carrying blood to the tongue and adjacent parts.

(b) Internal carotid. It is the larger outer branch. At its base it forms a little swelling, the *carotid labyrinth* or *gland*. Its lumen is converted into a labyrinth by folding of the walls. The inner cavity of carotoid labyrinth contains a network of small vessels and forms a spongy structure. It is probably a sense organ and controls blood pressure in the internal carotid artery. The internal carotid divides into 3 branches— a *palatine* to the roof of mouth, a *cerebral* to the brain, and an *ophthalmic* to the eye.

2. Systemic arch. It is the longest of the three arches and with greatest distribution of blood. The two systemic arches curve dorsally around the oesophagus and join with each other behind the heart to form the *dorsal aorta*. In its course each systemic arch gives off 3 arteries :

(a) Oesophageal. A small artery to oesophagus. It may arise from occipito-vertebral.

(b) Occipito-vertebral. It immediately sends an *occipital branch* to occiput or posterior part of head, and a *vertebral* branch to vertebral column and spinal cord.

(c) Subclavian. It is a large artery supplying the shoulder region and extending into the forelimb as *brachial* artery.

All these arteries exhibit bilateral symmetry but from the left systemic arch an additional branch is given off, the *oesophageal* which is absent in right side.

Dorsal aorta. As already said, it is formed by the union of both the systemic arches. It runs posteriorly lying mid-dorsally, just beneath the vertebral column. It gives off the following arteries :

(a) Coeliaco-mesenteric. It is a single large artery, arising from the junction of the two systemic arches. It has two main branches : the

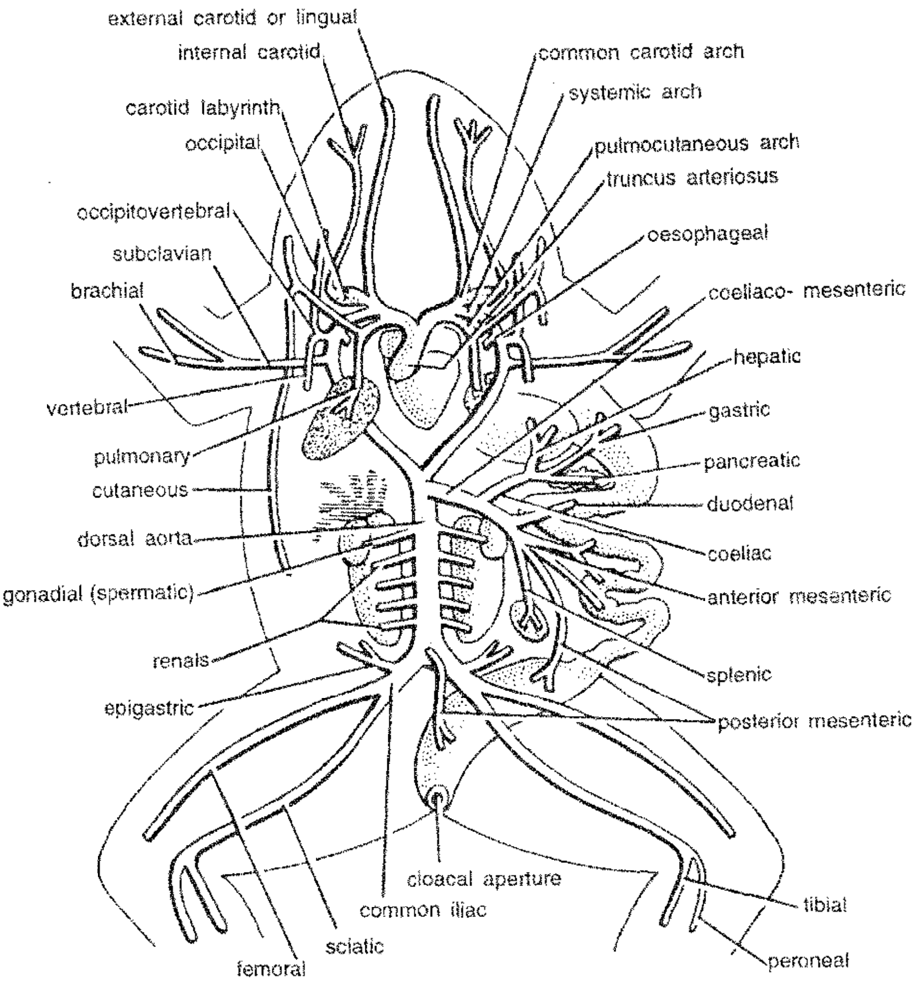


Fig. 22. Frog. Arterial system in ventral view.

coeliac to stomach, pancreas and liver; and the *anterior mesenteric* to spleen and intestine.

(b) Gonadial. A pair of short arteries to gonads, called *spermatic* in male frog and *ovarian* in female frog.

(c) Renal. While passing between the two kidneys, dorsal aorta sends off 5-6 pairs of small *renal arteries* in a series into both the kidneys.

(d) Posterior mesenteric. It arises from the posterior end of dorsal aorta, or sometimes from anterior mesenteric. It goes to large intestine or rectum.

(e) Common iliacs. The dorsal aorta finally bifurcates posteriorly into two common iliacs, each supplying an *epigastric* to ventral body wall, *recto-vesicular* to rectum and urinary bladder, *femoral* to hip and upper thigh, and *sciatic* to lower leg.

3. Pulmocutaneous arch. It divides into two main arteries, *pulmonary* to the lung and *cutaneous* to skin of dorsal and lateral sides and various other structures. Of these *auricularis* supply blood to tympanum, thymus gland, lower jaw, pharynx and hyoid etc. However, *dorsalis* supplies the skin of dorsal side and *lateralis* supplies the skin of lateral sides of the body.

[III] Venous system

The venous system includes veins or those blood vessels in which blood of body returns to the

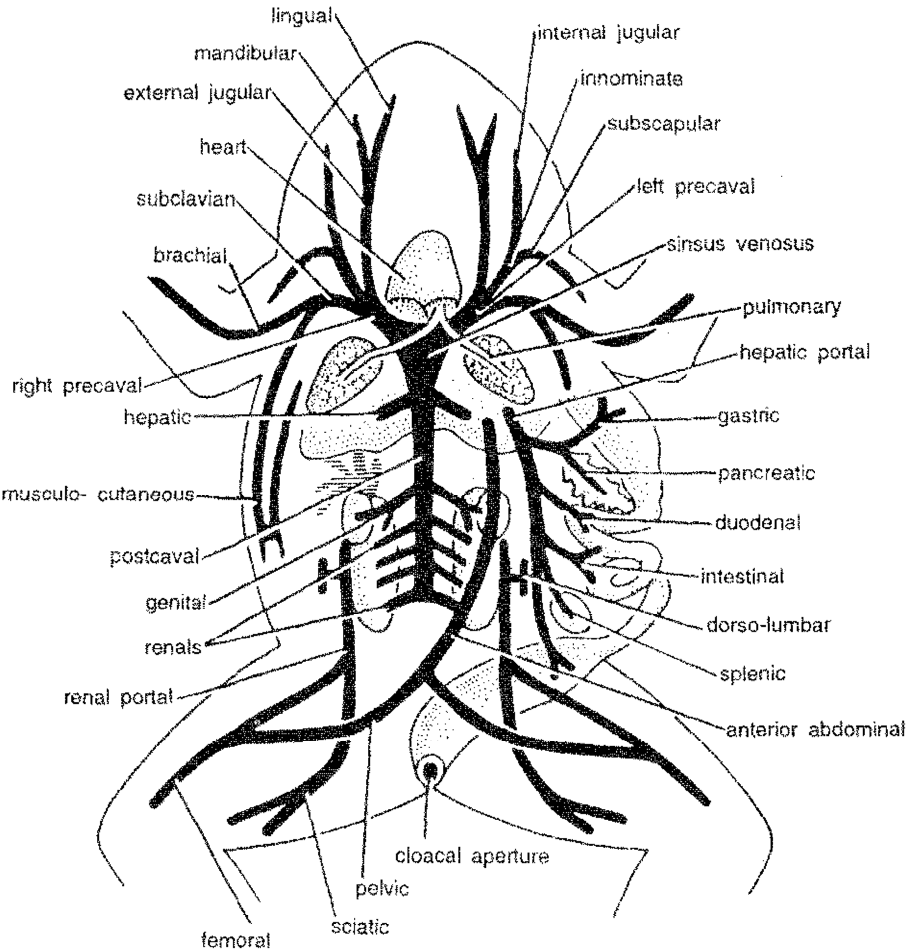


Fig. 23. Frog. Venous system on ventral view.

heart. In frog, it can be studied in four parts : (1) *Pulmonary veins*, (2) *caval veins*, (3) *renal portal veins*, and (4) *hepatic portal vein* (Fig. 23).

1. Pulmonary veins. Oxygenated blood from two lungs is collected by right and left pulmonary veins which unite to form a common pulmonary vein opening directly into the left auricle on the dorsal side.

2. Caval veins. Deoxygenated blood from rest of the body travels towards heart in three large vessels, two *anterior venae cavae* and single *posterior vena cava*, all the three opening into sinus venosus.

(a) Anterior venae cavae or precavals. The right and left precavals or anterior venae cavae collect venous blood from the anterior part of body. Each precaval is formed by the union of 3 major veins which meet simultaneously :

(i) External jugular. It is formed by the slender and sinuous *lingual* from tongue and *mandibular* from outer margin of lower jaw.

(ii) Innominate. It is formed by *internal jugular* from cranial cavity and orbit and *subscapular* from shoulder and back of arm.

(iii) Subclavian. It is formed by the *brachial* from forelimb and the *musculo-cutaneous* from side of body and head.

(b) Posterior vena cava or postcaval. The single postcaval is a large, dark-coloured vein, lying ventral to dorsal aorta. Its posterior end is formed between the two kidneys from which it drains blood by 5-6 pairs of *renal veins*. It also receives a pair of *genital veins* (spermatic in male, ovarian in female) from gonads directly or through anteri_r pair of renal eins. The postcaval then runs f^rwards, d^rsally t^ the liver and receiving from it a pair of short, stout *hepatic veins*, before opening into the posterior angle of sinus venosus.

3. Renal portal system. Like dogfish, frog also has two well developed *portal systems*, renal portal and hepatic, which are curiously interconnected. The veins which carry blood to a capillary system in kidneys constitute the *renal portal system*. Blood of each hindleg is collected by two veins, an outer *femoral* and an inner *sciatic*. On entering the abdominal cavity the femoral divides into a dorsal *renal portal* and a ventral *pelvic vein*. The renal portal unites with the sciatic and while running along the outer border of kidney of its side it receives blood from lumbar region by a *dorso-lumbar vein*. Renal portal vein enters the kidney by several branches which break up into capillaries. The pelvic veins of both sides unite to form a median ventral or *anterior abdominal vein*. It receives blood from urinary bladder and ventral abdominal wall and runs towards to enter liver into which it breaks up into capillaries. Before entering liver, the anterior abdominal and hepatic portal veins are connected by a small loop.

4. Hepatic portal system. A large *hepatic portal vein* is formed by the confluence of several branches from stomach, intestine, spleen and pancreas. It carries blood of alimentary canal, laden with digested foodstuffs, to the liver into which it breaks up into capillaries. Connected with hepatic portal vein, in the region of liver, is the anterior abdominal vein, as already described.

[IV] Blood of frog

Blood, the chief circulatory fluid of body, is really a liquid connective tissue. It contains a clear liquid, called *plasma*, in which are suspended various types of free cells, called *blood corpuscles*.

1. Plasma. Plasma forms nearly two-third part of blood. It is largely water (90%) in which are dissolved mineral salts, absorbed foods (sugars,

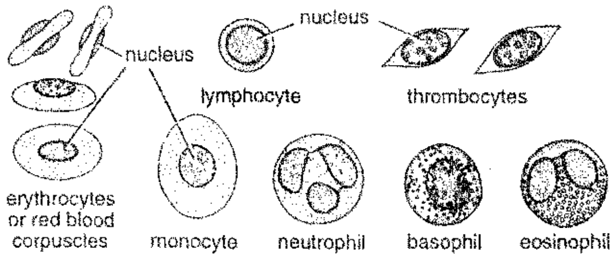


Fig. 24. Frog. Types of blood cells.

proteins), excretory wastes (urea), secretions (hormones), and other soluble substances.

2. Corpuscles. Blood cells or corpuscles are mainly of three kinds. (i) *Erythrocytes* or red blood corpuscles (RBC) are oval, flattened, nucleated, biconvex and 14 by 23 μ in size. They number from 250,000 to 450,000 per cubic millimeter of blood. They bear the respiratory pigment *haemoglobin*, which is a yellow to red iron-containing protein that serves to carry oxygen in chemical combination to the tissues. (ii) *Leucocytes* or white blood corpuscles (WBC) are colourless, nucleated and mostly amoeboid cells of at least five types. They average 5,000 to 7,000 per cubic millimeter. Most of them are phagocytic, ingesting bacteria and other foreign particles that appear in blood, and remove dead or old tissue cells. The WBC of frog are — *Lymphocytes*, *monocytes* and *granulocytes*. The granulocytes may be neutrophilic, eosinophilic and basophilic. (iii) *Thrombocytes* or blood platelets are small, nucleated, spindle cells playing an important part in coagulation. When a blood vessel is injured, the disintegration of thrombocytes releases an enzyme *thrombin*. It changes soluble *fibrinogen* of blood plasma into insoluble *fibrin*. The latter forms the clot which seals the wound to prevent further loss of blood. Blood cells are produced mainly in bone marrow and spleen, the latter also destroys the old worn out cells (Fig. 24).

[V] Lymphatic system

Lymphatic system of frog is more primitive than that of higher vertebrates. It is made of *lymph, lymph vessels, lymph hearts, lymph spaces* and *spleen* (Figs. 25 & 26).

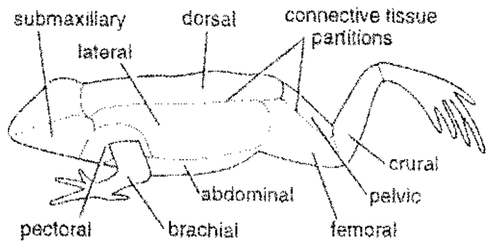


Fig. 25. Frog. Lymph sinuses in lateral view.

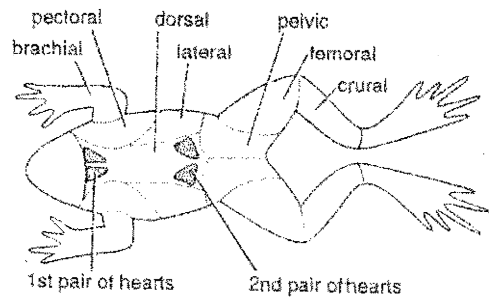


Fig. 26. Frog. Lymph hearts and sinuses in dorsal view.

1. Lymph. Blood confined to blood vessels does not come directly in contact with body cells and tissues. It is filtered regularly from capillaries into intercellular spaces forming the *tissue fluid* or *lymph* which bathes the tissues and lubricates many of the internal organs. Being a filtrate of blood, it closely resembles plasma containing leucocytes but lacking erythrocytes and some blood proteins. It functions as the middle man passing over food and oxygen to cells and waste materials to blood. The tissue fluid is continually being removed into lymph vessels in which it is called *lymph*.

2. Lymph vessels. Lymph vessels or *lymphatics* are thin-walled delicate vessels of various sizes, forming networks but are difficult to see. *Lymph capillaries* unite to form larger vessels which open into the venous system, thus returning lymph back to blood from which it originates. Some small openings (*stomata*) in the peritoneum communicate with lumph vessels.

3. Lymph hearts. Lymph vessels open into veins at four places in frog. At each opening, the lymph vessel forms a small rhythmically contractile sac, called a *lymph heart*, which slowly drives lymph into vein. Thus frog has 2 pairs of lymph hearts. One pair situated anteriorly below the scapulae, open into subscapular veins. Another pair lying posteriorly on either side of the tip of urostyle open into femoral veins.

4. Lymph spaces. In frogs and toads, some lymph vessels become dilated to form huge lymph *channels* or *sinuses*, unlike other vertebrates. There are extensive subcutaneous spaces under skin (dorsal, lateral, abdominal etc.) because of which the skin is loosely attached. These spaces are separated by connective tissue septa. One of the most important is the *subvertebral lymph space* above kidneys.

5. Spleen. In the mesentery near rectum lies a small, round and dark red gland, the *spleen*. It contains the largest mass of lymphatic tissue in body. It destroys worn out erythrocytes and produces antibodies, new erythrocytes and lymphocytes which are phagocytic in nature.

Nervous System

As in other vertebrates, the nervous system of frog is composed of 3 main sub-divisions :

(1) *Central nervous system* comprising *brain* and *spinal cord*.

(2) *Peripheral nervous system* including *cranial* and *spinal nerves*.

(3) *Sympathetic nervous system* made up of *sympathetic nerves* and *ganglia*.

[I] Brain

Brain is a white-coloured, elongated and somewhat flattened structure, lying well protected inside the cranium of skull. It is surrounded by two connective tissue membranes, called *meninges* (singular, *meninx*). The inner or *piamater* is delicate, pigmented, vascular and closely applied to brain. The outer *durameter* is tough fibrous and lines the cranial cavity. The narrow space between the membranes and the inner cavities of brain are filled with a clear, watery and lymphatic *cerebro-spinal fluid* which protects and nourishes brain. The inner cavities of brain, called *ventricles*, are continuous with one another.

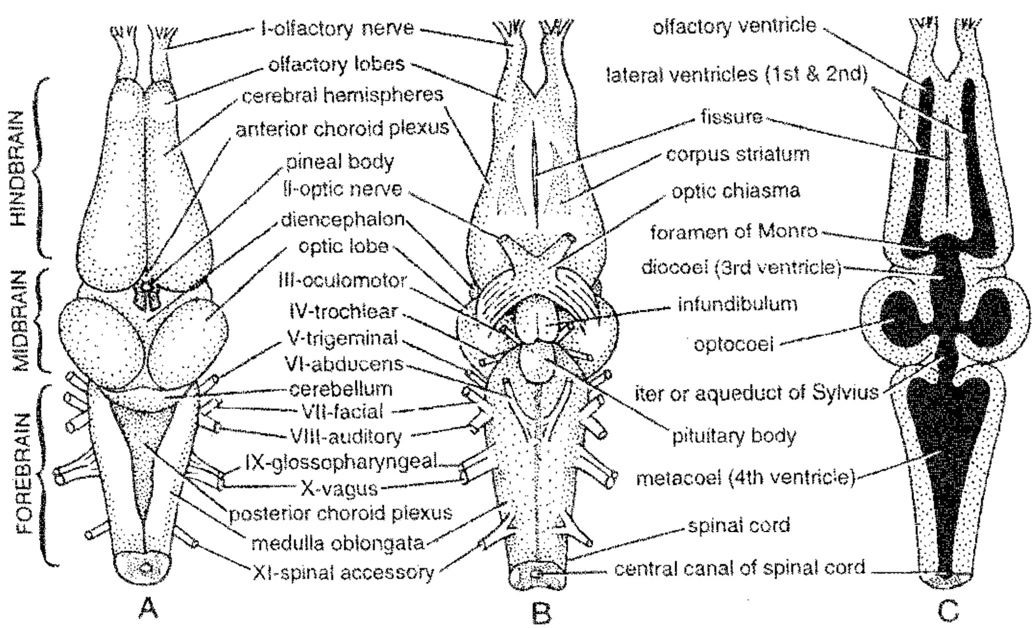
Brain of frog shows advancement over that of dogfish in the greater development of cerebrum and optic lobes. Brain can be described under the usual 3 main parts-forebrain, midbrain and hindbrain (Fig. 27).

1. Forebrain. It includes two olfactory lobes, two cerebral hemispheres and a diencephalon.

(a) Olfactory lobes. There are two anteriormost, rather small and spherical lobes each sending a small olfactory nerve to the nasal chamber of its side. The two lobes are united but each, contains a separate small cavity, the *olfactory ventricle* or *rhinocoel.* Olfactory lobes are concerned with sense of smell which is poor in frog.

(b) Cerebral hemispheres. Posteriorly, the olfactory lobes are demarcated by a slight constriction from two large *cerebral hemispheres* forming the *cerebrum.* These are long, oval and smooth structures, narrow in front but broad behind, and separated from one another by a deep mid-longitudinal groove or fissure. The large cavities of hemispheres, called I, II or *lateral ventricles* or *paracoels,* are continuous anteriorly with the olfactory ventricles. Posteriorly, they unite with each other and with the III ventricle or diocoel of diencephalon through a common opening called *foramen of Monro.* Thin roof of cerebrum is called *pallium* but each ventro-lateral side is thick, called *corpus striatum* (singular), which is made of white medullated nerve fibres and cells. The two *corpora striata* (pleural) are joined together by a transverse fibrous tract, the *anterior commissure.* The hemispheres are the seat of memory, intelligence, consciousness and will, and regulate voluntary actions.

(c) Diencephalon. It is the short, rhomboid, depressed region just behind the cerebrum. Its small cavity, III *ventricle* or *diocoel,* has thick lateral walls called *optic thalamic* (singular, *thalamus*) and a thick floor, called *hypothalamus.* Its dorsal roof contains a network of blood capillaries, called *anterior choroid plexus,* behind which arises a small hollow projection, the *pineal stalk,* that runs to the brow spot. In tadpole a small spherical *pineal body* is attached to the stalk. But, it is detached and comes to lie outside skull in adult frog. Ventral surface of diencephalon bears the X-shaped *optic chiasma* formed by the two optic nerves crossing each other. Just posterior



(Z-3) Fig. 27. Frog. Structure of brain. A—Dorsal view. B—Ventral view. C—Longitudinal horizontal section showing ventricles.

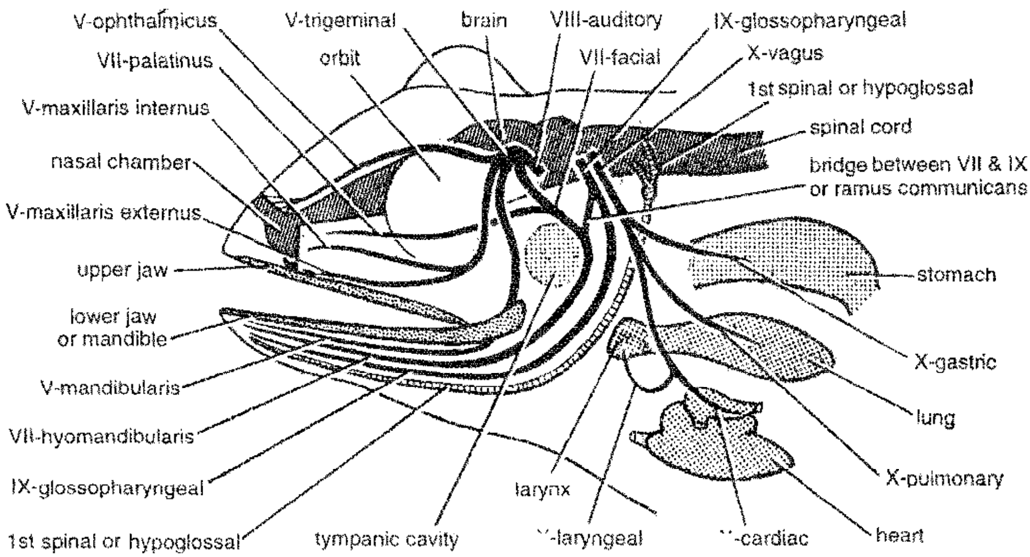


Fig. 28. Frog. Dissection of cranial nerves in left view.

***Table 1.* Cranial Nerves of Frog.**

Number	Name	Origin	Distribution	Nature
O	**Terminal**	Forebrain	Lining of nose	Sensory (probably)
I.	**Olfactory**	Olfactory lobe	Lining of nose	Sensory (small)
II.	**Optic**	Diencephalon	Retina of eye	Sensory (vision)
III.	**Oculomotor**	Midbrain ventrally	4 muscles of eye	Motor
IV.	**Trochlear**	Midbrain dorsally	Superior oblique muscle of eye	Motor
V.	**Trigeminal**	Medulla laterally		Mixed
	(a) *Ophthalmic*		Skin of snout	Somatic sensory
	(b) *Maxillary*		Skin of upper jaw	Somatic sensory
	(c) *Mandibular*		Muscles of lower jaw, tongue	Visceral motor
VI.	**Abducens**	Medulla ventrally	External rectus of eye	Motor
VII.	**Facial**	Medulla laterally		Mixed
	(a) *Palatinus*		Roof of buccal cavity	Visceral sensory
	(b) *Hyomandibularis*		Tympanum, skin of lower jaw, tongue	Visceral motor
VIII.	**Auditory**	Medulla laterally	Internal ear	Sensory (hearing)
IX.	**Glossopharyngeal**	Medulla laterally	Tongue, hyoid, pharynx	Mixed
X.	**Vagus (Pneumogastric)**	Medulla laterally		Mixed
	(a) *Laryngeal*		Laryngotrachial chamber	
	(b) *Gastric*		Stomach	
	(c) *Pulmonary*		Lung	
	(d) *Cardiac*		Heart	

to optic chiasma is a large median bilobed projection, the *infundibulum*, which bears a flattened oval *pituitary body* or *hypophysis*. Diencephalon is concerned with vision and balance.

2. Midbrain. It is the broadest part of brain containing a narrow canal, the *iter* or *aqueduct of Sylvius*, which is continuous with III ventricle in front and IV ventricle behind. Midbrain bears dorsolaterally two large rounded *optic lobes*, called *corpora bigemina*. Their canals, called *optocoels*, open into iter. Two thick longitudinal bands of nerve fibres, called *crura cerebri*, run longitudinally beneath optic lobes connecting diencephalon and medulla. The optic lobes inhibit spinal cord reflexes, and each controls the opposite side of body.

3. Hindbrain. The posterior part of brain includes cerebellum and medulla oblongata.

(a) ***Cerebellum.*** It is a poorly developed narrow transverse solid ridge or band, placed dorsally just behind the optic lobes. It controls equilibrium and muscular coordination which are of little importance in frog.

(b) ***Medulla oblongata.*** It is the last small conical part which is continuous with spinal cord without distinction. Its triangular cavity, called *IV ventricle* or *metacoel*, is continuous anteriorly with iter and posteriorly with the central cavity of spinal cord. The thin and highly vascular dorsal roof of metacoel forms the *posterior choroid plexus*. Medulla controls important involuntary functions such as heart beat, metabolism, respiration, etc. which continue even if rest of the brain is removed. But removal of medulla is soon followed by death.

[II] Spinal cord

The spinal cord extends posteiorly from medulla oblongata through foramen magnum and lies protected within the neural canal of vertebral column. It is short, thick, cylindrical, somewhat flattened and white in colour. Like brain, spinal cord is also surrounded by the two meninges, piamater and duramater, containing protective and

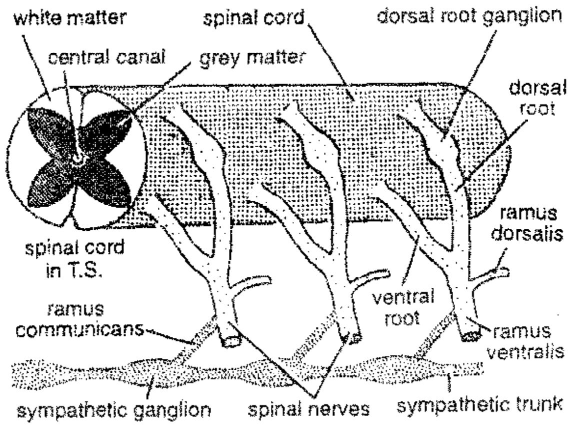


Fig. 29. Frog. A part of spinal cord showing origin and branching of three spinal nerves.

nourishing cerebro-spinal fluid. Posteriorly it terminates into a fine, non-nervous filament, *filum terminale*, in the urostyle. Spinal cord shows swellings in two places—*brachial enlargement* between forelimbs and *sciatic* or *lumbar swelling* anterior to filum terminale. Throughout its length run two longitudinal grooves, the mid-dorsal called *dorsal fissure* and the mid-ventral called *ventral fissure*. It encloses a narrow *central canal* which is a continuation of the ventricles of brain. Spinal cord is made of outer *white matter* composed chiefly of nerve fibres and inner *gray matter*, largely of nerve cells. Spinal cord is mainly concerned with the reflex actions (Fig. 29).

[III] Cranial nerves

10 pairs of cranial nerves originate from brain of frog. According to some workers, the O or *terminal nerves* are also present so that the actual number becomes 11 pairs. Their number, name, origin, distribution and nature are briefly indicated in the accompanying Table 1 (Fig. 28).

[IV] Spinal nerves

Frog has 10 pairs of spinal nerves, often reduced to only 9 pairs. This unusually small number is expected in an animal with so short a spinal cord. Every spinal nerve on either side arises from spinal cord by two roots which unite just as the nerve comes out of neural canal through an

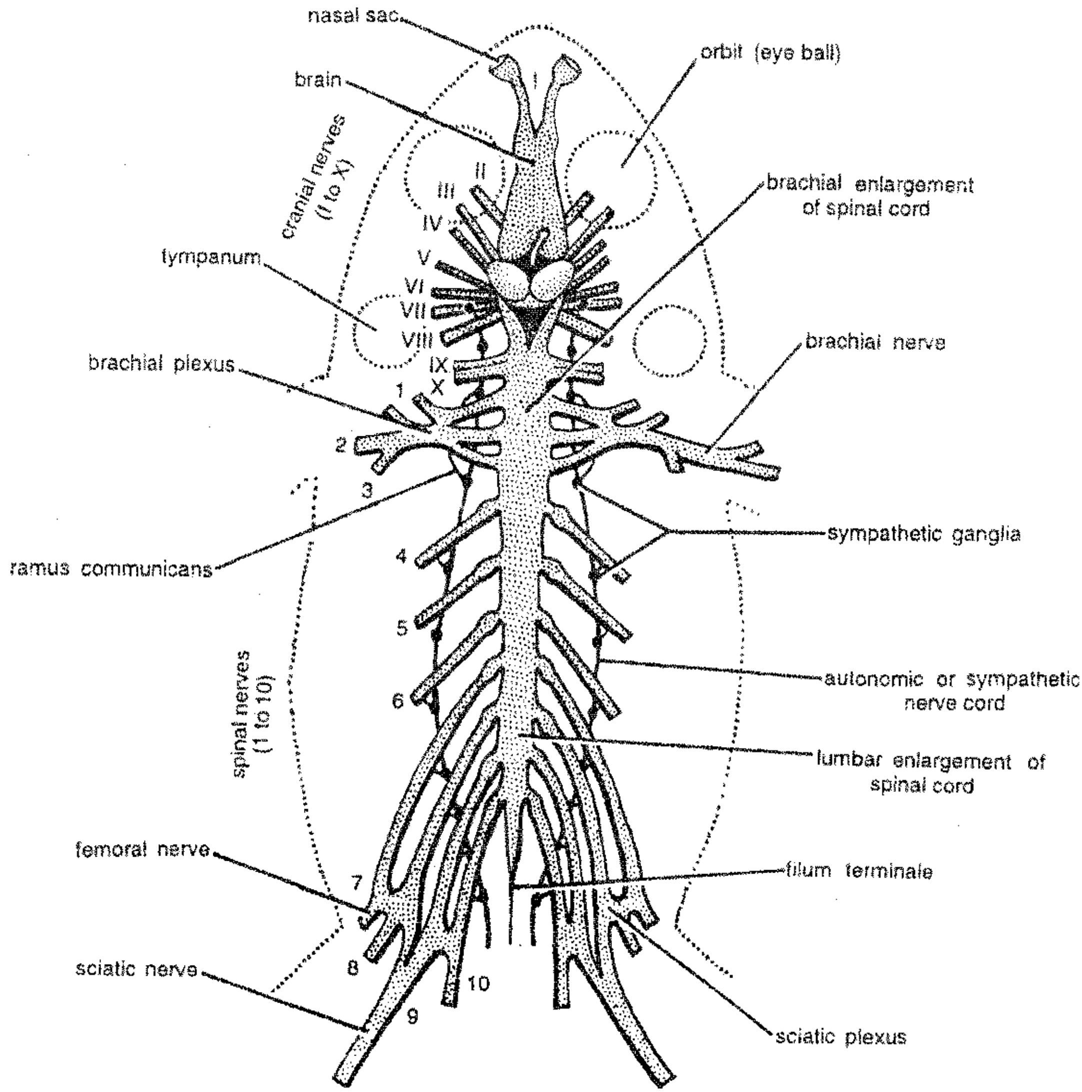


Fig. 30 Frog. Nervous system in dorsal view, showing origin of cranial nerves I-X and spinal nerves 1-10.

intervertebral foramen. *Dorsal root* bears a *ganglion* containing nerve cells. It consists entirely of afferent or sensory nerve fibres which carry impulses from various body parts towards the spinal cord. *Ventral root* consists only of efferent or motor nerve fibres which carry impulses from spinal cord to the tissues of body. Thus, all spinal nerves are mixed in nature made up of both sensory as well as motor fibres. In salientians (e.g. frog), white soft chalky masses, called calcareous bodies or *glands of Swammerdam*, cover the dorsal root ganglia and are believed to form reserve supplies of calcium. Immediately after origin, each spinal nerve gives off 3 branches: a short *ramus dorsalis* to dorsal skin and muscles, a large *ramus ventralis* to ventral skin and muscles, and a very small *ramus communicans* to join the nearest sympathetic ganglion (Fig. 31).

The first spinal nerve called *hypoglossal* comes out of neural canal between first and second vertebrae and turns anteriorly to supply the muscles of tongue. The second spinal nerve is

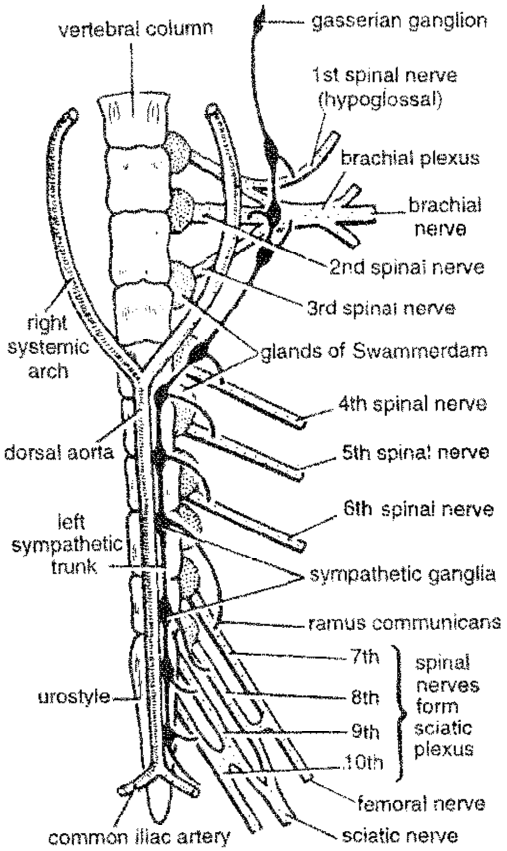


Fig. 31. Frog. Dissection showing spinal nerves 1-10 and sympathetic trunk on the left side only.

large and stout. Joined by the third spinal nerve and a small branch from hypoglossal, it forms a network, the *brachial plexus*, and then forms the *brachial nerve* which supplies the forelimb. Fourth, fifth and sixth spinal nerves are small and run obliquely to skin and muscles of abdomen. Seventh, eighth and ninth nerves are large and run backwards to form the *sciatic plexus* from which a large *sciatic nerve* and some small nerves supply the hind limb. Tenth spinal nerve is generally absent in *Rana tigrina*, or may be present only on one side, when it emerges through a hole in urostyle near its anterior end. Besides a branch to sciatic plexus, it supplies the urinary bladder, cloaca and other parts.

[V] Sympathetic nervous system

Sympathetic nervous system includes two slender delicate thread-like nerve cords, the *sympathetic trunks*, running beneath the vertebral column, one on either side of the dorsal aorta. Each trunk bears a series of 10 *sympathetic ganglia*, which are connected with adjacent spinal nerves by small nerves called *rami communicantes* (singular *ramus communicans*). Corresponding ganglia of both the sympathetic cords are also connected together by small transverse commissures. On each side, the sympathetic cord continues anteriorly to enter skull to join first the *vagus ganglion* of X nerve and then forward again to join the *gasserian ganglion* of V or trigeminal nerve where it finally ends. Sympathetic ganglia distribute nerves chiefly to circulatory system, digestive tract and glandular organs and regulate activities not under the control of will such as rate of heart beat, muscular tone of blood vessels, secretion of digestive juices, muscular movements of stomach and intestine, etc.

Sense Organs

The sensory system includes *receptors* or *sense organs*. These receive sensations or *stimuli* due to changes in the external or internal environment. Sensory nerves carry nervous impulses from sense organs to the central nervous system where they are interpreted as characteristic sensations. Each kind of stimulus affects a particular sense organ. Like man, frog has five special senses of touch, smell, taste, sight and hearing.

[I] Organs of touch or tangoreceptors

Frog has numerous microscopic cutaneous sense organs or *tangoreceptors* present under epidermis of skin. These are either in the form of simple networks of *nerve endings* scattered among cells or as compact groups of cells forming *corpuscles* projecting into papillae of epidermis. They are sensitive to various types of stimuli such as touch, chemicals, temperature, humidity, light, pain, etc. The tadpole has a *lateral line system* which is absent in adult frog.

[II] Organs of taste or taste buds

Gustatoreceptors or taste organs are in the form of *taste buds* present in small papillae on the tongue and floor and roof of buccal cavity. A taste bud consists of elongated spindle-like receptor cells or taste cell ending in fine hair-like processes for sampling food which is taken into mouth. The other cell which is found in association with taste cells is called, *supporting cell*. Receptor cells are innervated by fibres of VII and IX cranial nerves.

[III] Organs of smell or olfactory organs

Epithelial lining of two nasal cha...bers for...s the *olfactoreceptor* or the organ of smell. It contains tall olfactory receptor cells with tufts of fine cilia on their outer ends and nerve fibres attached to their inner ends. With supporting cells which are simple epithelial cells. The fibres unite to form the olfactory nerve which carries the sensations about odours to brain.

[IV] Organs of sight or eyes

Photoreceptors or the organs of sight are the two large eyes, similar in general structure and function with those of other vertebrates. Each eyeball is roughly spherical and lodged inside an orbit in the ˈorso-lateral si ˈe of hea ˈ protecte ˈ by *eyelids*. It can be moved by 6 extrinsic *muscles* attacˈ e ˈ to its posterior wall an ˈ similar to tˈ ose .f ..gfis... T... .re *external* an. *internal oblique muscles* while the other four are *rectus muscles*. Frog can protrude its eye with the help of *levator bulbi* and can withdraw with the help of *retractor bulbi*. The outer one-third exposed part of eye is transparent, while inner two-third concealed part is opaque. The wall of eye ball is composed of three concentric layers or coats—sclerotic, choroid and retina (Figs. 32 & 33).

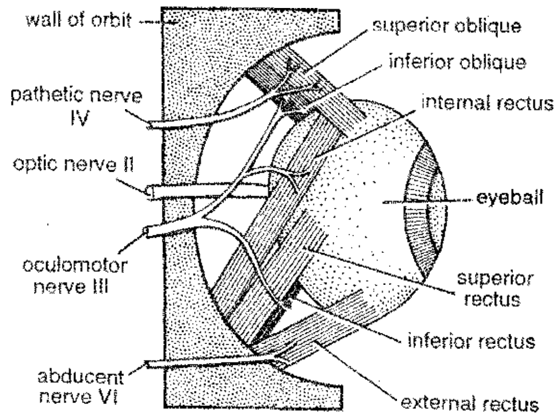


Fig. 32. Frog. Dissection of right eyeball in dorsal view showing eye muscles and their nerve supply.

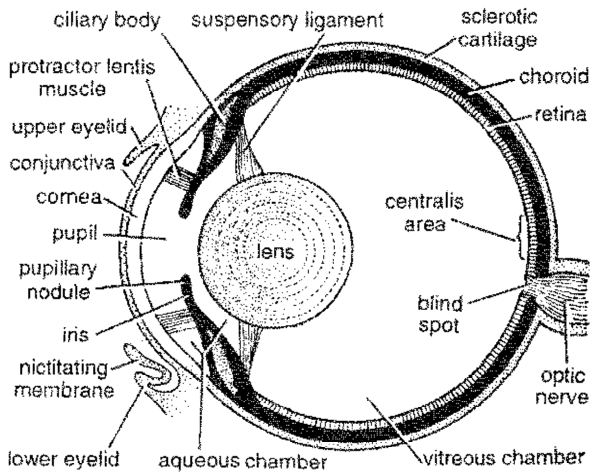


Fig. 33. Frog. Diagrammatic V.S. of eyeball.

1. Sclerotic. The outer thick, protective coat, made by tough white fibrous connective tissue and cartilage is called *sclerotic*. Its anterior exposed and raised circular part is modified into the transparent *cornea* to permit entry of light rays into the eye. Cornea in turn is covered by a thin transparent continuation of skin, called *conjunctiva*. A continuation of lower eyelid forms the transparent third eyelid or nictitating membrane which can be spread to cover the front of eye over *conjunctiva*. Both are lubricated and kept moist by the secretion of a *Harderian gland* found in the orbit.

2. Choroid. Underneath sclerotic is the richly vascular and darkly pigmented *choroid coat* which prevents all light-except that entering through cornea. In front, choroid is separated from cornea forming a vertical pigmented circular disc called *iris*, with a central opening, the *pupil*, through which light can enter. Pupil can be reduced or increased by circular and radial muscles of iris, which acts like a diaphragm. At the base of iris, the choroid is radially thickened to form the *ciliary body* containing ciliary muscles. Behind the pupil is present a large, spherical and transparent crystalline *lens* enclosed in a delicate *lens capsule*. It is held in place by *suspensory ligament* (= *protractor lentis*) from ciliary body. The small anterior chamber of eye between cornea and lens is filled with a watery fluid, *aqueous humour*. The larger posterior chamber behind the lens contains a jelly-like substance, *vitreous humour*. Both humours serve to maintain the form of eyeball.

3. Retina. It is the innermost and most sensitive layer restricted to the posterior part of eyeball behind ciliary body. It is itself made of several layers. Outermost is the pigmented layer adhered to choroid. Beneath it lie specialized sensory cells, the *rods* and *cones*, followed by several layers of other sensory cells. Inner-most layer is formed by nerve fibres which converge to form the *optic nerve*. Light falling on retina stimulates rods and cones and the impulses are conducted by optic nerve to brain. The spot where optic nerve comes out of the eyeball is called the *blind spot*. It lacks rods and cones and does not form an image. Near it, lies the *yellow spot* where the most distinct image is formed.

Working of eye. The eye of frog works like a "box camera". Pupil can be dilated or contracted to admit more light in darkness and less light in brightness. Light rays coming from an object into eye are refracted by cornea and lens and form an inverted image on the retina. The impulses set up by the stimulation of rods and cones are transmitted to brain over optic nerve. Unlike the lens of human eye, the frog's lens does not change in shape or position resulting in poor accommodation. Therefore, frog is *myopic*, that is, it can efficiently see only near objects. Due to widely separated eyes, frog has *monocular vision*, that is, it can perceive movements better than other forms.

Photochemical basis of image formation depends upon the photosensitive pigments present in the photosensitive cells. *Rhodopsin* (visual purple) present in rods and *Iodopsin* (visual violet) present in cones are the prime photosensitive chemicals. Synthesis of these two pigments is mediated by vitamin A. When light falls on these pigments, their photochemical decomposition takes place, which can create impulses in the photosensitive cells of retina.

[V] Organs of hearing and equilibrium or ears

Statoacoustic organs meant for hearing and equilibrium are a pair of ears attached to skull postero-laterally in all vertebrates. An ear of frog consists of only two parts, *middle* and *internal* ears. There is no *external ear* which is so conspicuous in mammals (Figs. 34 & 35).

1. Middle ear. The cavity of middle ear is called *tympanic cavity*. It is closed externally by the conspicuous *ear drum* or *tympanic membrane* which is a dark, flat, circular patch of skin behind eye. It is tightly stretched over a ring-like cartilage, *annulus tympanicus*. Middle ear cavity contains air and communicates with pharynx ventrally through a canal, the *Eustachian tube*. With air present on both the sides of ear drum, it can vibrate without being damaged under the impact of striking sound waves. The bony partition between tympanic cavity and auditory capsule is perforated by a small window-like oval aperture, the *fenestra ovalis*, which remains closed by a membrane and a cartilaginous nodule, the *stapedial plate*. A slender club-like rod of bone and cartilage, the *columella auris*, extends across the tympanic cavity. Its outer end is attached to the ear drum while inner end to the stapedial plate. Columella is equivalent to hyomandibula of dogfish.

2. Internal ear. The internal ear or auditory capsule is formed by the prootic and exocipital bones. Its cavity is filled with a clear, protective watery fluid, the *perilymph*, into which floats the complicated inner ear or *membranous labyrinth*. It is similar in structure and function to the inner ear of a fish. Its sac-like body or *vestibule* is made of a larger dorsal oblong *utriculus* and a smaller ventral oval *sacculus*. Posterior portion of sacculus forms two small rounded diverticula, *lagena* and *pars basilaris*. Lagena is the forerunner of the cochlear duct of higher vertebrates. Pars basilaris seems to be a part of lagena. Above the two is

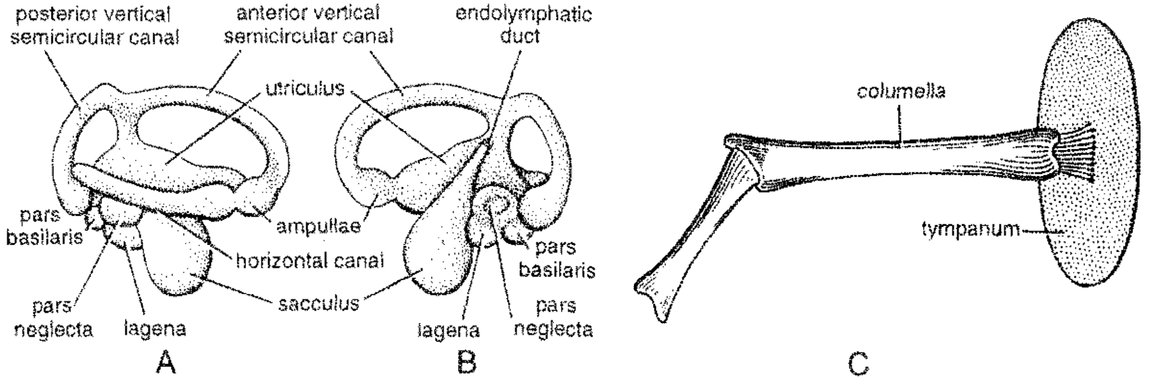


Fig. 34. Frog. Membranous labyrinth. A—Outer view. B—Inner view. C—Columella auris.

another protuberance, *pars neglecta*, which comes from utriculus. Three *semicircular canals*—anterior and posterior vertical and horizontal—arise from utriculus and are arranged at right angles with one another. Only one end of each canal is slightly swollen into an *ampulla*. A small narrow *endolymphatic duct* arises from inner dorsal end of sacculus and terminates in an expanded thin-walled endolymphatic sac over hind brain inside skull.

Histology of membranous labyrinth. Membranous labyrinth is filled with a milky fluid, the *endolymph*, containing suspended innumerable small particles of calcium carbonate, called *otoliths*. The thin wall of labyrinth is made of dense fibrous tissue, lined with cubical epithelium which is modified at certain spots forming elevated sensory patches called *acoustic spots* or *ridges*. These form the actual receptors of ear. An acoustic ridge is made up of *supporting cells* and tall *sensory hair cells* each bearing a stiff sensory hair-like process at the free end while basally connected to fibres of *auditory* or *VIII cranial nerve*. The sensory spots of ampullae are called *cristae*, while those in vestibule are termed *maculae*.

Working of ear. Ear performs two functions—*hearing* and *equilibrium*.

(a) Hearing. Sound waves directly impinging upon tympanum produce vibrations which are transmitted through columella and stapedial plate of middle ear to perilymph of auditory capsule. From perilymph, vibrations are transmitted to endolymph of membranous labyrinth and stimulate

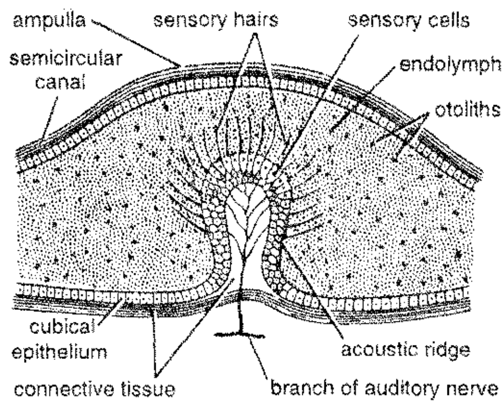


Fig. 35. Frog. V.S. of ampulla through an acoustic ridge or crista.

the sensory hair cells of sacculus and lagena. The nerve impulses reaching brain through auditory nerve are perceived as sound.

(b) Equilibrium. Utriculus and the three semicircular canals which are arranged in three different planes, are concerned with the maintenance of equilibrium of body. Any change in the position of body disturbs the suspended otoliths which stimulate the sensory hair cells of utriculus and three canals. Impulses are carried by the auditory nerve to brain which accordingly directs the body muscles to correct the balance of body.

Urinogenital System

The excretory and reproductive systems are functionally unrelated. But in males, the excretory products (urine) as well as genital products (sperm) pass out through common urinogenital ducts, so that the two systems are generally described together as urinogenital system. Sexes being separate, each frog is either male or female.

[I] Excretory system

Excretory system is similar in both male and female and includes a pair of *kidneys*, their ducts (*ureters*), an *urinary bladder* and *cloaca*.

1. Kidneys. The two kidneys lie posteriorly, outside abdominal coelom in the large subvertebral lymph sinus, attached one on either side of vertebral column. They are covered with peritoneum on their ventral surfaces only. The kidneys are *mesonephric*. They are elongated, flat and reddish-brown structures with outer edges smooth and convex but inner edges notched and straight. The ventral surface of each kidney has an elongated narrow yellow *adrenal* or *suprarenal gland* which is an important endocrine gland. To the anterior end of each kidney several small finger-like *fat bodies* and a *testis* (in male) or *ovary* (in female) are attached (Fig. 36).

Histological structure. Histologically, each kidney is a compact mass of innumerable (about 2,000) highly twisted microscopic *uriniferous tubules* or *nephrons* and blood vessels, embedded in connective tissue. Tubules are the functional units of kidney. They are lined with a glandular and at places with ciliated epithelium. Proximal or closed end of a tubule forms a double walled cup with a narrow opening, called *Bowman's capsule*. It encloses a bunch or network of fine capillaries, the *glomerulus*. Capsule and glomerulus together constitute a *renal corpuscle* or *Malpighian body*. A small afferent branch of renal artery carries blood into glomerulus while it is taken out by an efferent branch joining a renal vein. The uriniferous tubule remains much convoluted and surrounded by a capillary network from renal portal vein. At its other end, each tubule opens into a *collecting tubule* running transversely across the kidney near its dorsal surface. In turn, all the transverse collecting tubules open towards inner margin of kidney into a longitudinal *Bidder's canal*, and towards outer margin into a

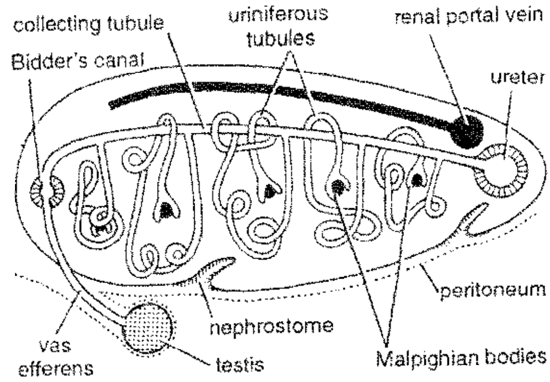


Fig. 36. Frog. Diagrammatic T.S. of kidney.

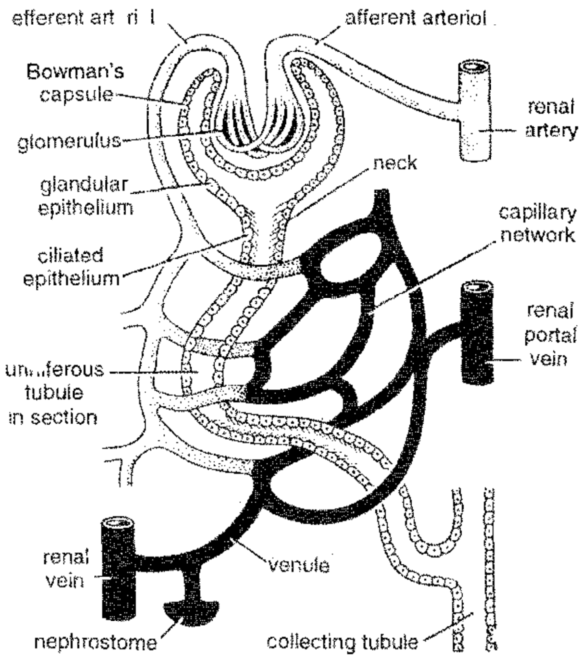


Fig. 37. Frog. A uriniferous tubule in section with its blood capillaries.

longitudinal *ureter*. Ventral surface of each kidney has many ciliated funnels called *nephrostomes*. They drain wastes from body cavity (coelom) and connect to renal veins in frog, or to uriniferous tubules in tadpoles (Fig. 37).

2. Ureters. From posterior outer margin of each kidney leaves a *urinary* or *Wolffian duct*, also called *ureter*. It is a fine, white tube which extends backward to open into the dorsal wall of cloaca. The openings of both the ureters are located on two papillae placed side by side dorsally in cloaca. In male frog, the ureters are called *urinogenital ducts* since they pass out sperms as well as urine.

3. Urinary bladder. A large transparent, bilobed, thin-walled elastic urinary bladder opens into t e ventral wall of cloaca by a sphinctered aperture opposite and below the openings of ureters.

4. Cloaca. It is a small median chamber into which open the anus, urino-genital apertures and urinary bladder. Cloaca opens to outside by a sphinctered cloacal a erture lying at the hi d e d of trunk between the bases of hindlegs.

Physiology of excretion. Frog is *ureotelic* excreting predominantly urea along with water. Due to *ultrafilteration* from blood circulating in glomerulus, excessive water containing nitrogenous wastes (especially urea), inorganic salts, glucose, etc. is filtered out into Bowman's capsule. While this glomerular filterate passes through uriniferous tubule, useful substances are rea' sor' ed into ' lood due to *selective* and *active filtration*. The remaining fluid forming *urine* is carried by collecting vessels into ureter and passes down into cloaca. It is either stored temporarily in urinary bladder or eliminated through cloacal aperture.

[II] Male reproductive system

Male reproductive system consists of two *testes* attached to kidne s, several *vasa efferentia* and two *urinogenital ducts*. Copulatory organs are lacking (Figs. 38 & 39).

1. Tests. A testis is an elongated (1.25 cm long) or ovoid, light-yellow body attached to the antero-ventral surface of each kidney by a double fold of peritoneum, called *mesorchium*. Near the anterior end of testis, several branched finger-like fat bodies arise which provide reserve food used to nourish developing spermatozoa and during hibernation. Histologically each testis is a compact mass of much coiled *seminiferous tubules*, the epithelial lining of which produces spermatozoa by spermatogenesis. A mature *sperm* is microscopic, elongated, about 0.03 mm long structure. It consists of a small rounded anterior *acrosome*, a long cylindrical *head* containing nucleus, a short *middle piece* containing centrioles and mitochondria, ana a much elongated posterior motile *tail* terminating in a flagellum.

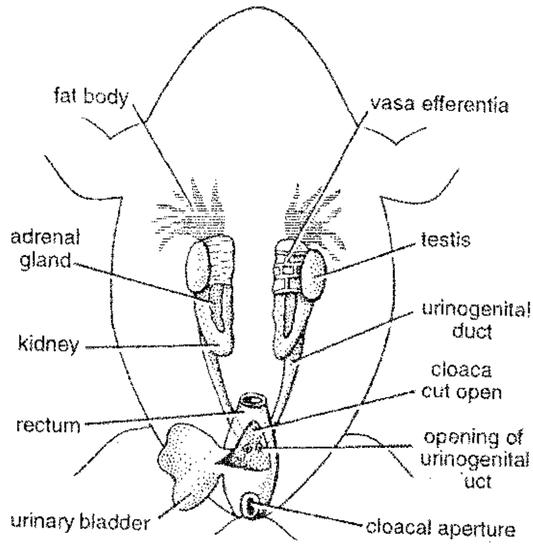


Fig. 38. Frog. Male urinogenital organs.

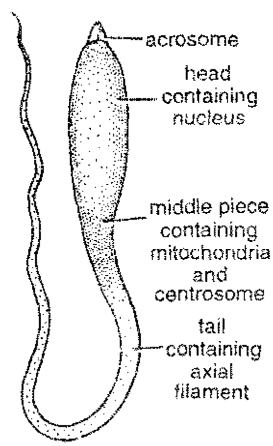


Fig. 39. Frog. A mature sperm.

2. Vasa efferentia. All the seminiferous tubules in a testes are connected to form 10 or 12 narrow tubes, the *vasa efferentia*. These leave from the inner margin of testis, run through mesorchium and enter the inner margin of kidney to open into the Bidder's canal. The latter is connected to the ureter through collecting tubules of kidney. Thus vasa efferentia conduct mature spermatozoa from testis to the ureter of kidney.

3. Urinogenital duct. As already mentioned earlier, ureter in male frog is both a urinary duct and a vas deferens, hence it is called a urinogenital duct. The ducts of both the sides open into roof of cloaca separately on urinogenital papillae. In some species of frog, the urinogenital ducts are enlarged near kidneys or cloaca forming *seminal vesicles* for temporary storage of spermatozoa until needed.

[III] Female reproductive system

Female reproductive system consists of two *ovaries* and two *oviducts* (Figs. 40 & 41).

1. Ovaries. Each ovary is attached to the dorsal abdominal wall, near kidney, supported by a peritoneal fold called *mesovarium*. It is a large, irregularly folded, multilobed, hollow sac greyish or blackish in colour. In breeding season, the two ovaries become greatly enlarged. Histologically, each ovary contains innumerable dark round *ova* in different stages of development. Ova arise from germinal epithelial lining by oogenesis. When ripe, the ova are shed by rupture of ovarian wall into the body cavity from where they are moved by cilia of peritoneum into the ostia of oviducts. *Fat bodies* are also attached in front of ovaries just as before testes in male frog.

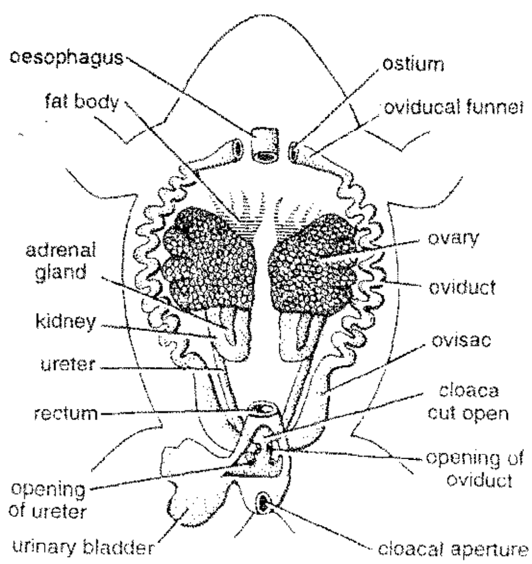


Fig. 40. Frog. Female urinogenital organs.

2. Oviducts. The two oviducts are long and much coiled white glandular tubes not connected directly to the ovaries. Their anterior ends form ciliated funnel-like openings, the *ostia*. These are placed quite anteriorly in the body cavity at the bases of lungs one on either side of oesophagus. Cilia present on the inner walls of oviducts move the eggs posteriorly while glands secrete an albuminous coat around each egg during its passage. The posterior ends of oviducts open dorsally into cloaca separately on papillae just in front of the apertures of ureters. Just before entering cloaca, each oviduct forms a thin-walled enlargement, the *ovisac*, sometimes erroneously called "uterus". The eggs are collected inside ovisacs before being laid.

An unfertilized ripe egg of frog is spherical and nearly 1.75 mm in diameter. Its upper black pigmented half containing nucleus is called *animal hemisphere* or *pole*. The lower whitier half containing yolk is called *vegetal hemisphere* or *pole*. Quantity of yolk is much larger than in the egg of *Branchistoma*. Egg of frog is *telolecithal* and radially symmetrical. Around the egg is a two-layered *vitelline membrane* of its own secretion. The outer albuminous coat on contact with water swells into a thick jelly like layer which probably prevents overcrowding and protects from infections and predators.

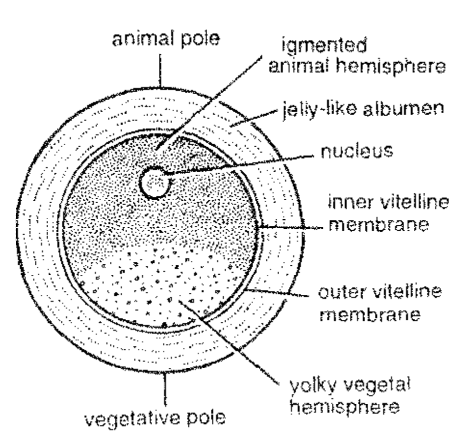


Fig. 41. Frog. An unfertilized ripe egg.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the food, feeding habits and the digestive organs of *Rana tigrina.*
2. Give an account of different modes of respiration in frog.
3. Describe the structure and working of heart of frog.
4. Give an account of arterial and venous system of frog.
5. Give a detailed account of the structure of brain of frog.
6. Give an account of the urinogenital system in *Rana tigrina.*

» *Short Answer Type Questions*

1. What is a valve ? Show the utility of various valves present in the heart of a frog.
2. Give an account of lymphatic system of frog.
3. Describe in a tabular form the origin, distribution and nature of cranial nerves of frog.
4. Describe the following organs in frog and explain how frog is adapted to conditions in water and on land — (a) organs of hearing and (b) organs of vision.
5. Describe the functions of liver, pancreas and kidney in *Rana.*
6. Make well labelled diagrams to illustrate the following in frog—(i) Arterial or venous system, (ii) V.L.S. of brain, (iii) T.S. kidney, (iv) V.S. skin, (v) T.S. testis or ovary.
7. Write short notes on—(i) Amplexus, (ii) Hibernation, (iii) Laryngo-tracheal chamber, (iv) Renal portal system, (v) Reflex arc, (vi) Sympathetic nervous system, (vii) Truncus arteriosus.

» *Multiple Choice Questions*

1. The crossopterygian fishes gave rise to :
   (a) Labyrinthodontia (b) Anura
   (c) Phyllospondyli (d) Apoda
2. *Rana tigrina* is a member of the order :
   (a) Lepospondyli (b) Anura
   (c) Apoda (d) Urodela
3. The frog swims in water by :
   (a) Powerful forward thrusts of its forelimbs
   (b) Powerful backward thrusts of its forelimbs
   (c) Powerful backward thrusts of its hind limbs
   (d) Powerful forward thrusts of its hind limbs
4. The tongue of frog is :
   (a) Short, protrusible and attached at the front end
   (b) Short, protrusible and attached at the distal end
   (c) Long, non-protrusible and attached at the front end
   (d) Long, protrusible and attached at the front end
5. During hibernation or aestivation frog lives upon :
   (a) Stored glycogen and fat
   (b) Stored glucose and fat
   (c) Stored starch and fat
   (d) Stored galactose and fat
6. In frogs, the sexual embrace between male and female is called :
   (a) Aplexus (b) Amplexus
   (c) Spawning (d) Swarming
7. The three rectal ciliates in frog are :
   (a) *Nyctotherus, Balantidium* and *Trichomonas*
   (b) *Balantidium, Opalina* and *Entamoeba*
   (c) *Opalina, Nyctotherus* and *Balantidium*
   (d) *Opalina, Balantidium* and *Amoeba*
8. The third eyelid in frog is called :
   (a) Pineal eye (b) Upper eyelid
   (c) Lower eyelid (d) Nictitating membrane
9. The number of voluntary muscles in frog is about :
   (a) 200 (b) 300 (c) 400 (d) 500
10. Salivary glands in frog are :
    (a) Absent (b) 1 pair (c) 2 pairs (d) 3 pairs
11. The teeth in frog are meant for :
    (a) Chewing
    (b) Preventing prey from slipping
    (c) Tearing (d) Cutting
12. Stomach in frog is attached to the dorsal body wall by means of a mesentery called :
    (a) Oxygaster (b) Endogaster
    (c) Mesogaster (d) Megagaster
13. The hepatopancreas duct opens into :
    (a) Buccal cavity (b) Oesophagus
    (c) Stomach (d) Duodenum
14. Common bile duct in frog is :
    (a) Combined cystic ducts from gall bladder and hepatic ducts from liver
    (b) Combined cystic ducts from gall bladder
    (c) Combined hepatic ducts from liver
    (d) Combined hepatic and pancreatic ducts
15. The gastric glands are activated for the secretion of HCl by :
    (a) Enterogastrone (b) Gastrin
    (c) Insulin (d) Renin
16. The liquefied semi digested acidic food in stomach is known as :
    (a) Bolus (b) Bile (c) Chyme (d) Rhyme

17. Which of the following is not an intestinal hormone in frog :
    (a) Enterogasterone (b) Cholecystokinin
    (c) Secretin (d) Gastrin
18. Which of the following is not a function of bile :
    (a) Hydrolysis of carbohydrates
    (b) Neutralizing acidity of chyme
    (c) Emulsification of fat
    (d) Activation of pancreatic lipase
19. During buccal respiration in frog :
    (a) Nostrils remain closed and glottis remains open
    (b) Nostrils remain open and glottis remains closed
    (c) Both nostrils and glottis remain closed
    (d) Both nostrils and glottis remain open
20. The auricles in frog are marked off externally from the ventricle by :
    (a) Interauricular groove
    (b) Interventricular groove
    (c) Coronary sulcus (d) Auriculo-ventricular septa
21. Sinus venosus in frog is formed by the union of :
    (a) 2 precavals and 2 post cavals
    (b) 1 precaval and 2 post cavals
    (c) 1 precaval and 1 post caval
    (d) 2 precavals and 1 post cavals

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (a) 11. (b) 12. (c) 13. (d) 14. (a) 15. (b) 16. (c) 17. (d) 18. (a) 19. (b) 20. (c) 21. (d).

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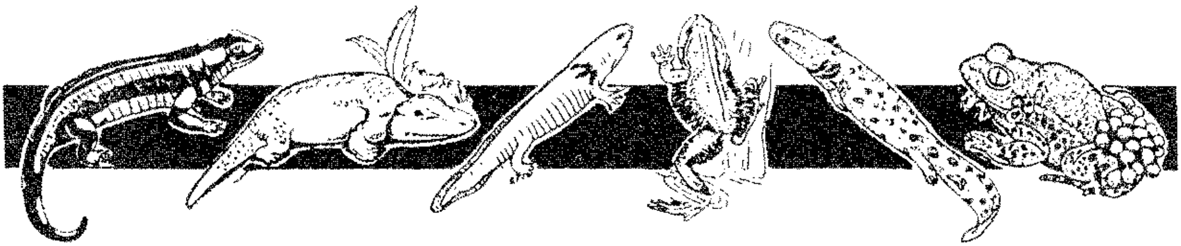

Class 6. Amphibia

The greatest event in the phylogenetic history was a transition from aquatic to terrestrial mode of life, and Amphibia were the first animals to attempt this transition. But they are not fully terrestrially adapted and hover between aquatic and land environments. The name of the class also indicates this double life (Gr., *amphi*, dual, double+*bios*, life). Structurally, Amphibia are between the fish on one hand, and the reptiles on the other.

General Characters

1. Aquatic or semiaquatic (freshwater), air and water breathing, carnivorous, cold-blooded, oviparous, tetrapod vertebrates.
2. Head distinct, trunk elongated. Neck and tail may be present or absent.
3. Limbs usually 2 pairs (tetrapod), some limbless. Toes 4-5 (pentadactyle) or less. Paired fins absent. Median fins, if present, without fin rays.
4. Skin soft, moist and glandular. Pigment cells (chromatophores) present.
5. Exoskeleton absent. Digits clawless. Some with concealed dermal scales.
6. Endoskeleton mostly bony. Notochord does not persist. Skull with 2 occipital condyles.
7. Mouth large. Upper or both jaws with small homodont teeth. Tongue often protrusible. Alimentary canal terminates into cloaca.
8. Respiration by lungs, skin and mouth lining. Larvae with external gills which may persist in some aquatic adults.
9. Heart 3-chambered (2 auricles+1 ventricle). Sinus venosus present. Aortic arches 1-3 pairs. Renal and hepatic portal systems well developed. Erythrocytes large, oval and nucleated. Body temperature variable (poikilothermous).
10. Kidneys mesonephric. Urinary bladder large. Urinary ducts open into cloaca. Excretion ureotelic.

11. Brain poorly developed. Cranial nerves 10 pairs.
12. Nostrils connected to buccal cavity. Middle ear with a single rod-like ossicle, columella. Larval forms and some aquatic adults with lateral line system.
13. Sexes separate. Male without copulatory or-an. Gonoducts open into cloaca. Fertilization mostly external. Females mostly oviparous.
14. Development indirect. Cleavage holoblastic but unequal. No extra-embryonic melbranes. Larva a tadpole which metamorphoses into adult.

Classification of Amphibia

The living amphibians are represented by about 2,500 species, a very much smaller number than that of other principal classes of vertebrates. However, these represent a mere shadow of the great amphibian radiations of the past, ranging from mid-Palaeozoic (Devonian) to early Mesozoic (Triassic). They dominated the World during Carboniferous, but most of them have become extinct since long. About 10 orders of extinct Amphibia are known only by fossil remains.

The classification most generally followed now-a-days was provided by G. Kingsley Noble (1924). He recognized 3 orders of extinct and 3 orders of living amphibians. In the past, all extinct groups of Amphibia were placed under a single subclass *Stegocephalia* (Adam Sedgwick) and all living groups in another subclass *Lissamphibia*. This arrangement has been followed in this text for the convenience of our young readers.

Subclass I. Stegocephalia (Extinct)

Limbs pentadactyle. Skin with scales and bony plates. Skull with a solid bony roof, leaving openings for eyes and nostrils. Permian to Triassic.

Order 1. Labyrinthodontia

Oldest known tetrapods called stem Amphibia. Freshwater or land forms. Salamander or crocodile like. Teeth large with characteristically much folded dentine similar to their crossopterygian

Fig. 1. *Eryops*, a fossil labyrinthodont.

ancestors. Carboniferous to Triassic. Example : *Eryops* (Fig. 1).

Order 2. Phyllospondyli

Small salamander-like. Head large, flat. Vertebrae tubular. Notochord and spinal cord housed in common cavity. Believed to be ancestors of modern Salientia and Urodela. Carboniferous to Permian. Example : *Branchiosaurs* (*Ichthyostega*).

Order 3. Lepospondyli

Small salamander or eel-like. Vertebrae cylindrical, each made of a single piece. Neural arch and centrum continuous. Ribs articulating intervertebrally. Regarded ancestral to modern caecilians (Gymnophiona). Carboniferous to Permian. Examples : *Diplocaulus*, *Lysorophus*.

Subclass II. Lissamphibia (living)

Modern Amphibia lacking dermal bony skeleton. Teeth small, simple.

Order 1. Gymnophiona or Apoda
(Gr., *gymnos*, naked+*ophioneos*, serpent-like) or (Gr., a, without + *podos*, foot)

1. Limbless, blind, elongated worm like, burrowing tropical forms known as caecilians.
2. Tail short or absent, cloaca terminal.
3. In some dermal scales embedded in skin which is transversely wrinkled.
4. Skull compact, roofed with bone.
5. Limb gridles absent.
6. Males have protrusible copulatory organs. Examples : About 55 species. *Ichthyophis*, *Uroaeotyphlus* (Fig. 2).

Order 2. Urodela or Caudata

(Gr., *Ura*, tail + *delos*, visible) or (L., *cauda*, *tail*)

1. Lizard-like amphibians with a distinct tail.
2. Limbs 2 pairs, usually weak, almost equal.
3. Skin devoid of scales and tympanum.
4. Gills permanent or lost in adult.
5. Males without copulatory organs.
6. Larvae aquatic, adult-like, with teeth.
7. About 300 species in 5 suborders.

Suborder 1. Cryptobranchoidea

1. Most primitive. Permanently aquatic.
2. Adults without eyelids and gills.
3. Angular and prearticular separate.
4. Premaxillary spine short.
5. Fertilization external.

Examples : *Cryptobranchus*, *Megalobatrachus*.

Suborder 2. Ambystomatoidea

1. Adults terrestrial with eyelids.
2. Angular fused with prearticular.
3. Premaxillary spine large.
4. Vertebrae amphicoelous.
5. Fertilization internal.

Example : *Ambystoma*.

Suborder 3. Salamandroidea

1. Vertebrae opisthocoelous.
2. Teeth on palate and prevomers.
3. Three sets of cloacal glands.
4. Fertilization internal.

Examples : *Triton* and *Triturus* (newts), *Salamandra* (salamander), *Desmognathus*, *Amphiuma* (congo eel), *Plethodon*.

Suborder 4. Proteidae

1. Aquatic bottom dwellers representing permanent larval forms, without eyelids.
2. Adults with 3 pairs of external gills and 2 pairs of gill slits.
3. Skull cartilaginous, without maxillae.
4. Jaws with teeth.

Examples : *Proteus* (olm), *Necturus* (mud-puppy).

Suborder 5. Meantes

1. Aquatic representing permanent larvae.
2. Forelimbs small, hind limbs absent.
3. Three pairs of external gills.
4. No eyelids, no cloacal glands.
5. Jaws with horny covering.

Examples : *Siren* (mud eel), *Pseudobranchus*.

Order 3. Salientia or Anura

(L., *saliens*, leaping) or (Gr., *an*, without + *aura*, *tail*)

1. Specialized Amphibia without tail in adults.
2. Hind limbs usually adapted for leaping and swimming.
3. Adults without gills or gill openings.
4. Eyelids well-formed. Tympanum present.
5. Skin loosely-fitting, scaleless; Mandible toothless.
6. Pectoral girdle bony. Ribs absent or reduced. Vertebral column very small of 5-9 presacral vertebrae and a slender urostyle.
7. Fertilization always external.
8. Fully metamorphosed without neotenic forms.
9. About 2,200 species of frogs and toads in 5 suborders.

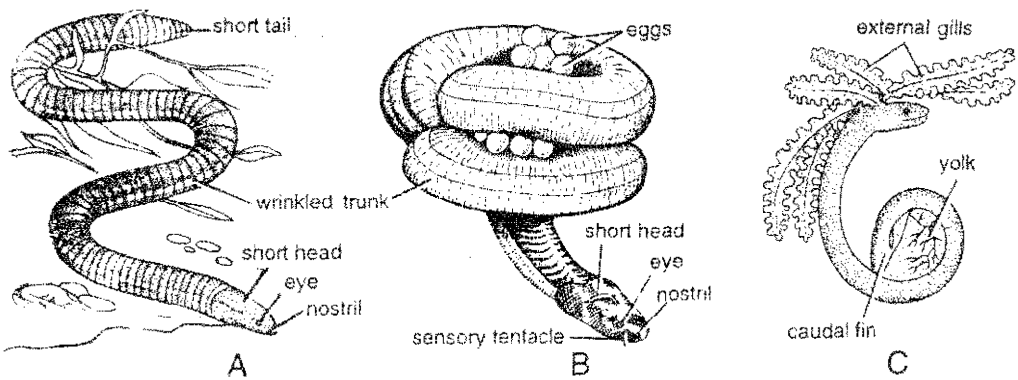

Fig. 2. *Ichthyophis glutinosa*. A—Male. B—Female guarding her eggs. C—Gilled larva.

Suborder 1. Amphicoela

1. Vertebrae amphicoelous. Presacral 9.
2. Free ribs and 2 relict tail muscles.
3. Fertilization internal.

Examples : *Leopelma, Ascaphus.*

Suborder 2. Opisthocoela

1. Vertebrae opisthocoelous. Scapula small.
2. Ribs free in adult or larva.

Examples : *Alytes* (midwife toad), *Bombinator, Discogiossus, Pipa, Xenopus.*

Suborder 3. Anomocoela

1. Vertebrae procoelous or amphicoelous.
2. Free ossified ribs absent.
3. Upper jaw with teeth.

Examples : *Pelobates, Scaphiopus.*

Suborder 4. Procoela

1. Vertebrae procoelous. Presacral 5-8.
2. Urostyle with 2 condyles. No free ribs.

Examples : *Bufo* (common toad), *Rhinoderma, Dendrobates, Hyla* (tree toad), *Gastrotheca* (marsupial frog).

Suborder 5. Diplasiocoela

1. First 7 vertebrae procoelous, 8th vertebra amphicoelous, sacral or 9th vertebra convex anteriorly and bears 2 condyles posteriorly.
2. Pectoral girdle usually fused to sternum (firmisternal). Ribs absent.

Examples : *Rana* (common frog), *Polypedates* or *Rhacophorus* (tree frog).

Other Amphibia

[I] Limbless amphibians

The limbless amphibians or caecilians, sometimes called blindworms, belong to the order Gymnophiona or Apoda. They mostly inhabit the tropical and subtropical regions of America, Africa and Asia. Except few aquatic forms, they are strictly burrowing. They burrow in moist ground with their strong heads, feeding mostly on worms and other small invertebrates. They have long slender, worm like body with much reduced tail so that vent or cloaca is almost terminal. They have neither girdles nor limbs but possess minute dermal scales buried in the skin. They may have as many as 250 vertebrae. Their eyes are

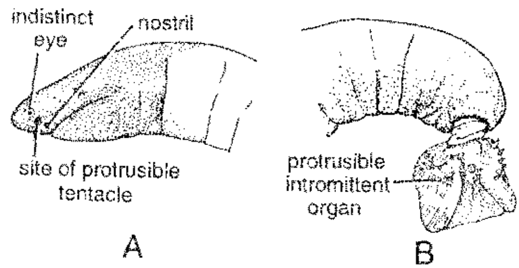

Fig. 3. *Caecilia tentacula.* A—Head and. B. Tail end.

rudimentary, concealed and practically functionless, hence the common name blindworms. However, they can feel their way about by means of a protrusible sensory tentacle, lying in a groove between the eyes and nose. Male copulates with female by a protrusible cloaca and fertilization is internal. Large eggs are usually laid in masses in moist ground near water. Female of *Ichthyophis*, common form in southeast Asia including India, shows *parental care* by carefully coiling her body around eggs till they hatch. The larval stage passed inside egg has 3 pairs of external gills which are lost when it hatches. *Uraeotyphlous* is another oviparous form also found in India in Malabar and Cochin. Some types of Apoda are viviparous or ovoviviparous, such as the South American aquatic form, *Typhlonectes.*

[II] Salamanders and newts

Tailed amphibians, belonging to the order Caudata or Urodela, include salamanders, newts and allied forms. These are elongated, lizard-like forms more generalized than frogs and undergo less profound changes in structure and habits at metamorphosis than do frogs. All possess a well developed tail and a lateral line system in adult as well as larval condition. Limbs are usually weak and subequal and terminal mouth is bounded by jaws with or without teeth. Eyelids and tympanum are lacking. Their skin is close-fitting unlike that of frogs and toads. They live on worms, small arthropods and small molluscs.

Urodeles show a gradual transition from aquatic to terrestrial life and generally fall in two groups (Fig. 4) :

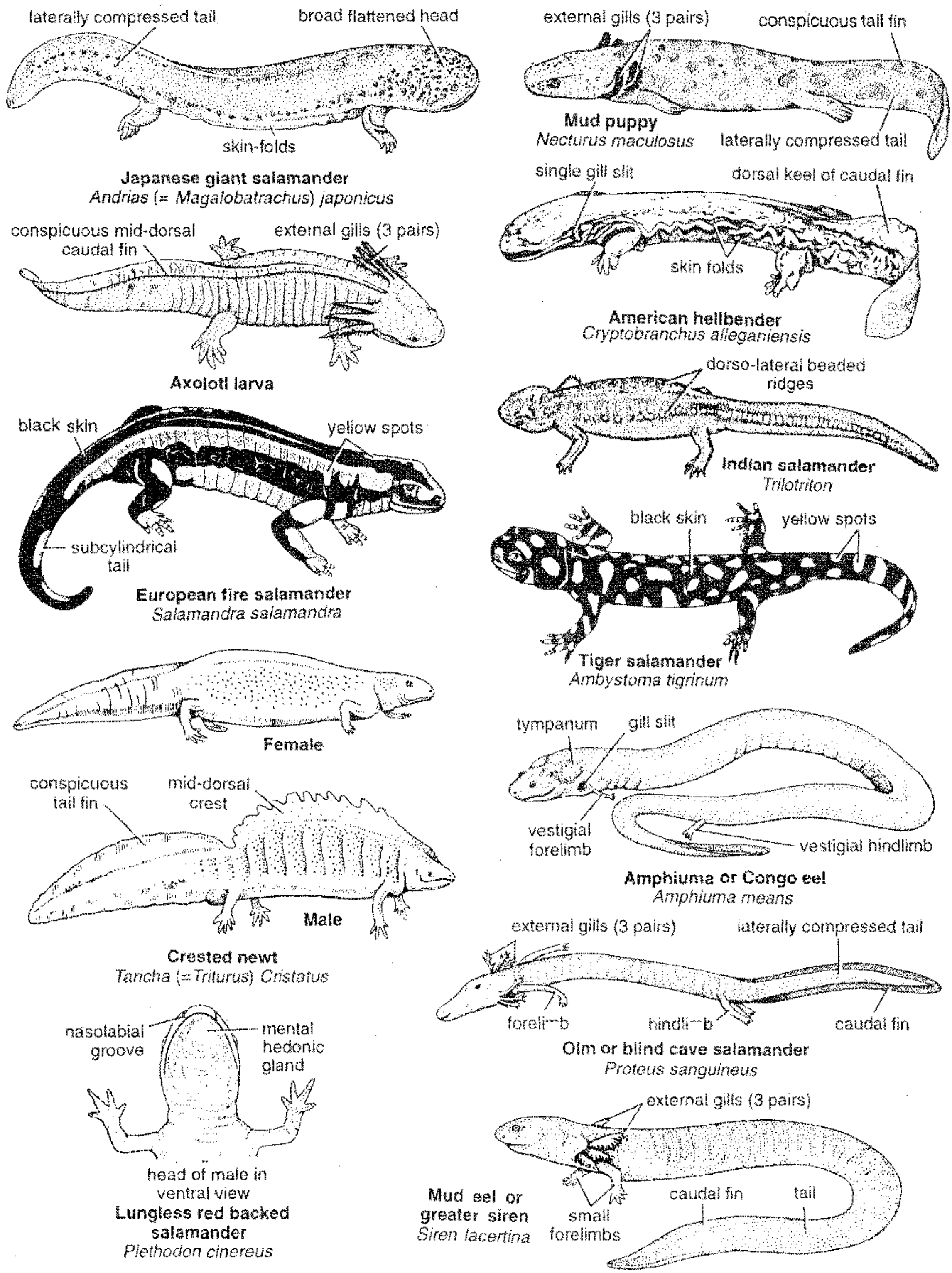

Fig. 4. Some urodele amphibians. Salamanders and newts.

1. Perennibranchs. These forms retain gills and are aquatic throughout life. Examples : *Necturus, Proteus, Siren.*

2. Caducibranchs. These forms lose their gills upon becoming adults that generally assume a terrestrial mode of life. These further form two subgroups :

(a) Derotrematous. Transitional forms losing gills but retaining gill slits as adults. Examples : *Amphiuma, Cryptobranchus, Megalobatrachus.*

(b) Salamandrine. With complete absence of branchiate organisation, Examples : *Ambystoma, Triturus, Salamandra.*

Megalobatrachus. The largest caudate known is the Japanese and Chinese giant salamander, *Andrias* or *Megalobatrachus japonicus*, about 175 cms long. It has no gill slits.

Cryptobranchus. The American hellbender, *Cryptobranchus alleganiensis*, about 68 cm long, looks more ferrocious because of its broad flattened head, laterally compressed tail with a deep dorsal keel, wrinkled chin, and a wrinkled fleshy fold on either side of trunk. 2 pairs of limbs are functional with 4 fingers and 5 toes. It has no gills but a single gill-slit (spiracle) is retained for letting out water during buccal respiration. It feeds voraciously on bottom upon fish fry, aquatic insects, crustaceans, molluscs and worms and has a life span upto 28 years. Fertilization is external.

Ambystoma **(=*Ambystoma*).** Some urodeles exhibit *neoteny* and *paedogenesis.* The most striking example is that of the tiger salamander, *Ambystoma tigrinum*, of America. Its poisonous skin has round yellow and orange spots all over the body. In western U.S.A. and Maxico, perhaps because of some hormonal deficiency or lack of iodine in water, the larvae fail to metamorphose, retain their external gills (3 pairs), and aquatic life, but become sexually mature to produce young ones. These morphologically immature but sexually mature stages are called *axolotls*. Retention of larval characteristics by them is *neoteny* and reproduction by them is *paedogenesis*. However, when fed on exogenous thyroid extract, they lose gills, develop lungs and metamorphose into usual air-breathing terrestrial adults.

Salamandra. The common spotted or fire salamander of Europe, *Salamandra salamandra*, is *viviparous*. The terrestrial adult has shining black skin with yellow spots. Gills or gill slits are absent and tail is subcylindrical. Male lays sperm in a capsule, called *spermatophore*, which is picked up by female with her cloacal lips to fertilize her eggs internally. Eggs are retained and develop inside the body of female who gives birth to larvae which complete their development in water. The crimson spotted newt of America, *Notophthalmus viridescens*, formerly called *Triturus viridescence*, has similar habits and life cycle.

Taricha **(=*Triturus*).** The European large crested newt, *Taricha cristatus*, formerly known as *Triton* or *Triturus cristatus*, is also terrestrial, resembles common salamander in structure, but exhibits marked *sexual dimorphism*. The males are slightly bigger than females. During breeding season, the males become brightly coloured and develop a mid-dorsal crest on body and a conspicuous median tail fin. The newt discharges a sufficiently venomous secretion from its dorsal glands toward off enemies.

Trilotriton. The Indian salamander, *Trilotriton*, found in Eastern Himalaya, is 15 to 20 cm long. The head bears two dorso-lateral ridges which become beaded on trunk. There is a mid-dorsal vertebral ridge. The tail is bilaterally compressed and carries a median vertical tail fin.

Plethodon. Several kinds of American salamanders have neither lungs nor gills but respire through skin or lining of bucco-pharyngeal cavity, such as *Plethodon*. They inhabit cool and swift mountain streams, well oxygenated and excellent for cutaneous respiration. A characteristic structural adaptation is the presence of *nasolabial grooves* which help in clearing nostrils of water being flushed out by glandular secretion. The male develops a *hedonic gland* on chin, during breeding season the secretion of which stimulates the female during courtship.

Amphiuma. Some salamanders have rudimentary limbs. *Amphiuma means*, or the Congo-eel, inhabiting North American swamps and rice fields, has an elongated, eel-like body about one meter long. Eyes are devoid of eyelids. There are four branchial arches. But limbs are absurdly small having 2 or 3 digits. Adults has no external gills but lungs and 1 pair of gill-slits.

Proteus. Blind salamanders are found in many deep and dark limestone caves of Europe and America. *Proteus anguineus* is the European blind cave dweller or olm. The neotenic adult has elongated eel-like body, very weakly developed limbs with 3-2 digits, 3 pairs of red branched external gills, 2 gill slits, laterally flattened tail with a caudal fin, white unpigmented skin and degenerate eyes covered by opaque skin. However, if the larvae are kept in red light, they develop functional eyes and pigmented skin.

Necturus. *Necturus maculosus*, the most widely spread North American water newt or mud-puppy, is 30-40 cm long. Broad head and elongated trunk are flattened dorsoventrally, while tail is compressed laterally, bearing a prominent tail fin. It has feebly developed small limbs with 4 digits each. Nostrils are rather far apart. Eyes are small without eyelids. Lungs are reduced. There are 3 pairs of fringed external gills and 2 pairs of gill slits. The lateral line system is well developed. It represents a permanent neotenic larval stage and, unlike axolotl of *Ambystoma*, can not be induced to discard its external gills by administration of thyroxin. It is a nocturnal perennibranchiate with feeding habits similar to those of *Cryptobranchus*. Eggs are layed under submerged stones and are guarded by females.

Siren. *Siren lacertina*, or the mud-eel, is found in muck or swamplands of North America. It is a permanent neotenic from like *Necturus* with elongated eel-like body, 3 pairs of external gills and 3 pairs of gill slits. However, it has no teeth, eyelids and hindlimbs, but only small forelimbs bearing 4 fingers each. Pterigoids are greatly reduced. Coracoid exists as a separate ossified piece. A well developed *vomeronasal* organ (Jackobson's organs) is present. It swims like an eel and burrows in soft mud.

[III] Frogs and toads

Frogs and toads belong to the order Salientia or Anura. It is the most successful and the largest group of living amphibians including about 2,200 species. They are characterized by having loosely-fitting skins, no tails when adult and hindlegs adapted for leaping. They breathe by moving the floor of their mouth. There is hardly any sharp distinction between frogs and toads. But a *frog* is usually soft-skinned and partly aquatic, whereas a *toad* is harder-skinned and more terrestrial. The differences between a true frog (Fam. Ranidae) and a true toad (Fam. Bufonidae) have been enumerated in a Table in the next chapter (Fig. 5).

Ascaphus. Nearly all frogs and toads fertilize their eggs externally. One of the exceptions is the American bell toad *Ascaphus truei*. This small toad is about 5-6 cm long. It lives in the swift cool mountain streams along the Pacific coast of North America. A tail-like cloacal projection in male frog is used as copulatory organ for internal fertilization of female's eggs. This toad has reduced lungs but has several primitive features such as tail muscles, amphicoelous vertebrae, free ribs, abdominal ribs and posterior cardinal veins.

Alytes. ***Alytes obstetricans***, commonly known as the mid-wife toad, belongs to family Discoglossidae of suborder Opisthocoela. It is found in some European countries (France and Italy) and is 5 to 8 cm long. It is characterized by having vertical pupil, disc-like, non-protrusible tongue, no teeth on lower jaw, ribs throughout life, and no vocal sacs in male. Tympannum is distinct. Pupil is vertical. Males show parental care by entangling eggs around their hindlegs and staying in damp places until tadpoles hatch to enter water.

Bombinator. *Bombinator igneus*, the European fire-bellied toad, is only 5 cm long. Its dorsal surface is cryptically coloured to conceal it from predators. If attacked, it at once throws back its

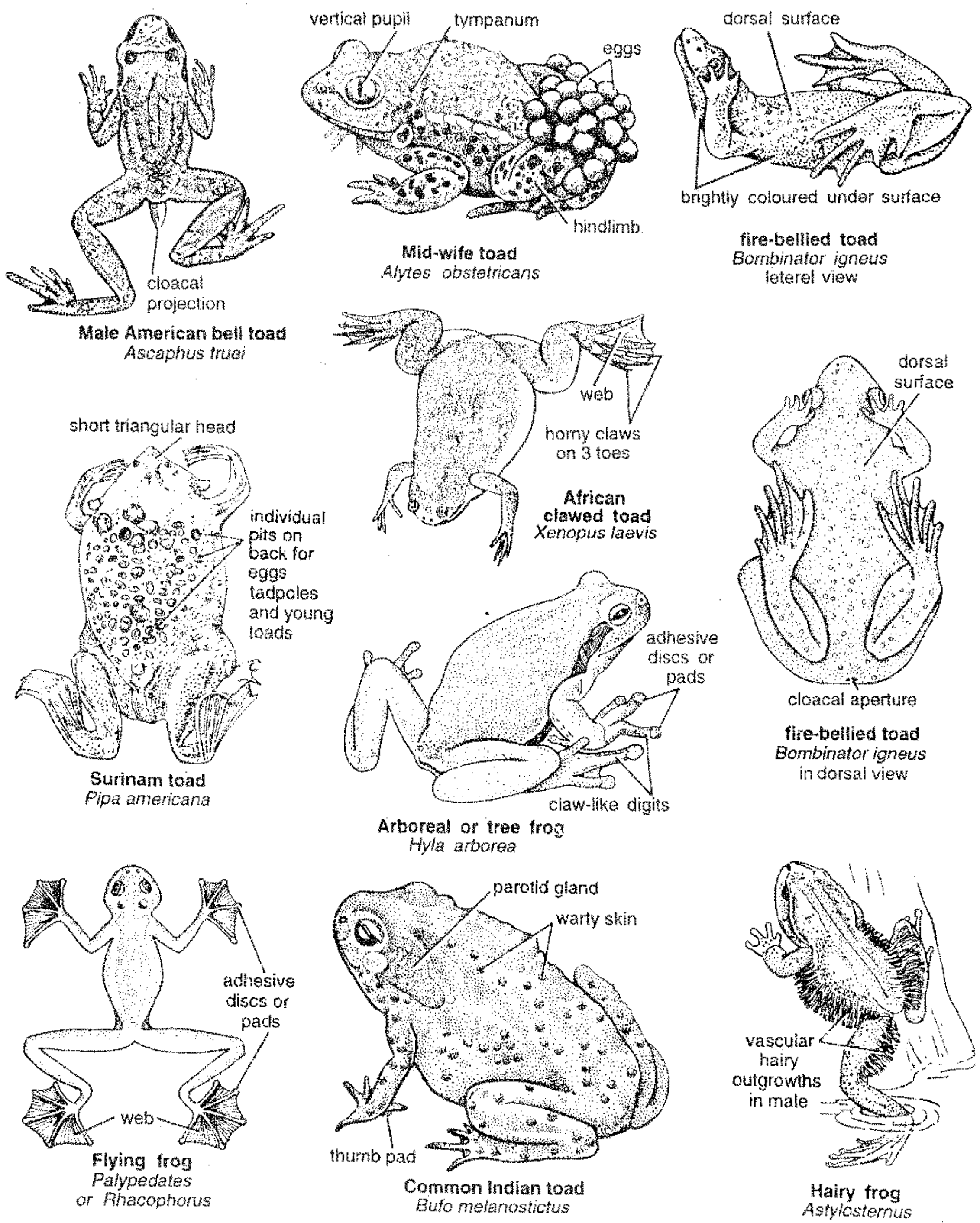

Fig. 5. Some anuran amphibians. Frogs and toads.

head and limbs to reveal the bright warning colouration of the ventral surface. If mistakenly captured, the predator will spit it out because of its bad taste. The toxins in its skin induce vomiting so that predators avoid it in future.

Xenopus. The African clawed toad, *Xenopus laevis* is 10 cm long. It lacks tongue, eyelids and distinct tympanum. The pupil is round. It has some teeth in upper jaw and a tentacle under each eye. Fingers are free but toes are webbed and the first three bear horny claws. Vertebrae are opisthocoelous. Sacral vertebrae can slide to and fro on pelvis thus lengthening or shortening the size of toad. *Xenopus* is used as a test in diagnosis of human pregnancy. Female does not exhibit parental care like *Pipa*.

Pipa. The Surinam toads are represented by 15 species and are all aquatic. *Pipa pipa* of Trinidad and Northern South America is about 15 cm long. It is very ugly, with much flattened body, short triangular head and long webbed toes. Tongue, teeth and usually eyelids are absent. It is famous for the unique method of parental care. During breeding reason, dorsal skin of female becomes soft and pitted. The male presses fertilized eggs on females back so that each sinks into a little pocket or vascular pouch and covered by a lid or operculum of uncertain origin. Here they develop directly into young toads which emerge after about three month's incubation. The larvae do not develop external gills at all.

Bufo. Family Bufonidae of suborder Procoela includes about 300 species of true toads, most of which belong to the genus *Bufo*. They occur in all continents except Australia. Common Indian toad is *B. melanostictus*, found upto 3,000 metres in Himalaya. They live on land, remain concealed during day, but become active at night when they feed on worms, snails and especially insects trapping them with their sticky tongues as frogs do. They have no teeth on either jaw. They have broad waist, short hindlimbs, harsh warty skin, ridges on head and an elevated poison—secreting parotoid gland behind each tympanum. When disturbed toads frequently urinate and produce noxious unpalatable secretions from skin glands, so that they are rarely eaten by enemies. There is a widespread but baseless superstition that handling of a toad will cause warts on hands.

Hyla. Genus *Hyla* including arboreal frogs, belongs to family Hylidae of suborder Procoela. It is a large genus containing 350 species spread throughout the world and adapted for life in trees. *Hyla arborea* is 5 to 8 cm long and green in colour. Terminal bones of digits are claw-shaped and swollen basally into glandular adhesive discs which enable them to climb trees. An extra cartilage between two last phalanges gives them a better grip. Large vocal sacs help in making a very loud voice which can be heard a long distance.

Rhacophorus. *Polypedates* or *Rhacophorus* is a common genus of tree frogs inhabiting Africa and South Eastern Asia. Characteristic feature is the large webs developed in between the much elongated digits which also terminate in conspicuous rounded adhesive pads or discs as in *Hyla*. Webs and flattened body serve as a parachute in gliding from a higher elevation to a lower one, so that they are designated "flying frogs". *R. malabaricus* and *R. maculatus* occur in India and can glide 9 metres or more from tree to ground. Eggs are usually laid in gelatinous form over water, whence tadpoles drop into water. *R. reticulatus* is Srilankan species in which female carries eggs attached to its belly.

Astylosternus. In the so-called African hairy frog, *Astylosternus*, the male has extensive vascular filamentous or hair like cutaneous papillae on groins, flanks and thighs. The filaments develop especially during breeding season. These are probably respiratory and compensate for the poorly developed lungs during reproduction when need for oxygen is greater.

Rana goliath. The largest frog (anuran) on record is *Rana goliath* found in West Africa. It is longer than 30 cm from tip of snout to cloaca. This giant is said to devour animals as big as rats and ducks.

Phyllobates. The smallest frog on record is *Phyllobates limbatus* of Cuba. It is hardly 12.5 mm long.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give the diagnostic characters of class Amphibia. Classify modern Amphibia giving salient features and examples of each order.

» *Short Answer Type Questions*

1. ›ifferentiate between frog and toad in tabular form.
2. ʌrite short notes on — (i) *Ambystoma*, (ii) *Amphiuma*, (iii) *Bufo*, (iv) *Icthyophis*, (v) Stegocephalia, (vi) Urodela.

» *Multiple Choice Questions*

1. In Amphibians respiration takes place by :
   (a) Gills, lungs, skin and buccal lining
   (b) Gills and lungs
   (c) Skin and gills
   (d) Gills, lungs and buccal lining
2. Erythrocytes in Amphibians are :
   (a) Oval and enucleated
   (b) Oval and nucleated
   (c) Convex and nucleated
   (d) Convex and nucleated
3. Excretion in amphibians is :
   (a) Ammonotelic (b) Aminotelic
   (c) Ureotelic (d) Uricotelic
4. Ear ossicle present in the middle ear of frog is :
   (a) Iris (b) Collumella auris
   (c) Auris (d) Columella
5. Extinct amphibians are placed in the subclass :
   (a) Stegocephalia (b) Lissamphibia
   (c) Lepospondyli (d) Cyptobranchoidea
6. Caecilians belong to the order :
   (a) Urodela (b) Gymnophiona
   (c) Anura (d) Opisthocoela
7. Neoteny refers to :
   (a) Retention of rudimentary organs
   (b) Metamorphosis
   (c) Retention of larval characteristics in adults
   (d) Reproduction in larvalforms
8. In *Plethodon* the nasolabial grooves help in :
   (a) Clearing pharynx
   (b) Clearing buccal cavity
   (c) Clearing eyes
   (d) Clearing nostrils

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d)

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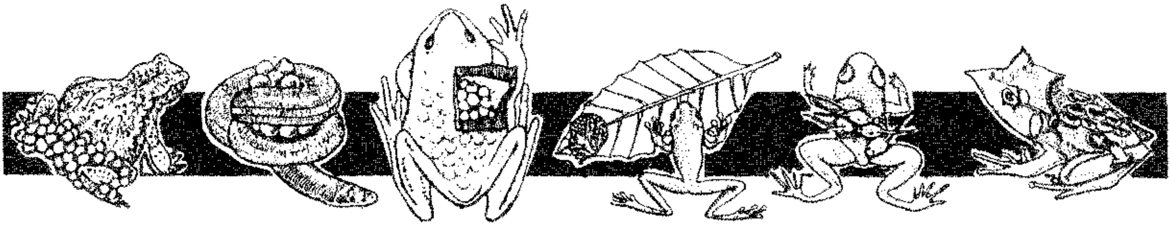

Amphibia : General Account

Neoteny and Paedogenesis

Definitions. The two terms, paedogenesis and neoteny (coined by Kollwann) are often used as synonyms which is not correct. In fact they stand for two rather basically different evolutionary developmental processes. *Neoteny* refers to the retention of a larval or embryonic trait in the adult body. Familiar examples are retention of embryonic cartilaginous skeleton in adult in Chondrichthyes; and the larval gills in some adult salamanders. *Paedogenesis* or *paedomorphosis* refers to development of gonads and/or production of young ones by an otherwise immature, larval or preadult animal. The examples are scattered in several groups or animals (e.g. gall fly, liver fluke, salamanders). Thus, whereas neoteny emphasizes the retention of embryonic or larval features in the *adult* body, paedogenesis stresses precocious development of gonads in *larval body*.

Amphibian examples. Some aquatic larval urodeles delay or fail to metamorphose, yet become sexually mature, mate and produce fertile eggs. Do they represent neoteny or paedogenesis ? The distinction between these two processes becomes blurred or overlapped in these amphibians. These animals may either be looked upon as *adults*, which retain certain larval characteristics not having metamorphosed. This is *neoteny*. Or, they may be considered *larvae* in which reproductive organs develop precociously. This is *paedogenesis*.

Axolotl. Classical and most informative examples of neoteny and paedogenesis among Amphibia (vertebrates) are furnished by *Ambystoma* (or *Amblystoma*). *A. maxicanum* lives in Lake Xochimilco in the highlands of Mexico and the closely related. *A. tigrinum* (tiger salamander) in high altitudes of Colorado (North America). Ordinarily they go through typical gilled

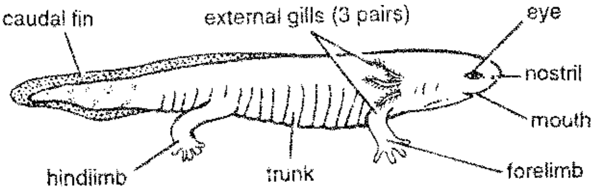

Fig. 1. Axolotl larva of tiger salamander, *Ambystoma tigrinum*.

aquatic larval stages, then metamorphosis, to transform into adult air-breathing land forms. However, under certain circumstances, the larvae do not metamorphose, retain their gills and aquatic habitat but become sexually mature. This sexually mature but morphologically immature, larval stage with external gills is called an *axolotl*. The name was given by natives of Mexico who captured them for food. In Aztec axolotl means "servant of water". At one time axolotls were considered a separate genus, *Siredon*, *S. axolotl*, *S. mexicanum*, *S. pisciformis* etc. (Wagler, 1830). However, in 1865, some axolotls brought to Paris in France discarded their gills and fins and underwent metamorphosis to become adult terrestrial salamanders. Axolotls have been important laboratory experimental animals for a century, for most of them now used worldwide have descended directly from those sent to Paris in 1864 and 1868 (Fig. 1).

Environmental factors affecting neoteny. The significance and causes of neoteny are not properly understood. Environmental factors affect metamorphosis in several ways. Abundance of food, cold temperature or insufficient iodine (a component of thyroxin hormone that induces amphibian metamorphosis) may cause failure of metamorphosis and retention of larval features. This is indicated by the fact that drying up of swamps, lack of food and rise in temperature in surrounding water induce axolotls to metamorphose. As already mentioned, axolotls breed in Mexico and south-western parts of U.S.A. When transferred to the eastern states or experimentally treated with thyroxine or TSH, these axolotls lose their gills, assume lungs and become adult air-breathing native tiger salamanders. Response of larval tissues to thyroid hormones is reduced as temperature drops an disappears entirely below 5°C. The genetic basis for metamorphosis seems to be multifactorial, variable and subject to selective pressure. Genes for transformation have become suppressed in ne-tenic populations but not entirely absent for there is occasional appearance of metamorphosed individuals.

The cause of neoteny among amphibians has not been properly understood. Various extrinsic and intrinsic factors are supposed to be responsible for such an unusual phenomenon.

Extrinsic factors

(1) Abundance of food and other favourable requisites in the aquatic life is the cause of retention of larval features (Gadow, 1903).
(2) Deepwater and coldness inhibits the secretion of thyroxin (Shufeldt).
(3) Saline nature of water is responsible for neoteny (Weismann).
(4) Low temperature is responsible for the arrest of metamorphosis (Huxley, 1929).

Despite of extensive reaserches on the role of extrinsic factors on metamorphosis it is still not clear that whether extrinsic factors are exclusively responsible for arrest of metamorphosis. So the existence of other factors, internal and physiological becomes apparent.

Intrinsic factors

Many experimental evidences have been advanced by different investigators. Gressner (1928) was of the opinion that insulin hormone inhibits metamorphosis. But recent researches incline to reveal that metamorphosis is primarily influenced by (i) varying threshold levels of thyroxin and its analogues and (ii) by the degree of responsiveness of the larval tissues to the hormones.

During early premetamorphic stage in amphibian development, the level of thyroxin is kept very low in the body by genetic mechanism (Etkin, 1968). Etkin and his coworkers have also established the role of prolactin on metamorphosis. They have shown that the level of prolactin which acts as an inhibitor in the overall control of metamorphosis remains high at this time. In the light of modern genetics it may be suggested that the structural genes guiding the synthesis of thyroxin are "switched off" by some operator genes, whereas, the genes guiding the formation of prolactin are "switched on". In such condition, hypothalamus becomes sensitive to the available level of thyroid hormone in the blood stream. The neurosecretory apparatus of the hypothalamus produces a substance called *thyrotropin releasing factor* (TRF). TRF stimulates the anterior lobe of pituitary to produce *thyroid stimulating hormone* (TSH), which in turn enhances the rate of thyroid secretion. As the level of TSH rises during prometamorphosis, the level of prolactin suddenly falls, so the metamorphosis starts. Poor secretion of thyroid glands and the irresponsiveness of the larval tissues to the hormone are responsible for neoteny.

In amphibian development the tadpole larva undergoes progressive metamorphosis and transforms into an adult. This is a normal occurrence in amphibians. But deviation from the normal pathway of development is found in the life cycle of many urodeles. Such deviated pathways of development in axolotls due to extrinsic as well as intrinsic environmental factors may be regarded as "canalisation", i.e., buffering of development against environmental change. Neoteny is looked upon as a consequence of adaptations to neighbouring environments where retention of larval gills and other larval features may be advantageous.

G.K. Noble (1954) regarded that the retention of larval features during sexual maturity has nothing to do in the phylogeny of the amphibians. This is quite evident from the heterogenous characters of the Perennibranchiata where all the neotenous species are included. Neoteny as such may have some importance in the individual groups.

Types of neoteny. Neoteny is *partial* when metamorphosis is delayed due to temporary ecological or physiological changes in environment. It is shown by tadpoles and larvae tiding over winter. *Intermediate neoteny* is shown by axolotls which also reproduce sexually but undergo metamorphosis in suitable conditions. Under experimental conditions in laboratories, it is possible to produce either axolotls or transformed individuals. The extreme or *total neoteny* is shown by several perennibranchiate salamanders such as *Necturus, Siren* and *Proteus*. They remain larval throughout. Even treatment with thyroxine fails to induce metamorphosis; the tissue response is absent.

Significance of neoteny. Weismann (1875) thought neoteny to be a case of retarded evolution or *atavism*, that is, reversion to ancestral condition. However, this is now regarded to be of secondary specialization, a physiological adaptation of advantage. This is also proved by the great heterogeneity of all neotenous perennibranchiate forms.

Parental Care in Amphibia

Looking after the eggs or the young until they are independent, to defend from predators, is known as *parental care*. It is a very important factor for survival. Animals exhibit a great diversity in caring for their eggs and young during their development. Perhaps, no group shows more diversity than to the amphibians, especially those living in tropical regions. Anurans show much greater diversity than urodeles and apodans. The methods of caring by Amphibia generally fall under two broad categories : (i) Protection by nests, nurseries or shelters and (ii) Direct caring by parents (Figs. 2 & 3).

[I] Protection by nests, nurseries or shelters

Amphibians have evolved countless interesting methods to give protection to their defenceless eggs and larvae from predators.

1. Selection of site. Many amphibians lay eggs in protected, moist microhabitats on land. Many tropical frogs and toads lay eggs on land near water. Many tree frogs lay their eggs not on land but on leaves and branches overhanging water. Species of *Phyllomedusa, Rhachophorus, Hylodes*, etc. glue their eggs to foliage hanging over water. *Rhacophorus malabaricus* in India and

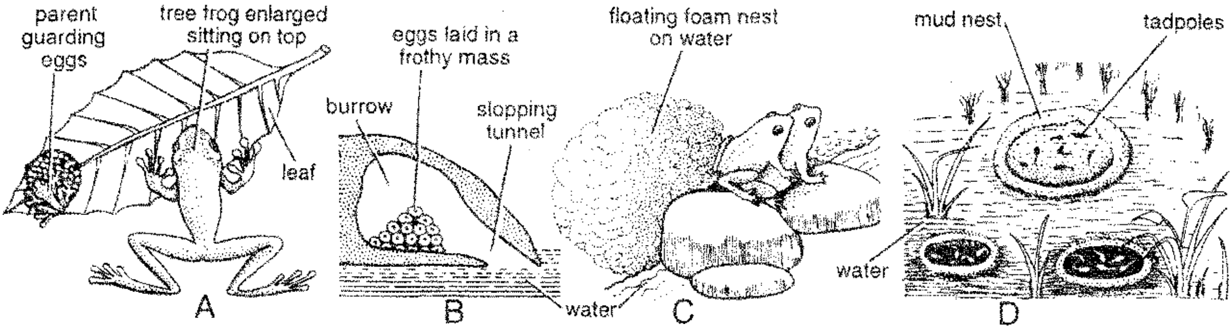

Fig. 2. Parental care in Amphibia. Protection by nests, nurseries or shelters. A—A tree frog guarding eggs glued to a leaf overhanging water. B—Foam nest of *Rhacophorus schlegeli* in a slopping burrow near water. C—Foam nest floating on water. D—Mud nest of *Hyla faber*.

Chiromantis of Africa also deposit their spawn on trees. Many tree frogs deposit eggs in water that accumulates in epiphytic tropical plants. Free from reach of aquatic egg predators in their microhabitats, the tadpoles on hatching drop into water beneath to complete their metamorphosis.

2. Defending eggs or territories. Males of green frog *Rana clamitans* and other species maintain territories and attack small intruders to defend eggs. Male or female even guards the eggs. In *Mantophryne robusta*, the male actually sits over and holds with hands the elastic gelatinous envelope containing eggs numbering 17. Some tree frogs laying eggs above water may sit beside the eggs or rest on top of them. Removal of guarding frogs may result in desiccation or death of eggs.

3. Direct development. In some terrestrial or tree frogs, such as *Eleutherodactylus, Arthroleptis, Hylodes* and *Hyla nebulosa*, the eggs hatch directly into little frogs thus avoiding larval mortality. In the red backed salamander, *Plethodon cinereus*, the hatchlings are miniatures of the adults.

4. Foam nests. Many amphibians convert copious mucous secretions into nests for their young. In the Japanes tree frog, *Rhacophorus schlegeli*, the mating couple digs a hole or tunnel into which eggs are left in a frothy mass to avoid desiccation. During rains, hatching tadpoles are washed down the slopping tunnel into pond or river water for further development. The female of South American tree frog, *Leptodactylus mystacinus*, stirs up a frothy mass of mucus, fills it in holes near water and lays eggs in them. The tadpoles developing in these improvised nests can readily enter water. Some anurans lay eggs in nests of foam floating on water. The female emits huge mucus that she beats into a foam with her hindlegs to lay eggs. When tadpoles hatch they drop from foam into water.

5. Mud nests. In Brazilian tree frog, *Hyla fabre*, the male digs a little crater-like hole or nursery in mud in shallow water, in which the female lays her eggs. The nest is 30 cm in diameter and 5 to 8 cm deep. Tadpoles hatch within this relatively safer barrier and develop until they are large enough to fend themselves.

6. Tree nests. The South American tree frog, *Phyllomedusa hypochondrales*, lays eggs in a folded leaf nest with margins glued together by cloacal secretion. The tadpoles when formed fall straight into water below. Another tree frog, *Hyla resinfictrix*, lines a shallow tree cavity with bees wax obtained from the hives of certain stingless bees. Female lays eggs when this cavity is filled with rain water. Here, the young develop relatively free from predators.

7. Gelatinous bags. In *Phrynixalus biroi* large eggs are enclosed in a sausage-shaped transparent gelatinous membranous bag, secreted by female and left in mountain streams. *Salamandrella keyserlingi*, a small aquatic salamander also deposits 50 to 60 small eggs in a gelatinous bag which is fastened to aquatic plants.

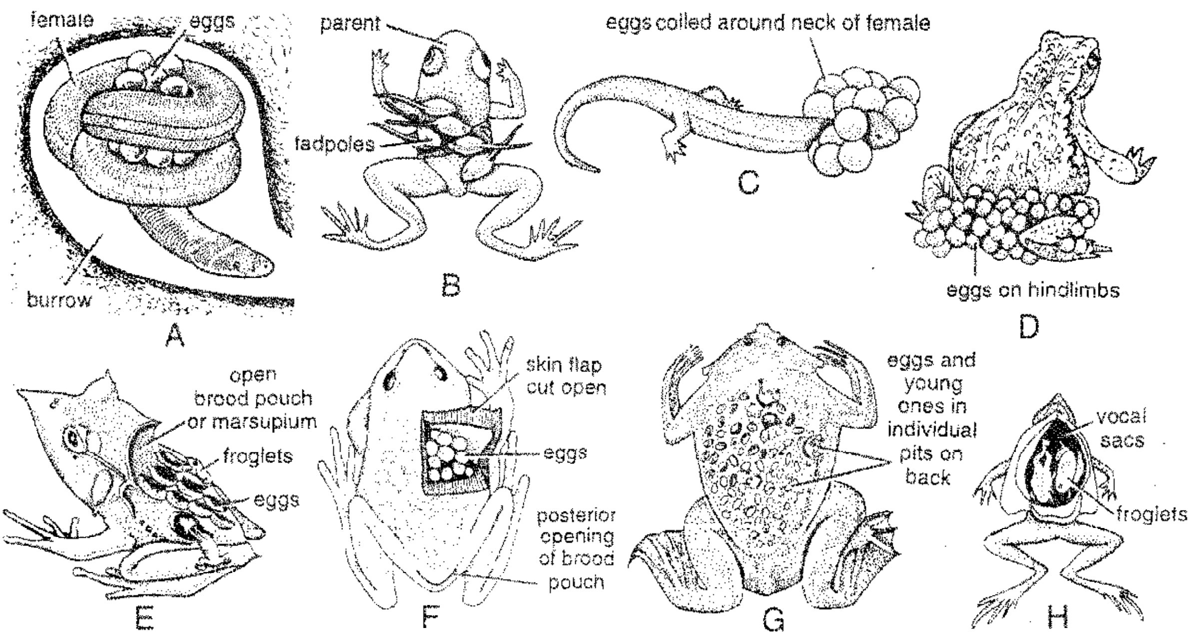

Fig. 3. Direct parental care in Amphibia. A—Female *Ichthyophis* coiling round eggs. B—Transportation of tadpoles attached to back of a parent. C—*Desmognathus fuscus* with eggs. D—Male *Alytes obstetricans* carrying eggs around his thighs. E—A marsupial frog with eggs exposed in open brood pouch on back. F—*Nototrema* or *Gastrotheca*, with flap of dorsal brood sac cut open to show eggs. G—In *Pipa*, eggs develop completely into individual capsules on back of female. H—Froglets inside vocal sacs cut open of male *Rhinoderma darwinii*.

[II] Direct carrying by parents

1. Coiling around eggs. In Congo eel, *Amphuima* and certain caecilians like *Ichthyophis* and *Hypogeophis*, the female lays large eggs in burrows in damp soil and carefully guards them by coiling her body around them until they hatch. The female of Salamander, *Plethodon* also coils round the eggs which are laid in small packages in the hollow of a rotton log or beneath a rock. In *Megalobatrachus maximus*, it is the male who coils around the eggs.

2. Transferring tadpoles to water. Some species of small frogs (e.g. *Phyllobates, Arthroleptis, Pelobates, Dendrobates*) in both tropical Africa and South America, deposit their eggs on ground. The tadpoles hatching out, fasten themselves to the back of one of the parents with their sucker-like mouth and transported to water.

3. Eggs glued to body. Many amphibians, instead of remaining with the eggs, carry the eggs glued to their body. In the dusky salamander, *Desmognathus fuscus*, female carries the string of eggs coiled around her neck, until they have hatched. In Srilankan tree frog, *Rhacophorus reticulatus*, the eggs are glued to the belly of female. An interesting case is that of the European midwife toad, *Alytes obstetricans*. When the female lays eggs, the male entangles them around his hindlegs. He carries them with him until they are ready to hatch. At that time he releases the tadpoles into nearest water.

4. Eggs in back pouches. In one group of tree frogs called *marsupial frogs* or *toads*, the female carries the eggs on her back, either in an open oval depression, a closed pouch or in individual pockets. The eggs develop into miniature frogs before they leave their mother's back. In the Brazilian tree toad, *Hyla goeldii* or *Cryptobatrachus evansi*, the posterior part of the back of female forms a sort of incipient brood pouch in which the eggs remain exposed. In *Nototrema* (=*Gastrotheca*), the eggs are covered by skin forming a single large brood pouch which opens posteriorly in front of the cloacal aperture.

A similar adaptation is seen in the completely aquatic Surinam toad, *Pipa*. In breeding season, skin of female's back becomes thick, vascular, soft and gelatinous. The male presses fertilized eggs against female's back, where they sink into individual pits. A hinged cover forms over each egg enclosing it in a small capsule. Complete metamorphosis occurs with capsules. The tiny toads leaving mother are tailless and do not enter water.

5. Organs as brooding pouches. Male of the terrestrial South American Darwin's frog, *Rhinoderma darwinii*, pushes at least two fertilized eggs into his relatively large vocal sacs. Here, they undergo complete development to emerge out as fully formed froglets. In West African tree frog, *Hylambates breviceps*, the female carries eggs in her buccal cavity. In *Arthroleptis*, it is the male who keeps the larvae in his mouth. The only known case of gastric incubation in vertebrates is found in the Australian frog, *Rheobatrachus silus*. The female keeps the eggs in her stomach. The tadpoles are expelled through mouth after metamorphosis.

6. Viviparity. Some anurans are ovoviviparous. They retain eggs in the oviducts and the females give birth to living young. African toads, *Nectophrynoids* and *Pseudophryne* give birth to little frogs. The European Salamander, *Salamandra salamandra* produces 20 or more small young while the Apline salamander, *S. atra* gives birth to one or two fully developed young. Viviparity is widespread in order Gymnophiona, and 3 out of 4 families have this mode of reproduction. Common examples are *Typhlonectes*, *Geotrypetes*, *Dermophis*, etc.

Origin and Ancestory of Amphibia (Tetrapoda)

Earliest Amphibia. The earliest fossils of Amphibia (Tetrapoda) are known as *Labyrinthodontia* because of the folded nature of dentine of their teeth. They probably originated 300 million years ago, during Devonian period and flourished through Carboniferous and Permian periods before extinction in Triassic.

Piscine ancestry. It is universally accepted that amphibians have originated from fishes. Resemblance of Amphibia to fish is seen in most systems of the body. Both are cold-blooded. Both respire by gills early in life, in some cases throughout life. Both have air bladders serving as lungs. Like fishes, aquatic amphibians have a canal system. To prevent desiccation in air, both usually lay eggs in water where larval development usually continues.

Devonian fishes. Three major groups of advanced bony fishes were contemporaries of Labyrinthodontia during Devonian period—Actinopterygii, Dipnoi and Crossopterygii. Which of these groups gave rise to the first amphibians ? Actinopterygii are far off the main course of tetrapod evolution because of many specializations. Dipnoi have several features of close resemblance to Amphibia in their anatomy and embryology. But they have also been too specialized to be considered as ancestral to Amphibia. Particularly, the skeleton of their fins is not reminiscent of that of a primitive tetrapod. Thus, the older view that Dipnoi, gave rise to amphibians is no longer held. Their similarity probably resulted due to convergent evolution. On the other hand, it is now believed that the earliest amphibians (labyrinthodonts) arose from primitive crossopterygian fishes.

Crossopterygian ancestry. Origin of Amphibia can be traced back to the freshwater carnivorous rhipidistian crossopterygians of Devonian period, represented by the genera *Osteolepis* and *Eusthenopteron*. They show extensive morphological similarities with early amphibians or labyrinthodonts, which are evidence of their close phylogenetic relationship.

(1) Pentadactyl limb of amphibians is supposed to have arisen from the crossopterygian fin lobe. There are clear homologies between the limb bones of ostelepid crossopterygians and early tetrapods (labyrinthodonts).

(2) Their skulls and jaws are similar and can be equated bone by bone.

(3) Both rhipidistians and early tetrapods were predators, armed with sharp, strong teeth,

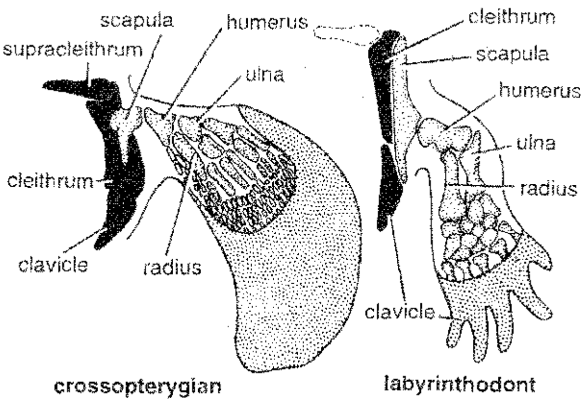

Fig. 4 Similarity between limbbones of osteolepid crossopterygian fish and a primitive tetrapod or labyrinthodont.

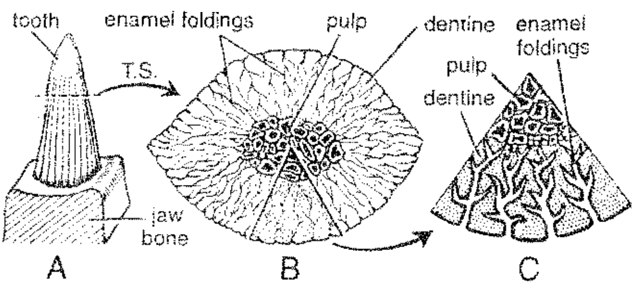

Fig. 5. Structure of a labyrinthine tooth. A—Entire tooth. B—T.S. of tooth. C—A portion of T.S. magnified.

with a peculiar labyrinthine infolding of the enamel.

(4) Position of external and internal nares is similar.

(5) Air bladders were used as lungs during short migrations from pond to pond.

(6) *Ichthyostega*, a primitive labyrinthodont fossil found in Green land, has both crossopterygian and amphibian characteristics and represents a transitional stage.

Possible polyphyletic origin. The three orders of living Amphibia—Apoda, Urodela and Anura—are so different as to suggest a polyphyletic origin of amphibia. Eric Jarvik supports a diphyletic origin. He suggests origin of Urodela and Apoda from porolepid rhipidistians through lepospondyls (a group of small Carboniferous and Permian forms), while origin of Anura from osteolepid rhipidistians through labyrinthodonts. His views are not accepted by all. Another view traces the ancestry of all 3 orders from lepospondyls.

Causes for transition from water to land. What was the need for early crossopterygians to leave their aquatic hubitat to come on land with unknown possibilities ? There is no dirth of theories or explanations. According to one view, Devonian was a period of seasonal droughts. Certain rhipidistian crossopterygians had sufficiently developed lobe fins to move over land to ponds containing water. Periodic escapes resulted in conversion of their lobe fins into pentadactyl tetrapod limbs. Another view contrasts between aquatic and terrestrial habitats during Devonian. Compared to water, land had more O_2 in air, food, cover, shelter and breeding places. On the other hand, land had less impurities and less predators.

Adaptations to amphibious life. The transition from water to land was gradual. Amphibia, being the lowest and earliest tetrapods are not fully adapted to a terrestrial life like reptiles. Transition from water to land involved important changes in almost every system of body. Some striking modifications acquired by amphibious Amphibia over the ancestral aquatic fishes may be summarized as follows :

1. Locomotion. Streamlined body retained for swimming. Limbs developed in place of paired fins.

2. Skeleton. Vertebral column becomes more rigid. Pectoral girdle lost connection with skull. Pelvic girdle attached to vertebral column and two halves firmly united.

3. Muscles. Stronger muscles to lift body above ground.

4. Respiration. Gills replaced by lungs for gaseous exchange in air. Cutaneous respiration supplements pulmonary respiration.

5. Circulatory system. Changes occured to provide for respiration by lungs and skin.

6. Eggs and development. Eggs small and still laid in water. Developmental stages fish-like.

7. Sensory system. Addition of middle ear containing a bone (*columella auris*) for transmitting sound vibrations from tympanum to inner ear.

8. Skin. Skin transformed to support terrestrial life to resist desiccation.

Economic Importance of Amphibia

Nearly all amphibians are beneficial to mankind but frogs and toads are of special economic importance.

1. Scientific study. Frogs are dissected in laboratorities by school and college students all over the world, including India. They are also used extensively for physiological experiments, human pregnancy tests, pharmacology and as fish bait. Mud puppies (*Necturus*) are also dissected in U.S.A., while the newt *Diemictylus viridescens* is widely used in research.

2. As food. Millions of frogs are consumed as food by gourmets in U.S.A., Japan and many other countries. Usually the big fleshy hindlegs are eaten. Artificial rearing of frogs is not practicable. Other edible amphibians esteemed as food are *Necturus* and axolotls in America and giant salamanders (*Andrias*) in Japan.

3. Predation. Frogs and toads are destroyers of noxious insects. Toads in particular are of great value because they live in gardens where insects are most injurious. The French gardners even buy toads to control harmful insects. *Bufo marinus* has been introduced in tropical sugarcane fields to destroy injurious insects.

4. Medicinal value. Toads are used in Chinese medicines. Skin of toad secretes a digitalis-like substance that increases blood pressure when injected into humans.

5. Trade, art and recreation. Skins of frogs are used for glue, book-bindings and making delicate purses. Amphibians and their larvae provide motifs in the art of American Indians. Toads have played a role in the religious beliefs of primitive people since ancient times. Aesop (560 B.C.) included frogs among his fables. Tribal magicians in America used parts of frogs and toads in their magic. Bull frogs are said to participate in a jumping-frog contest held every year in U.S.A. Frogs and toads are kept as pets in household aquaria.

6. Poisonous Amphibia. A wide variety of irritating toxic compounds is produced by amphibians. Poison glands are located dorsally in skin and defense postures of anurans and urodeles present the dorsal glandular surface to their predators. Poisonous secretions (bufotoxins) of *Bufo marinus* are fatal to dogs and cats. Poison of *Dendrobates*, a South-American frog, is used by tribal people to poison the points of their arrows. Some poisonous amphibians, such as *Salamandra salamandra*, are warningly coloured. Hellbenders (*Cryptobranchus*) are said to be poisonous but not dangerous to man.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Write an essay on neoteny.
2. Discuss parental care in Amphibia.
3. Discuss origin and ancestery of Amphibia.

» *Short Answer Type Questions*

1. Discuss economic importance of amphibian.
2. Write short notes on — (i) Adaptations to amphibious life, (ii) Environmental factors affecting neoteny.

» *Multiple Choice Questions*

1. Paedogenesis refers to :
   (a) Precocious development of gonads
   (b) Retention of larval characters by adults
   (c) Retention of rudimentary characters in adults
   (d) Retrogressive metamorphosis
2. Partial neoteny refers to :
   (a) Sexual reproduction in larvae, capable of metamorphosis under suitable conditions
   (b) Delayed metamorphosis due to ecological or physiological changes in environment
   (c) Animal remains larval throughout
   (d) Animal fails to hibernate
3. Direct development is shown by :
   (a) *Rhacophorus* (b) *Rana clamitans*
   (c) *Hylodes*
   (d) *Leptodactylus*
4. Which of the following does carry eggs in its back pouches :
   (a) *Nototrema* (b) *Cryptobatrachus evansi*
   (c) *Pipa* (d) *Hylambates breviceps*

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d).

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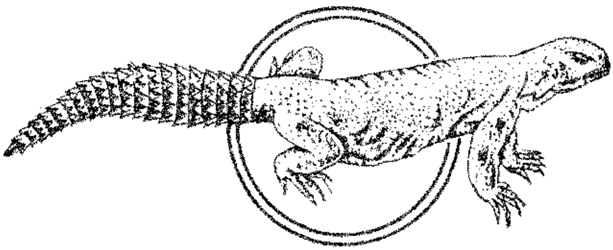


Type 8. *Uromastix hardwickii* : The Spiny Tailed Lizard

Suitability for Study

Many Indian universities prescribe the study of a lizard in their syllabi. *Uromastix* is generally dissected in the laboratories in North India, whereas *Calotes* in South India and Nepal, depending on local availability. *Hemidactylus* is also dissected in some laboratories. However, *Uromastix* gets preference over other lizards because of certain factors. It is common and easily available. It is gentle and easily captured. Its handy size is suitable for dissection work in practical classes. Moreover, this lizard has been fairly worked out and described. Quite recently (1982), Raj Tilak has given a sufficient account of the anatomy and bionomics of *Uromastix hardwickii* Gray, in a monograph written by him. The lizards can be kept alive in a wooden box with sand, grass and a bowl of water.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Division	Gnathostomata
Superclass	Tetrapoda
Class	Reptilia
Subclass	Diapsida
Superorder	Lepidosauria
Order	Squamata
Suborder	Lacertilia
Family	Agamidae
Type	*Uromastix hardwickii* (Spiny-tailed lizard)

Distribution

There are 11 species of the genus *Uromastix* inhabiting the desert regions of North Africa and North-Western Asia. Only one species, *Uromastix hardwickii*, is represented in India. It is found almost throughout North-Western India (Punjab,

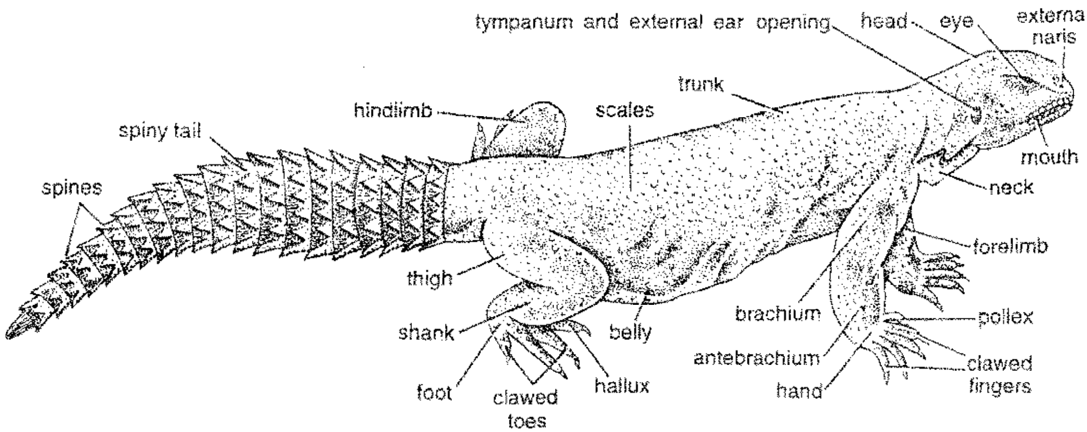


Fig. 1. *Uromastix hardwickii* Gray. External features.

Haryana, Rajasthan, Uttar Pradesh) and Gujarat. It has not been reported from South India. It also occurs in Sindh and Baluchistan in Pakistan. The lizard is popular by the name of "Sanda" in Hindi and "Sanha" in Punjabi.

Habitat

Uromastix inhabits dry sandy tracts such as deserts with scanty vegetation. It prefers soft, slimy and yellow soil. It is also called "sand lizard" because of its sandy habitat.

Habits

1. Nature. By nature, *Uromastix* is a gentle, timid and non-aggressive lizard. It is quiet and somewhat sluggish. It can be easily tamed in captivity. The mode of progression is of the "walking type".

2. Burrowing habit. *Uromastix* is a burrowing lizard. It digs its own burrow in the ground with its powerful claws. The burrow or tunnel is zigzag and 1 to 2 metres deep and usually occupied by a single individual. The size of the animal hiding in a burrow can be determined by observing the size of its opening. Smaller individuals burrow less than a meter, whereas larger individuals burrow 2 metres or still deeper. A small mound of sand near the opening of the burrow indicates presence of lizard in the burrow. Absence of such sandy mass indicates that the lizard has probably vacated the burrow. Sometimes the empty burrow is occupied by some snake.

Uromastix is diurnal. It retreats into burrow at night or in the day during very hot or cold weather. The burrow is also used for shelter and protection against enemies and for laying eggs. At night, the lizard closes the entrance of the burrow for safety.

3. Defensive mechanism. *Uromastix* is a non-aggressive and relatively defenceless lizard. When disturbed it tries to frighten away its persecutor by raising its head most characteristically, as well as opening its mouth. The massive and spiny tail also serves as a weapon for defence. If persued by a snake or mammalian predator, the lizard quickly enters its burrow with only the hind portion of the bristly tail projecting out and lashing violently sideways. If the enemy still tries to capture the tail, it is injured by the blows and driven away. In case the enemy is larger and more aggressive, the lizard is captured and eaten up. Based on this habit, some tribal people, known as Kunjars, adopt a novel method for capturing *Uromastix*. They make a hissing snake-like sound to frighten the lizards which rush into their burrows but project and wave their tails at the openings. The Kunjars simply catch them by their tails and pull them out of the burrows.

4. Feeding habit. *Uromastix* is chiefly herbivorous and feeds on grasses, flowers, fruits and succulent leaves of wild shrubs and trees. Sometimes it preys on insects. In captivity, it can be fed on pieces of bread and moistened or roasted gram.

5. Hibernation. During winter, usually from December till March, *Uromastix* undergoes hibernation in order to avoid the cold season. It suspends feeding, slows down all activities and passes through a period of dormancy inside its burrow. During hibernation, the lizard lives on the accumulated fat of the body. When the lizard comes out of hibernation in early spring, it appears quite lean and emaciated due to complete utilization of body fat.

6. Breeding. The breeding season of *Uromastix* begins in March and April in Northern India. The males become agile and aggressive and resort to fighting for the females. Courtship precedes copulation which takes place generally between 10 a.m. to 3 p.m. on a clear warm and sunny day. During mating, the male everts both of its hemipenes, one of which is inserted into the cloaca of the female to discharge the spermatic fluid. Fertilization is internal. The lizard is oviparous. The female lizard lays about 10 to 15 shelled eggs in its burrow in late April or early May. The eggs measure 20 to 30 mm in size, are dustry white in colour, rich in yolk and develop with the heat of the sun. Cleavage is meroblastic. The newly hatched young resemble the parents.

Economic Importance

The flesh of *Uromastix*, particularly the tail muscles, is eaten by some tribal people and considered a delicacy. The oil extracted from its fat bodies is sold by the roadside quacks, is claimed as cure for impotence and used as an embrocation (message). The powder of its faeces mixed with "kajal" is credited for curing corneal opacity. The skin of this lizard, though not much in demand, is used for making fancy leather articles and even exported. This particular lizard also makes a suitable material for dissection in the laboratories and for study in the classroom.

External Features

[I] Shape, size and colour

The body of *Uromastix* is elongated, massive and depressed. The length varies from 20 to 30 cm. The upper surface of the body is yellow brown with dark spots, whereas the lower surface is lighter and pale. There are black spots on the throat also and a large black spot on the front of each thigh.

[II] Division of body

The body has 4 distinct parts : head, neck, trunk and tail (Fig. 1).

1. Head. The head is relatively small, depressed and somewhat triangular. It is produced in front in a short but strongly curved *snout* with a blunt tip. The terminal *mouth* is a wide slit bounded by the immovable *lips* covered with scales. The lower lip is rounded, but the upper lip has a sharp edge which covers the lower lip. A little above the mouth, the anterior end of snout bears two oval openings of the *external nares*. At the time of digging each naris becomes closed by a prominent swelling of its posterior mucous lining serving as a valve. A pair of small elliptical *eyes* are located dorso-ventrally almost in the middle of the head one on each side. The pupil of eye is circular and the iris is light orange in colour. Each eye has 3 well developed and movable eyelids. The upper and lower eyelids are thick, opaque, the lower one more mobile and the two can completely close the eye. The third eyelid or nictitating membrane is thin, transparent and folded at the anterior corner of the eye. When needed, the nictitating membrane can be spread to cover the cornea and clean it. Behind and below each eye is a small and vertically oval shallow pit, the *external ear opening* or *auditory meatus*. Its anterior border is denticulate. At the bottom of the auditory meatus lies a brownish oval patch of skin, the *tympanum*.

2. Neck. The short neck connects the head with the trunk. When the neck is relaxed, the loose s in on its ventral an lateral si es becomes conspicuously folded transversely across the throat. But these cutaneous folds disappear when the neck is outstretched.

3. Trunk. The trunk of *Uromastix* is long, broad and depressed. Its dorsal surface is arched and rough, whereas the ventral surface is flat and smooth. The skin of its two lateral sides remains loosely folded. At the junction of the trunk and the tail is present mid-ventrally a slit-like transverse opening, the *cloacal aperture*. The trunk has two distinct regions : an anterior smaller but thick and hard-walled *thorax* and a posterior larger and soft-walled *abdomen*. Two pairs of limbs are attached to the trunk laterally.

4. Tail. T e tail is elongated, massive and dorso-ventrally compressed. It is shorter in length than the rest of the body. In the male lizard, at least in the breeding season, a pair of distinct nodule-like swellings due to hemipenes, are present mid-ventrally on the broad base of the tail just behind the cloacal opening. The dorsal surface of the tail is covered with whorls of large spinose scales. These provide a spiny armour to the tail which serves as an organ of defence. It is due to the presence of these spiny scales on the tail that *Uromastix* is named the "spiny-tailed lizard". Caudal autotomy is absent (Fig. 2).

[III] Appendages or limbs

As already mentioned, the lizard has two pairs of appendages or limbs, arising laterally from the trunk. The limbs are short but strong, well-developed, muscular and pentadactyle. They are adapted for burrowing and terrestrial life.

1. Forelimbs. These arise from the trunk just behind the neck, one on either side. These are smaller than the hind limbs. Each forelimb is made of an upper arm or *brachium*, forearm or *antebrachium* and the hand or *manus*. The manus bears 5 digits or *fingers* each ending in a curved, pointed claw. The first finger or *pollex* is the smallest, while the fourth finger is the largest. The lower surface of manus is provided with transverse rows of leaf-like adhesive pads.

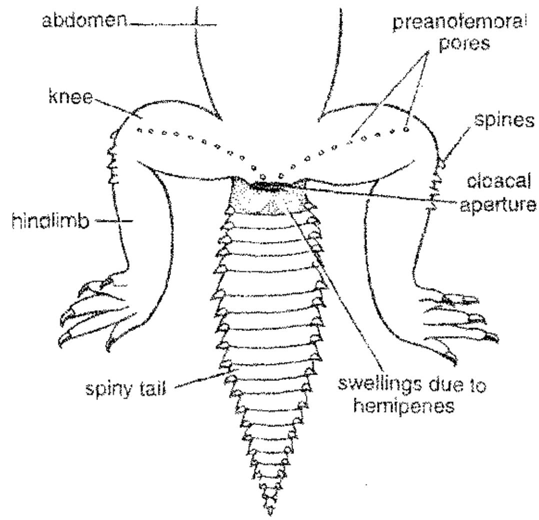


Fig. 2. *Uromastix.* Hind limbs and tail of male in ventral view showing cloacal aperture, femoral pores and swellings due to hemipenes.

2. Hind limbs. These arise somewhat ventro-laterally from the posterior end of the trunk. Each hind limb is made of proximal *thigh*, middle *shank* or *crus* and distal foot or *pes*. The pes bears 5 clawed toes of which the first toe or *hallux* is the smallest and the fourth toe is the largest. The lower surface of pes bears transverse rows of adhesive lamellae. A few spinose tubercles are present around each tibiofemoral or knee-joint.

Preanofemoral pores. The ventral surface of each thigh bears 2 to 18 minute pores arranged in a single curved row from cloaca to the knee-joint. These are termed *preanofemoral pores*. These are more conspicuous in male than in female. Each pore is surrounded by a ring of scales of which one is larger than others. The pores lead into tubular ectodermal glands producing a horny secretion that forms temporary spines which help in grasping the female during mating.

[IV] Exoskeleton (scales and claws)

Horny, overlapping epidermal *scales* covering the entire body, form the exoskeleton. These are shed off in flakes at regular intervals. The scales are small along the dorsal side of trunk, but large along the ventral surface. Scales on head differ in shape and size, the labial scales are small, supraocular scales smallest and the scales on the snout largest. The scales on the tail are quadrangular, relatively larger than those of trunk and head and bear a posteriorly directed spine. The tail also bears dorsal transverse rows of much bigger and strongly keeled spinose scales, providing a sort of armour to the tail. Some larger scales form spiny tubercles around the kneejoints. Scaly exoskeleton prevents loss of water and also protects body from mechanical injuries.

Tips of the digits are provided with sharp claws. Each claw is made up of a dorsal and a ventral scale like horny plates. The dorsal plate is called *unguis* and the ventral plate is called *subunguis*. The former is better developed than the latter.

[V] Sexual dimorphism

The male and female individuals in *Uromastix hardwickii*, apparently, are similar in external features, so that sexual dimorphism is not well marked. However, the two sexes can be distinguished in the following respects :

(1) The males are slightly smaller and darker in body colour. The females are somewhat larger and lighter in colour.

(2) During breeding season, the abdomen of female becomes somewhat broader.

(3) The preanofemoral pores are more prominent in male than in female.

(4) In male, during breeding season, a pair of nodule-like, rounded swellings, appear ventrally at the base of tail, just behind the cloacal aperture. These are due to presence of hemipenes. These are absent in female.

(5) The copulatory sacs or hemipenes in male open by a pair of apertures into the proctodaeum of cloaca. These are absent in female.

Body Wall

The body wall enclosing the spacious coelom, protects the delicate internal organs of the body. It is made of skin or integument, muscles and peritoneum.

1. Skin. The skin or integument of reptiles is fully adapted for terrestrial life. It is dry, scaly and lacking in cutaneous glands. It prevents loss of valuable body moisture through the surface. Histologically, the reptilian skin has the usual two layers : an outer *epidermis* and an inner *dermis*.

(a) Epidermis. It is the outer thin stratified epithelium derived from ectoderm. New cells are continually added by active division in the basal or innermost single layer of cells known as germinal layer or *stratum germinativum*. As living cells are pushed towards surface, they flatten and accumulate a horny scleroprotein known as *keratin*. When keratin is deposited in cells they are said to be keratinized or cornified and they die. The outermost dead cells, form a horny layer or *stratum corneum*, which is relatively thicker in reptiles. The horny layer produces scales which form the protective exoskeletal covering all over the body. Scales usually have free posterior border and more or less overlap each other. The scaly covering is shed off periodically in flakes (ecdysis). The horny layer covering the terminal ends of digits forms the claws. The *osteoderm* (ossified cutis) is absent in *Uromastix* but present in *Varanus*.

(b) Dermis. It is the deeper, rather thick layer of dense fibrous connective tissue beneath the epidermis. It contains muscles, nerves, blood vessels and chromatophores. There are no integumentary glands except a few femoral glands found on the ventral surface of the thighs. As already stated, in male these glands secrete a substance that hardens into temporary spines which assist in holding the female during copulation.

2. Muscles. Beneath the skin is a layer of muscles which play an important role in locomotion and in supporting the body of terrestrial vertebrates. Histologically the muscles are of three types : smooth, cardiac and skeletal. *Somatic muscles* associated with body wall and appendages are striated and under voluntary control. The *visceral muscles* associated with alimentary canal are smooth and involuntary.

3. Peritoneum. Lying beneath the muscles and lining the coelom is a thin layer of close fitting mesodermal cells. This is known as coelomic epithelium or *peritoneum*.

Coelom

Vertebrates have a large mesodermal body cavity between body wall and digestive tube. This is known as *coelom*. In fishes, amphibians and many reptiles, the coelom is divi e in two parts: a small anterior *pericardial cavity* housing the heart, and a large *pleuroperitoneal, perivisceral* or *abdominal cavity* housing most of the visceral organs including the lungs. It is the coelomic epithelium lining the abdominal cavity which is known as peritoneum.

Endoskeleton

The endoskeleton of *Uromastix* is not being described here. The usual practice in India is to study the endoskeleton of *Varanus* or monitar lizard, particularly in the practicals, as a type of reptiles. The same has been described in this book also in a subsequent chapter 38 in the Section on 'Vertebrate Osteology.'

Digestive System

The digestive system comprises the *alimentary canal* and the associated *digestive glands*.

[I] Alimentary canal

The digestive tract of *Uromastix* is complete. It is a long and convoluted canal, beginning from the mouth the terminating in the cloacal aperture. The various parts included are : mouth, buccal cavity, pharynx, oesophagus, stomach, small intestine, large intestine, cloaca and cloacal aperture (Fig. 4).

1. Mouth. Mouth is a wide gape or slit bordered by the jaws covered with fleshy but immovable lips. Both the lips are covered with horny scales. The edge of upper lip is sharp and progressively covers the rounded edge of the lower lip. The mouth leads into the buccal cavity.

2. Buccal cavity. The buccal cavity is narrow in front but broad posteriorly. It is lined with mucous membrane and contains teeth, tongue and internal nares (Fig. 3).

(a) Teeth. Teeth are borne by the premaxillae and maxillae of upper jaw and dentaries of lower jaw. They are small, conical and *acrodont* (Gr., *akron*, height or extremity; *odous*, teeth), that is, they are attached to the borders of the bones. A patch of teeth, *palatine teeth* are present on the plate. At the time of birth, young *Uromastix* is equipped with four *incisor teeth* in each upper and lower jaw, but as growth proceeds, the two central upper incisors are replaced by single large, cutting tooth, in the form of downward prolongations of

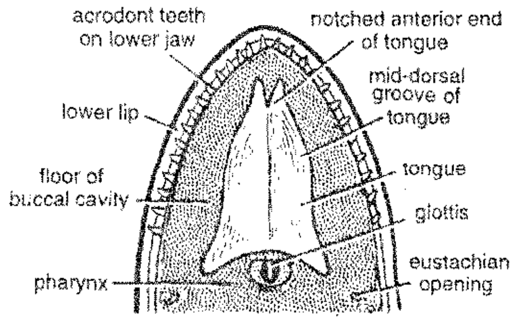


Fig. 3. *Uromastix*. Floor of buccal cavity.

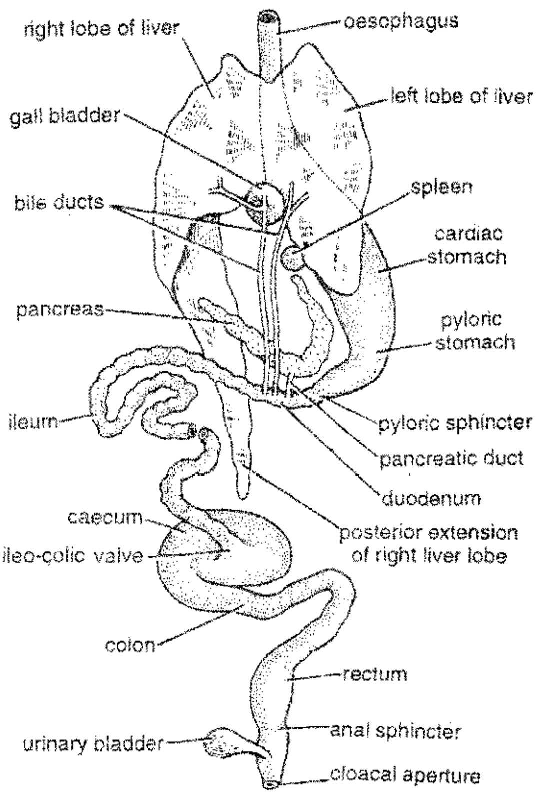


Fig. 4. *Uromastix*. Alimentary canal and digestive glands.

the pre-maxillary bone. However, in the lower jaw incisors of each mandible unite to form two cutting surfaces. *Canines* and *anterior molars* are worn down and show a toothless gap. The teeth wear out with age so that the front parts of the two jaws may become toothless in the adult lizard.

(b) ***Tongue.*** A well-developed, fleshy and roughly triangular *tongue* occupies the floor of the buccal cavity, attached all along its, mid-ventral line. Its anterior narrow end is free, notched (bifid) at the tip and protrusible. The posterior broad end is fixed and widely bifurcated. The tongue has a mid-dorsal groove and is covered with glandular papillae having taste buds.

(c) ***Internal nares.*** The external nares, situated anteriorly on snout, lead into the nasal chambers. The latter communicate with the buccal cavity through a pair of small rounded apertures, the *internal nares*. These open on the roof of buccal cavity near the anterior end.

3. Pharynx. The buccal cavity merges posteriorly into pharynx. Its mucous lining is thrown into longitudinal folds. The floor of pharynx carries a median longitudinal slit, the *glottis*, which leads into trachea. It lies between the posterior bifurcation of the tongue. On either side, near the jaw angle, opens a small rounded *aperture of eustachian tube*. The pharynx narrows posteriorly to lead into oesophagus through a wide aperture, the *gullet*. It is distensible, remains normally closed, but opens when food is swallowed. *Labial glands* are present which open on the lips. Upper labial glands are modified to form the poison glands in case of small snakes.

4. Oesophagus. The oesophagus of *Uromastix* is a long, narrow and muscular tube capable of great distension during swallowing of food. It passes straight down the neck, lying dorsal to trachea to join the stomach. Its inner wall is raised into several longitudinal folds.

5. Stomach. The stomach lies on the left side in the body cavity. It is a long tubular and curved sac wider than oesophagus. Its inner side is concave and outer side convex. Its anterior part is known as *cardiac stomach* and the posterior part as *pyloric stomach* (Figs. 5 & 6).

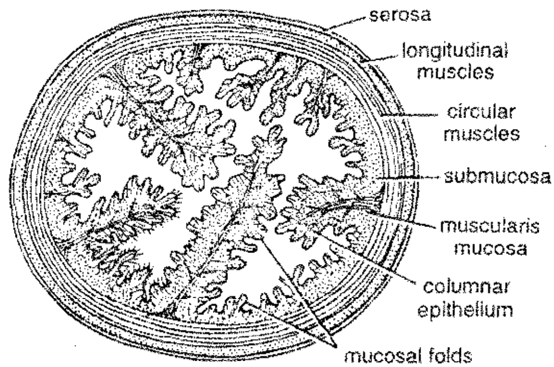


Fig. 5. *Uromastix*. T.S. Cardiac stomach.

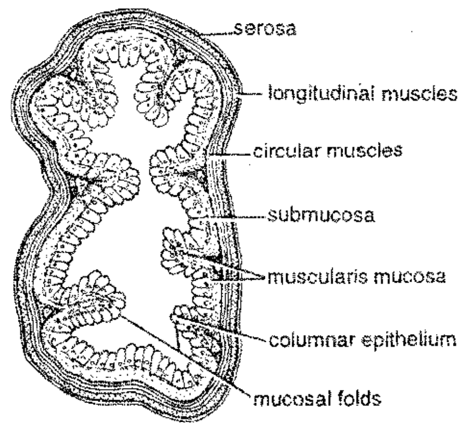


Fig. 6. *Uromastix*. T.S. Pyloric stomach.

The cardiac stomach lies dorsal to the left lobe of the liver. The stomach remains suspended by a fold of peritoneum called *mesogaster*, and the liver is attached to it by another fold called *hepatic omentum*. The wall of stomach is thick and muscular. Its inner mucous lining is thrown into longitudinal folds which are well developed in the cardiac stomach but less developed in the pyloric stomach. The end of pyloric stomach is marked by a constriction, which internally has a circular muscle, the *pyloric sphincter* or *valve*. It guards the passage of food from pyloric stomach into duodenum.

6. Small intestine. The small intestine is a long, narrow and coiled tube.

(a) ***Duodenum.*** Its anterior part or duodenum forms a U-shaped structure with the stomach. Between the two limbs of U is present the

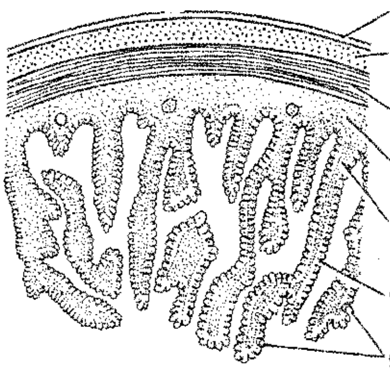


Fig. 7. *Uromastix*. T.S. Duodenum.

pancreas. The *duodenum*, receives the *bile* and *pancreatic ducts* (Fig. 7).

(b) Ileum. The duodenum passes imperceptively into the second part of small intestine called *ileum*, which is the longest part of the digestive tract. It is attached to the dorsal bodywall by the *dorsal mesentery*. The inner surface of duodenum and ileum is raised into closely-set, wavy longitudinal mucous folds which greatly increase the area of secretion and absorption. The ileum is relatively short in length in lizard as in other carnivorous animals. After a few coils, the ileum joins the large intestine.

7. Large intestine. The large intestine includes a proximal thin-walled *colon* and a distal thick-walled *rectum*.

(a) Colon. The anterior part of colon is dilated into a large blind pouch, the *caecum*. An *ileo-colic valve* is present internally at the junction of ileum and caecum. The contents of caecum and colon are visible through their thin walls. The function of colon is the formation of faeces and absorption of water.

(b) Rectum. Posteriorly, the colon narrows down to merge into the rectum. It is short, tubular and thick-walled and serves to store the faeces. Rectum leads behind into the cloaca, the two separated by a sphincter.

8. Cloaca. As in birds, the cloacal chamber of reptiles is *tripartite*, that is, internally divided into three linear chambers. The anterior chamber or *coprodaeum* receives the rectum. The middle

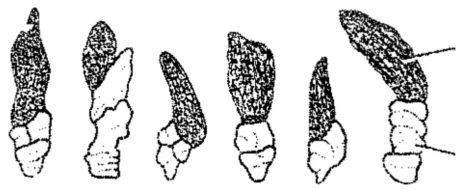


Fig. 8. *Uromastix*. Faecal pellets.

chamber or *urodaeum* receives the ureters and the gonoducts dorsally and the urinary bladder ventrally. A sphincter in the wall of ur[illegible] regulates the flow of urine in and out of the urinary bladder. The posterior chamber or *proctodaeum* opens to the outside by the *cloacal aperture* which is a transverse slit present at the junction of trunk with the tail on the ventral surface.

The cloaca serves for the reabsorption of water from the faeces and urine. Such conservation of water is a terrestrial adaptation as the lizard lives in an arid land with scarcity of water. The faeces and urine are converted into dehydrated cylindrical castings or *pellets* which are egested through the cloacal aperture (Fig. 8).

[II] Digestive glands

The glands associated with the alimentary canal are : salivary glands, gastric glands, liver, pancreas and intestinal glands.

1. Salivary glands. According to Keith, a few salivary glands open into the buccal cavity and probably secrete mucus.

2. Gastric glands. The microscopic gastric glands found in the mucous membrane of stomach discharge gastric juice in the lumen of stomach.

3. Liver. Liver is present behind the heart and between the two lungs in the body cavity. It is a large, bilobed gland, dark-red in colour. The *right lobe* of liver is larger, narrower and longer and its posterior end reaching up to the right gonad. The *left lobe*, lying ventral to the cardiac stomach, is shorter and broader. A minor *third lobe* is also reported to be attached dorsally to the left lobe. A small rounded gall bladder is present ventrally and posterior to the union of right and left lobes of liver. The liver cells secrete bile which is stored into the *gall bladder*. A *cystic duct* arising from the gall bladder joins with a hepatic duct from right lobe of liver, and with another hepatic duct from the small dorsal lobe. The combined duct runs posteriorly as the ***first bile duct*** to open into the duodenum. A *second bile duct* is also reported to originate from the left lobe of liver and open independently into the duodenum.

4. Pancreas. The pancreas is a narrow, elongated, whitish and diffused gland, situated in the loop between the pyloric stomach and the duodenum. The *pancreatic* duct opens into the duodenum near and just before the openings of the bile ducts for the discharge of the pancreatic juice.

5. Intestinal glands. Numerous microscopic intestinal glands occur in the mucous membrane of the small intestine and pour their intestinal juice into its lumen.

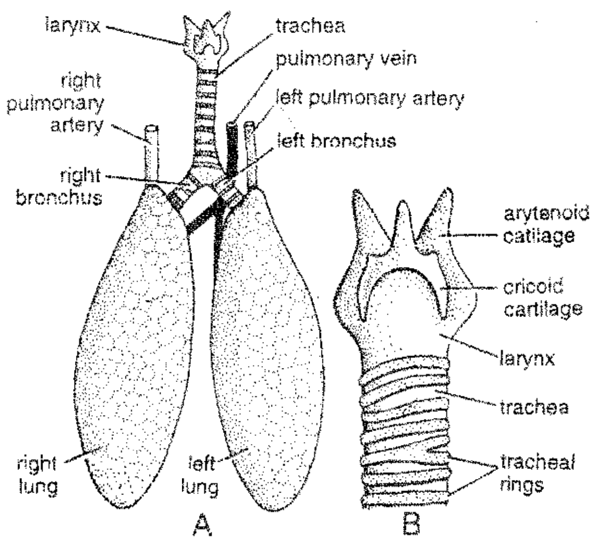


Fig. 9. *Uromastix*. A—Respiratory system in ventral view. B—Larynx and trachea in dorsal view.

Respiratory System

Respiration in reptiles in general is exclusively pulmonary, that is, taking place only by lungs.

[I] Respiratory passage

As already described, the *external nares*, present on snout open through *nasal chambers* and *internal nares* into the buccal cavity. A median longitudinal slit on the floor of pharyngeal cavity, called *glottis*, leads into a small box like chamber, called *larynx*. Its wall is supported by two *aryternoid* and one *cricoid cartilages*. The vocal cords are absent in *Uromastix*. The larynx leads into a long, cylindrical tube, the *trachea*, which runs posteriorly through the neck, ventral to oesophagus. The tracheal wall is supported by complete cartilaginous rings throughout its length to prevent it from collapsing. In the thoracic cavity, the posterior end of trachea bifurcates into two very small narrow tubes, the right and left *bronchi*, which are also supported by complete cartilaginous rings. Each bronchus enters the lung of its side through its anterior end.

[II] Respiratory organs

A pair of lungs form the respiratory organs of *Uromastix*. They lie in the thoracic cavity one on either side of the heart, dorsal to it and extend posteriorly along the outer margins of the liver lobes. They are elongated, fusiform, thin-walled, elastic and hollow sacs of orange colour, almost symmetrical in shape and extent. The cavity of a lung is continuous. The inner surface of lung wall is raised into a network of delicate ridges or *septa*, enclosing small air sacs or *alveoli*. The anterior part of each lung is better sacculated, thicker and more vascularized. As the gaseous exchange occurs within alveoli, the anterior part of a lung is more respiratory than its posterior part. Posterior part of the lung is considered as *reservoir* for the residual air. The bronchus entering a lung does not branch into bronchioles, as in higher vertebrates, but directly forms the alveoli. The deoxygenated blood is brought to a lung by a pulmonary artery and oxygenated blood carried away by a pulmonary vein back to the heart.

[III] Respiratory mechanism

The mechanism of respiration in lizard is different from that in a frog and also more effective. It is provided by the ribs and their intercostal muscles. During *inspiration*, the muscles pull the ribs outwards, enlarging the body cavity. As a result, the lungs expand the fresh air rushes into them from outside through nostrils. During *expiration*, the ribs are pulled back to their original position. Consequently, the body cavity is reduced, the lungs are pressed and their foul air goes out through the same passage.

Blood Vascular System

The blood vascular or circulatory system of *Uromastix* is closed and consists of : (i) the heart, (ii) arterial system, (iii) venous system, and (iv) blood.

[I] Heart

The heart of lizards (*Uromastix*) is typically reptilian and more advanced than that of Amphibia (Figs. 10–13).

1. External features. The heart lies midventrally and forward in the thoracic cavity, below the sternum. It is reddish in colour and roughly triangular in shape with its broad base, directed forwards and the pointed apex backwards.

(a) Pericardium. The heart lies protected within a two-layered, thin, transparent sac, the *pericardium*. The two layers of pericardial sac enclose a narrow *pericardial cavity* containing a watery *pericardial fluid*, which allows free movements of the heart and also protects it from shocks and mechanical injuries. The apex of the heart remains attached to pericardial wall by a small cord, the *gubernaculum cordis*, which keeps the heart in position.

(b) Auricles. The heart itself is a three chambered organ, made of two anterior *auricles* or atria and a posterior *ventricle*. A fourth accessory chamber, the *sinus venosus*, is attached dorsally upon the auricles. The right and left auricles are faintly demarcated from one another by a longitudinal *interauricular groove*. The right auricle gives off a small sac-like *diverticulum* from its antero-medial border on the dorsal side. The diverticulum is a normal feature of the heart in certain lizards, but its function is unknown.

(c) Ventricle. The ventricle is a conical and highly muscular chamber. It is distinctly marked off from the auricles by a transverse *auriculo-ventricular* groove or *coronary sulcus*. The apex of ventricle is obtusely rounded and tied to posterior pericardial wall by a well-developed ligamentous cord, the *gubernaculum cordis*. It penetrates the pericardium and reaches the upper margins of the liver. The left lateral surface of ventricle is evenly convex, while its right lateral surface shows a slight concavity.

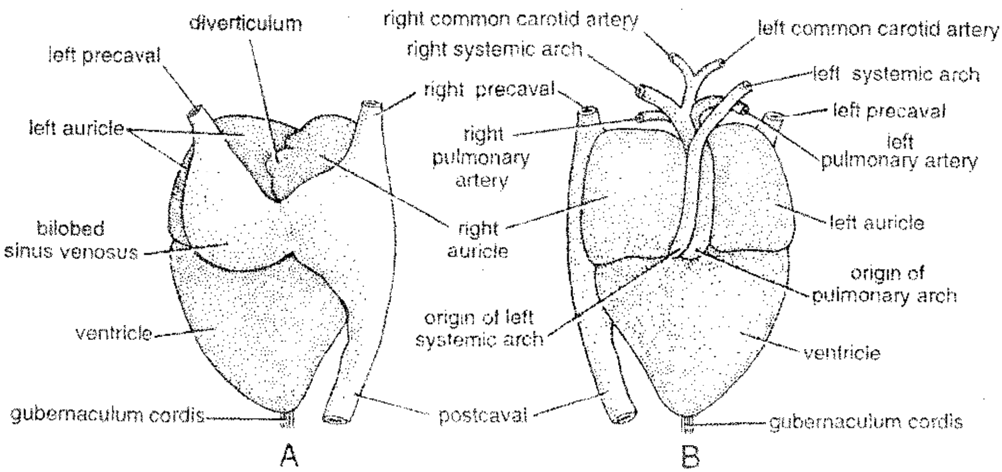


Fig. 10. *Uromastix*. External features of heart. A—Dorsal view. B—Ventral view.

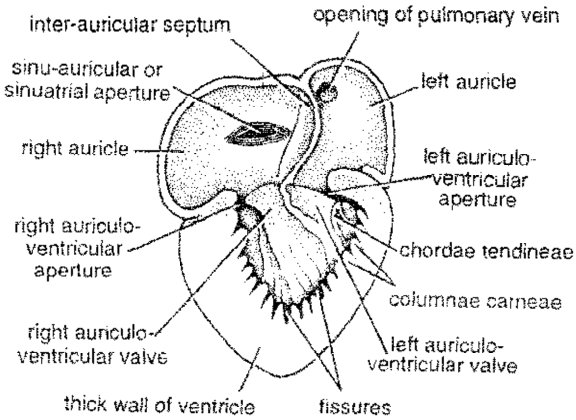


Fig. 11. *Uromastix*. Internal structure of heart in ventral view.

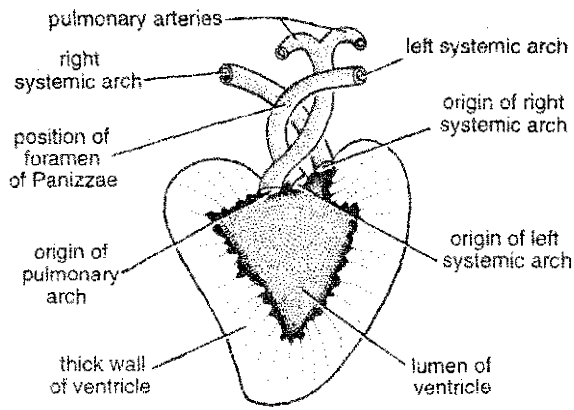


Fig. 12. *Uromastix*. Origin of aortic arches from ventricle.

(d) Sinus venosus. A large thin-walled and bilobed chamber, called *sinus venosus*, is attached transversely over the dorsal surface of the two auricles. It is formed by the union of the two precaval veins and one postcaval vein. They collect deoxygenated blood from the body and open into sinus venosus by three separate apertures. A constriction divides sinus venosus externally into a larger right lobe and a smaller left lobe. The sinus venosus is attached intimately with the right auricle because it opens into it through a *sinu-auricular* or *sinu-atrial aperture*.

2. Internal structure. The inner structure of the heart is visible in its section.

(a) Auricles. The two auricles or atria are thin-walled chambers completely separated by a thin, muscular and vertical partition, the *inter-auricular septum*. Its anterior end remains attached to the wall of the *auricles*, but the posterior end projects freely into the ventricle. The inner lining of auricular wall forms a network of low muscular ridges compared to *musculi pectinati* of higher vertebrates. The right auricle is larger than the left, a disparity commonly observed in lizards.

The dorsal wall of right auricle, near its medial border, bears the large oval or transverse slit-like *sinu-auricular aperture* of sinus venosus having thick and muscular lips. This aperture is often described in the books to be guarded by two flap-like valves. But, according to Bhatia (1929), the sinu-atrial valves are absent in *Uromastix hardwickii*. Instead, the thick and muscular lips serve to keep the aperture ordinarily closed, except when the blood is to be forced through it into the right auricle.

The common pulmonary vein, bringing oxygenated blood from the lungs, opens into the anterio-dorsal wall of the left auricle near the interauricular septum, by a small circular aperture. This aperture is usually devoid of valves in reptilian hearts. However, in *Uromastix hardwickii*, Bhatia (1929) describes a lip-like outgrowth from dorsal auricular wall which acts as a valve.

The two auricles communicate behind with the ventricle. Their respective right and left *auriculo-ventricular apertures* become separated due to a backward prolongation of the interauricular septum into the ventricle.

(b) Ventricle. The ventricle is single chambered. It has thick and muscular walls. The inner surface of ventricular wall is raised into prominent ridges, called *columnae carneae*, which greatly reduce the lumen of ventricle. Each auriculo-venticular aperture is guarded by a single semilunar flap, called the *auriculo-ventricular valve*. The two valves are the continuation of the inter-auricular septum into the ventricle. They allow the flow of blood only in one direction, i.e. from the auricles to the ventricle. The free edges of the valves are connected to the inner wall of the ventricle by firm cords, the *chordae tendineae*.

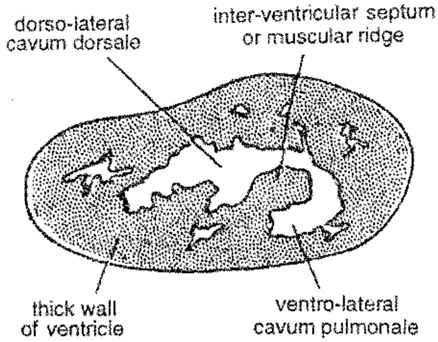


Fig. 13. *Uromastix*. T.S. ventricle to show muscular ridge.

Right side of the ventricle receives deoxygenated blood from the right auricle and the left side receives oxygenated blood from the left auricle. The chordae tendineae form a sort of incomplete septum and keep the blood in the two sides of the ventricle partially separated.

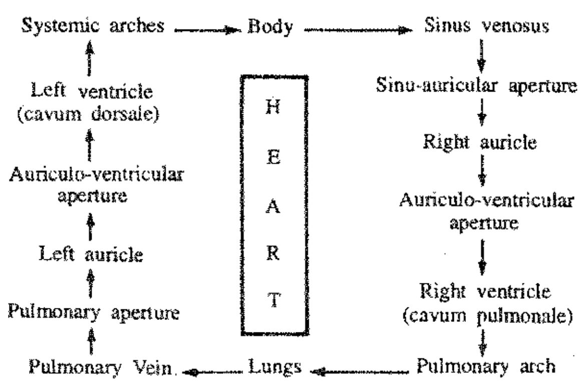
A prominent *muscular ridge* (= *Interventricular septum*), arises from the ventral wall of the ventricle on the left side and runs obliquely vertical towards right. After reaching up, it becomes horizontally inclined, subsequently, runs obliquely again and takes up a vertical course. It contains minute lacunae and trabeculae. It divides the cavity of ventricle into two unequal compartments, a larger dorsal chamber on the left, called *cavum dorsale*, and a smaller ventral chamber on the right, called *cavum pulmonale*. The two chambers are continuous with each other over the free border of the ridge.

Three *aortic arches*, one pulmonary and two systemic, arise directly and independently from the lumen of the ventricle, but not in the same plane. The *conus arteriosus* is absent. The pulmonary arch arises ventrally from cavum pulmonale, while the two systemic arches from cavum dorsale. Every arch has a pair of *semilunar valves* at its base which allow the flow of blood from the ventricle to the arch only.

The heart walls are made up of three layers—innermost, *tunica intima*, outermost the *tunica adventitia* and the intermediate one, the *tunica media*. Tunica media is made up of cardiac muscles. The heart is innervated with cardiac branch of Xth cranial nerve.

3. Course of circulation. Deoxygenated blood from body is returned to sinus venosus through caval veins. When sinus venosus contracts the blood is driven into the right auricle through sinu-atrial aperture. Meanwhile, the left auricle receives oxygenated blood from lungs through pulmonary vein. When the two auricles contract, the deoxygenated blood from right auricle passes into right side of ventricle (cavum pulmonale), while oxygenated blood from left auricle occupies the left side (cavum dorsale). Inspite of the spongy nature of the ventricular cavity, some mixing of pure and venous blood may occur. When the ventricle contracts, venous blood from right side is driven through pulmonary arch to the lungs. Simultaneously, oxygenated and partly mixed blood from left side goes into systemic arches and distributed to the body. Head receives the purest blood. The valves prevent backward flow of blood during contraction.

The course of circulation of blood through heart can be summarized graphically as below :



[II] Arterial system

Aortic arches. As already described, the three aortic arches, the *pulmonary* and the *right* and *left systemic*, originate separately a little to the right side of the ventricle (Fig. 14).

1. Pulmonary arch. The origin of pulmonary arch or trunk is clearly visible in the ventral view of the heart. It arises from the right ventral side of ventricle, that is, from cavum pulmonale. It runs forwards and soon divides into *right* and *left pulmonary arteries* which curve backwards to

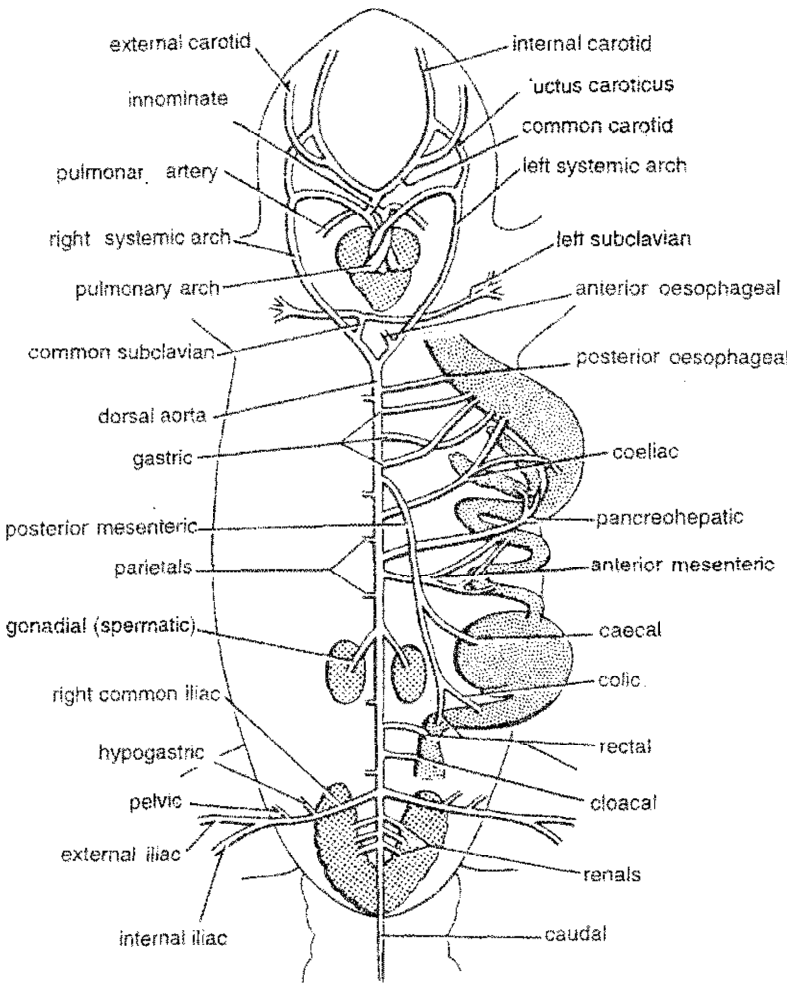


Fig. 14. *Uromastix.* Arterial system.

carry venous blood to the right and left lungs, respectively.

2. Systemic arches. The *right systemic* arises from the left side of the ventricle and carries *oxygenated* blood. The *left systemic* arises from the right side and carries *mixed* blood. The left systemic is fully visible in the ventral view of the heart, whereas the origin of the right systemic is not visible as it lies dorsal to the left systemic and the pulmonary arches. Just in front of the heart, the two systemics cross over to the opposite sides. At the point of contact while crossing each other, the two systemics communicate through a *foramen of Panizzae*. Both the systemics then curve upwards, backwards and inwards finally unite posterior to the heart in the mid-dorsal line to form the *dorsal aorta.*

Before forming the dorsal aorta, the right systemic arch gives off two prominent branches, the *innominate* and the *common subclavian.*

(a) Common carotids. Before curving to the right side, the right systemic gives off a very short vessel, the *innominate* or *carotis primaria,* which at once bifurcates into right and left *common carotids*. Each one of them runs ahead for some distance parallel to the systemic arch of its side and then divides into an *external* and an *internal carotid artery.* They supply oxygenated blood to the neck and various regions of the head. Each internal carotid is connected with the systemic arch of its side by a small vessel, the *ductus caroticus*. It represents the remanent of the embryonic lateral aorta. Carotid arteries arise only from right systemic arch, so that it is also known as *carotico-systemic arch*.

(b) Common subclavian. It arises from the right systemic arch a little before it joins the left one to form the dorsal aorta. It soon divides into the *right* and the *left subclavian arteries* supplying blood to the corresponding forelimbs. Each subclavian breaks into three branches :

(1) *scapular* to the scapular region,

(2) *coracoid* to the coracoid muscles, and

(3) *brachial* to the arm.

(c) Anterior oesophageal. The left systemic arch gives off a small *anterior oesophageal artery* which supplies the anterior part of oesophagus.

3. Dorsal aorta. As already stated, the *dorsal aorta* is formed by the union of the two systemic arches. It runs straight backwards mid-dorsally beneath the vertebral column, and distributes the following main branches on its way in the sequence given below :

(a) Posterior oesophageal. A single artery to the posterior region of oesophagus.

(b) Gastric arteries. Three small unpaired arteries to the anterior, posterior and middle regions of stomach.

(c) Posterior mesenteric. A single large artery running backwards to the large intestine and dividing into three branches : *caecal* (caecum), *colic* (colon) and *rectal* (rectum).

(d) Coeliac. An unpaired artery to stomach, pancres and spleen.

(e) Pancreo-hepatic. An unpaired artery to duodenum, liver and pancreas.

(f) Anterior mesenteric. An unpaired artery to small intestine breaking into several branches.

(g) Gonadial. One or two pairs to the gonads. They are called *spermatic arteries* in the male and *ovarian arteries* in the female lizard.

(h) Rectal. An unpaired artery to the rectum.

(i) Cloacal. A small, median, unpaired artery to cloaca and terminal part of rectum.

(j) Common iliacs. A pair of large arteries to the hind limbs. Each common iliac breaks into several branches : a *hypogastric* to the urinary bladder, a *pelvic* to the pelvic girdle, an *external iliac* to the thigh, and an *internal iliac* to the lower leg.

(k) Renal. Three pairs of small arteries to the kidneys.

(l) Caudal. Posterior continuation of dorsal aorta into the tail, running through the haemal canal of caudal vertebrae.

(m) Parietals. About 15 pairs of minor *dorso-lumbar* or *parietal arteries* given off at regular interval from dorsal trunk muscles and caudal muscles.

[III] Venous system

The venous system of *Uromastix* or any other vertebrate can be studied under the following four heads (Fig. 15).

(1) Pulmonary veins

(2) Caval veins

(3) Renal portal system

(4) Hepatic portal system

1. Pulmonary veins. A single pulmonary vein is formed by several branches from the two lungs. It runs along the ventro-lateral border of trachea, passes dorsally to the sinus venosus and opens into the left auricle close to the inter- auricular septum. It differs from all other veins in carrying oxygenated blood to the heart.

2. Caval veins. The venous blood collected from different parts of the body, except the lungs, is conveyed to the sinus venosus by three large *caval veins*. These are the right and left *anterior venae cavae* or *precavals*, and the single *posterior vena cava* or *postcaval*.

(a) Precavals. The right and left precavals return venous blood from the anterior body region, that is from head, neck, shoulders, forelimbs and thoracic wall. Each precaval is formed by the union of at least four major branches as follows :

(i) Common jugular vein. It is formed by the union of internal and external jugular veins at the level of tympanum. The *internal jugular* receives a *cerebral vein* from the brain and an *orbital vein* from the orbital region. The *external jugular* receives a *maxillary vein* from the upper jaw and

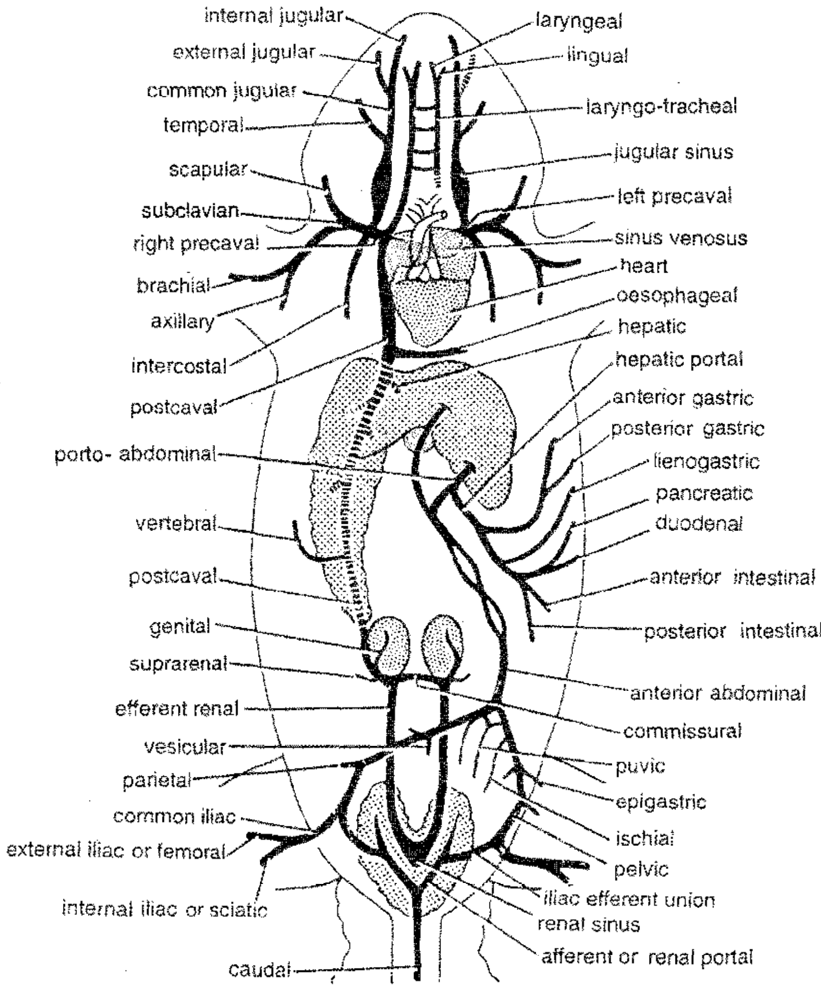


Fig. 15. *Uromastix*. Venous system.

a *mandibular vein* from the lower jaw. The common jugular then runs down the neck, receives a *temporal vein* from auditory region, and expands to form a large *jugular sinus* at the base of the neck.

According to some workers (Bhatia, 1929), there is no external jugular vein on the left side.

(ii) Subclavian vein. The subclavian joins the posterior end of the jugular sinus. It collects blood of the forelimb by three branches : *scapular* from shoulder region, *brachial* from arm, and *axillary* from arm-pit and thorax.

(iii) Intercostal vein. It collects blood from the skin and muscles of the chest and runs forwards to join the precaval internal to the subclavian.

(iv) Laryngo-tracheal vein. It is a slender vessel running parallel to the trachea. It collects blood from tongue (*lingual*), larynx (*laryngeal*) and trachea. It joins the precaval just before its entry into the sinus venosus. The laryngo-tracheals of both the sides are interconnected by 4 to 5 transverse loops. According to Bhatia (1929), the laryngo-tracheal vein of the left side does not join the left precaval.

(b) Postcaval. The venous blood from the posterior half of the body is collected by the posterior vena cava or postcaval. It has its origin from the kidneys. Blood of kidneys collects into a large central *renal sinus*, from which two *efferent renal veins* arise and run anteriorly upto the gonads. The right vein is stouter than the left, and both receive a few small branches from the dorsal bodywall. Just behind the gonads, the left efferent renal vein sharply turns medially and forms a *commissural vein* which joins the right efferent vein. A small *genital vein* and a very fine *suprarenal vein* from the gonad and suprarenal gland on each side pour into the commissural vein or the efferent renal vein of that side. The right efferent renal vein now becomes the *postcaval* which runs forwards through the right lobe of the liver. During its course it receives a *vertebral vein* from the vertebral column and a few *hepatic veins* from the liver. A small *oesophageal vein* joins the postcaval after it emerges anteriorly from the liver, but before it merges into the sinus venosus through its right posterior angle.

3. Renal portal system. Venous blood from the massive tail is gathered by a median *caudal vein*. It runs ventral to the caudal artery through the haemal canal of the caudal vertebrae. Reaching the kidneys, it divides into two *afferent renal* or *renal portal veins*, running forwards over the ventral surface of the kidneys and partly buried in their matrix. They receive *cloacal* and *rectal* veins from the cloaca and rectum respectively. The two renal portal veins break up into minute capillaries inside the kidneys.

The venous blood from each hind limb is collected by an *internal iliac* (or *sciatic*) and an *external iliac* (or *femoral*) vein. On entering the abdominal cavity, they unite to form a *common iliac vein*. It is connected to the renal portal vein of its side by a small transverse connection (the iliac afferent union), near the middle of the kidney. Each common iliac is further continued antero—laterally as the *pelvic vein*. On the way, it receives *parietal veins* from the posterior muscles, *vesicle vein* from urinary bladder, *epigastric* and *ischial veins* from dorsal body wall and *adipose veins* from fat body. A fine median *public vein* joins both the pelvics. The two pelvics meet each other mid-ventrally in front of the kidneys to form an *anterior abdominal vein*. It becomes double at places which is a primitive character indicating imperfect union of two lateral abdominal veins found in fishes. At the anterior end, the two components again become separated, one entering the left liver lobe directly, while the other joining the hepatic portal vein to form the *porto-abdominal vein* before entering the left liver lobe.

4. Hepatic portal system. The food-laden blood from various regions of the digestive tract is carried to the liver by a large *hepatic portal vein*. It is formed by the union of several branches, such as *anterior* and *posterior gastric* from stomach, *lienogastric* from spleen and a part of stomach, *duodenal* from duodenum, *pancreatic* from pancreas, *pyloric* from pylorus, *anterior intestinal* from ileum, and *posterior intestinal* from caecum, colon and rectum. Anteriorly, the hepatic portal vein unites with one branch of anterior abdominal vein to form the *portoabdominal vein* which enters the left lobe of the liver to branch into capillaries. As already described, the blood from the liver is collected by the hepatic veins which join the postcaval.

[IV] Blood

Birds and mammals are *warm-blooded* or *homoiothermous*, with regulated body temperatures. Whereas the lizard is *cold-blooded* or *poikilothermous*, like fishes and amphibians; i.e., without an internal arrangement to control the temperature of blood. The blood consists of a fluid matrix or plasma having different kinds of cells floating in it. As in frog, the red blood corpuscles are oval, nucleated and biconvex. Red blood cells of reptiles survive for longer period than mammals. The haemoglobin concentration and oxygen carrying capacity is just half as compared to mammals. White blood corpuscles are of same type as seen in other vertebrates.

Nervous System

The nervous system of *Uromastix* basically resembles that of Amphibia. However, it shows some advancement apparently because of the terrestrial mode of life. As in other vertebrates, the nervous system consists of the following three divisions :

1. Central nervous system, comprising brain and spinal cord.

2. Peripheral nervous system, comprising cranial and spinal nerves.

3. Autonomic nervous system, comprising two lateral trunks with ganglionic enlargements connected to spinal nerves.

[I] Brain

The brain of *Uromastix* is simple and similar to that of frog, but, comparatively, it is more advanced in the relatively greater size of cerebral hemispheres and smaller size of the olfactory lobes. The brain lies inside the cranial cavity covered by two membranes or meninges, the inner *piamater* and the outer *duramater* (Fig. 16).

The usual 3 divisions of the brain are : forebrain, midbrain and hindbrain.

1. Forebrain. It is the anterior part of the _rain inclu_ing _l_act_ry _ul_s, cere_ral hemispheres and diencephalon.

(a) Olfactory bulbs. The anteriormost part or *telencephalon* is in the form of two narrow and el ngate stalk-like *lfact ry peduncles* each having a distal, small, nodule-like *olfactory bulb*, from which originates an *olfactory nerve*.

(b) Cerebral hemispheres. Posteriorly, the olfactory peduncles are attached to the *cerebral hemispheres*. These are a pair of oval bodies, narrow in front and broad behind. They are closely applied together but clearly demarcated by a mid-dorsal groove, the *median longitudinal fissure*. The thin roof of each cerebral hemisphere is termed *pallium*, whereas the thick floor and the sides from the *corpus striatum*. The two corpora striata are connected together by a transverse *anterior commissure*. Above it lies the *hippocampal commissure* connecting the hippocampal regions of both the hemispheres. The pallium of *Uromastix*, however, shows an increase in thickness and number of neurons as compared with that of amphibians.

(c) Diencephalon. The *diencephalon* or *thalamencephalon* is a small rounded area covered between the cerebral hemispheres and the optic lobes, and hardly visible dorsally. Its roof is thin,

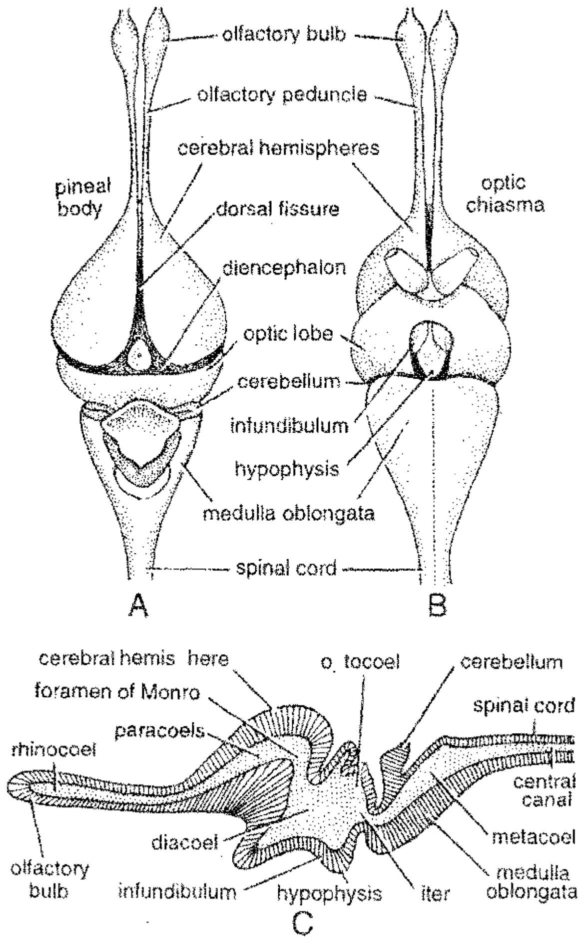


Fig. 16. *Uromastix*. Structure of brain. A—Dorsal view. B—Ventral view. C—Sagittal section showing ventricles.

non-nervous and highly vascular, forming the *anterior choroid plexus*. From the dorsal surface of diencephalon projects a median outgrowth, the *pineal apparatus,* comprising an anterior *parietal organ* and a posterior *pineal body* or *epiphysis*. The thick lateral walls of diencephalon form the *optic thalami*, and the thick floor is called the *hypothalamus*. The floor or ventral side is produced downwards into an *infundibulum*, behind which is attached the *pituitary gland* or *hypophysis*. In front of infundibulum, the two optic nerves cross each other forming the *optic chiasma*.

2. Midbrain. The middle part of brain, or the *mesencephalon*, includes two large rounded *optic lobes* placed dorso-laterally. The two thick longitudinal bands of nerve fibres beneath the optic lobes are termed *crura cerebri*.

3. Hindbrain. The posterior part of the brain is formed by the hindbrain or the *rhombencephalon*. It includes cerebellum and medulla oblongata.

(a) Cerebellum. The *cerebellum* or *metencephalon* is ill-developed, as in frog. It is a narrow, flat, semicircular ridge covering the anterior dorsal surface of medulla.

(b) Medulla oblongata. The triangular *medulla oblongata* or *myelencephalon* is broad in front by narrow and tapering behind. Its thin and highly vascular roof forms the *posterior choroid plexus*. Posteriorly, it shows a strong *ventral flexure* where it passes into the spinal cord.

Cavities of brain. The brain is a hollow organ with internal cavities known as *ventricles*. The *first* and *second lateral ventricles* or *paracoels* are the cavities of the two cerebral hemispheres. Each of them is connected anteriorly to the cavity of the olfactory lobe of its side, called *rhinocoel*. Posteriorly, the two paracoels communicate through a small aperture, the *foramen of Monro*, with the cavity of diencephalon, called the *third ventricle* or the *diacoel*. It is connected with the cavity of medulla oblongata, called the *fourth ventricle* or *metacoel*, through a narrow median passage, the *iter*. The cavities of the optic lobes or *optocoels*, are also connected with the iter.

The cavities of brain are continuous with that of the spinal cord. They are filled with a watery *cerebrospinal fluid* secreted by the choroid plexes.

Histology of brain. As usual, the brain is composed of an external *grey matter* made of nerve cells, and an internal *white matter* made of nerve fibres. Their arrangement is reversed in the medulla oblongata.

[II] Spinal cord

The spinal cord is a long, whitish and somewhat dorso-ventrally flattened tube lodged in the neural canal of the vertebral column. Its structure is of typical vertebrate plan and closely resembles that of frog. The meninges covering the brain are continuous over it. Its section presents the characteristic H-shaped pattern of the grey matter, with well-developed dorsal and ventral horns. A shallow mid-dorsal fissure and a prominent mid-ventral fissure are evident. Its central canal is filled with the cerebro-spinal fluid and is continuous with the fourth ventricle of medulla oblongata. The spinal cord controls the reflex activities.

[III] Nerves

There are 12 pairs of *cranial nerves*, the first 10 pairs corresponding with those of the fishes and amphibians. The two extra pairs are the *spinal accessory* (11th) and *hypoglossal* (12th). They arise from medulla behind the 10th pair. They innervate the muscles of the larynx, neck and tongue.

16 pairs of *spinal nerves* arise from the spinal cord. Each nerve originates by two roots, dorsal and ventral. The spinal nerves in *Uromastix* follow the general pattern of those of frog.

Sense Organs

The lateral line system, characteristic of fishes, is absent in reptiles. Sense organs have not been studied in *Uromastix*. The following description applies to the sense organs of *Lacerta* in particular and the reptiles in general. Little is known about the organs of touch and taste. Other sense organs are better developed than those of Amphibia (frog).

1. Olfactory sacs. The organs of smell are called the *olfactory sacs* or the *nasal chambers*. They are larger than those of frogs. They communicate with the exterior by *external nares* at the end of the snout and with the anterior part of mouth cavity by *internal nares*. The columnar epithelial lining of the olfactory sacs is smooth, unfolded and contains special *olfactory cells* sensitive to chemicals in solution. An olfactory cell is a narrow elongated cell having a nucleus in the swollen middle part, fine sensory processes at the free end, and a fine nerve fibril of olfactory nerve at the other end.

2. Jacobson's organs. Special additional olfactory organs, in the form of a pair of

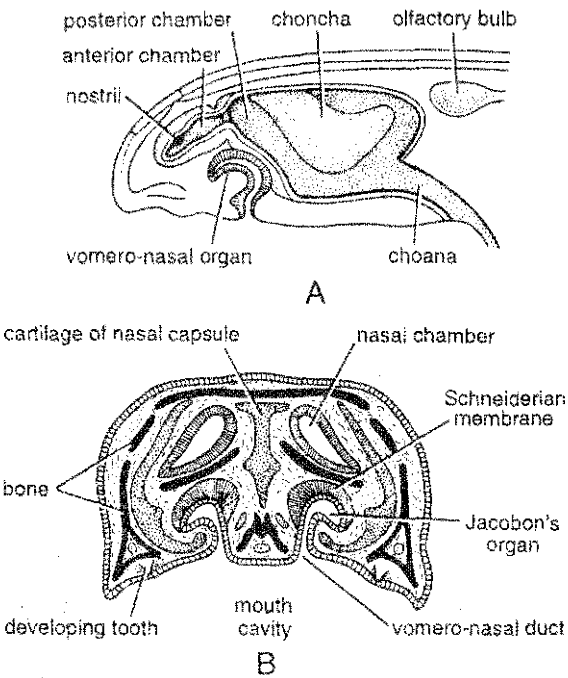


Fig. 17. *Uromastix*. Jacobson's organs and nasal chambers shown in sagittal section of head (A) and T.S. of snout (B).

vomeronasal organs or the *organs of Jacobson*, are found in some vertebrates located in between the roof of the mouth and the nasal cavities. They are absent in fish but occur as embryonic rudiments in most vertebrates. In reptiles, they are best developed in lizards, snakes and *Sphenodon*, but are absent in adult crocodiles (Fig. 17).

Jacobson's organs consist of a pair of blind sacs developed as ventral outgrowths of the nasal chambers. They are vascular and lined with olfactory epithelium which is innervated by the branches of olfactory and trigeminal nerves. Each sac opens into the mouth cavity by a duct in front of the internal nare.

The function of Jacobson's organs is uncertain. They are particularly well-developed in such animals that hold food in their mouth. Probably they serve to smell food and recognise its chemical nature by appreciating scent particles introduced into them by the tongue tips. They also help in such activities as enemy recognition, trailing prey, locating members of the opposite sex, courtship, etc.

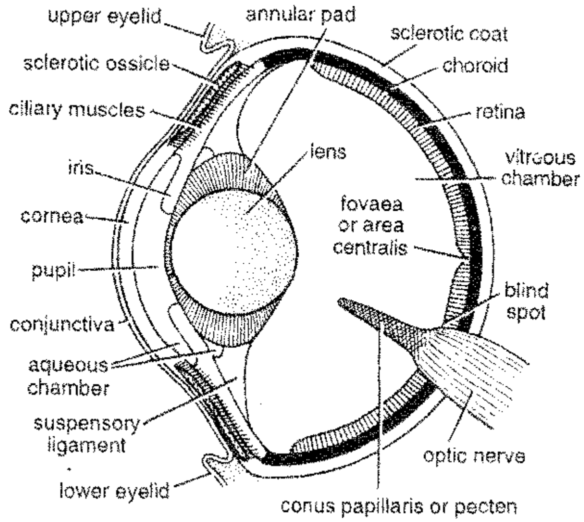


Fig. 18. *Uromastix*. V.S. eye.

3. Eyes. The eyes of reptiles show many s ecialization and advancements over those of Amphibia in order to function on land. In addition to the usual movable upper and lower eyelids, there is a well-developed third eyelid or *nictitating membrane* which slides across the moist cornea. *Harderian* and *lachrymal glands* are present, the secretions of which cleans and lubricate the nictitating membrane and cornea. The eyeball has the usual three layers : choroid, sclerotic and retina. The sclerotic is cartilaginous and the cornea is supported by a ring of 11 small *sclerotic bones* or *ossicles*. The *ciliary body*, present at the junction of sclerotic and cornea, contains well-developed *ciliary muscles* and *ciliary processes* forming the *suspensory ligament* attached to soft tissue around the lens, called *annular pad*. *Cones* are proportionately very numerous in retina. In cone cells yellow oil droplets are found which reduce the chromatic aberrations by filtering of light at the blue end of spectrum. Moreover, the cones in lizards are unique type called as *double cone*. Generally a cushion-like, vascular and pigmented process, called *pecten*, projects into the vitreous chamber from the blind spot. The function of peçtin is probably to nourish retina (Fig. 18).

Lizards depend chiefly on monocular vision. Sight appears to be keen. They perceive moving

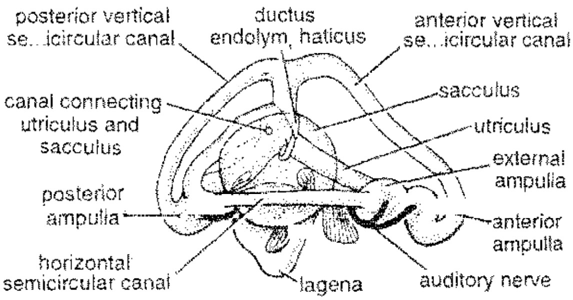


Fig. 19. *Uromastix*. Right membranous labyrinth (outer view).

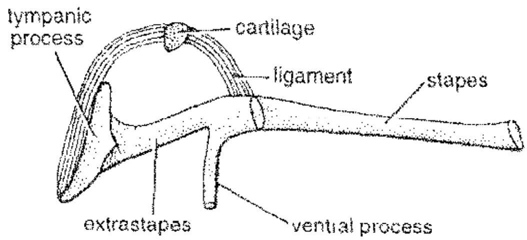


Fig. 20. *Uromastix*. Columella auris.

objects more readily than static ones. Power of accommodation is better than frog and brought about by changing the shape of the lens by pressing ciliary body against its periphery.

4. Ears. The external ear as such is absent, so that only middle and internal ears are present. The *external ear aperture*, situated behind and below each eye, leads into a vertically shallow pit, the *external auditory meatus*. It is basally closed by an oval patch of brownish skin, the *tympanum*.

The *middle ear* or *tympanic cavity* has the same basic plan as in frog. It is bounded externally by the tympanum and internally by the auditory capsule. It communicates with the mouth cavity by the *eustachian tube* which is longer and narrower than in frog. Extending horizontally across the tympanic cavity, is a slender rod-like ear ossicle, the *columella auris*. It is found attached with the tympanum, with the help of an *extra-columellar cartilage*. It is composed of two parts : a basal bony rod or *stapes* fixed internally into the membrane over *fenestra ovalis* of auditory capsule, and a proximal partly bony and partly cartilaginous *extrastapes* attached to the tympanum.

The *internal ear* or *membranous labyrinth* lies within the bony auditory capsule floating in a narrow space filled with a fluid, the *perilymph*. It is soft, delicate and consists of a cylindrical tube, the *utriculus*, and a large and rounded *sacculus*. Three *semicircular canals*, 2 vertical and 1 horizontal and each with a swollen *ampulla* at one end, open into the utriculus. A narrow tube, the *ductus endolymphaticus*, leads upwards from sacculus to end blindly in the duramater. A simple flat lobe of sacculus, called *pars lagena*, represents the cochlea of mammalian ear. Unlike cochlea of mammals, it is not coiled. It contains what is probably a special organ of hearing, the *papilla basilaris*. On the walls of this, which corresponds with the organ of corti in mammals. Some worker claim that another sensory area, the *macula lagenae* is also present near the apex of the duct, but its function is unknown.

Urinogenital System

In vertebrates, the excretory and reproductive organs are intimately associated so that they are usually studied together as the urinogenital system. In *Uromastix*, the sexes are separate and the sexual dimorphism is poorly developed.

[I] Urinary (excretory) system

The excretory organs are identical in both the sexes and include a pair of *kidneys*, a pair of *ureters* and a single *urinary bladder*.

1. Kidneys. The two kidneys lie far behind in the posterior abdominal cavity, just at the base of the tail. They are attached to the dorsal bodywall and covered with peritoneum on their ventral surfaces only. The kidneys are *metanephric*. They are dark-red, depressed and irregular in shape. Each of them consists of an anterior and a posterior lobe. The broad anterior lobes of both the kidneys remain free and apart, whereas the narrow posterior lobes become united together. As a result, the partially fused kidneys appear V-shaped. A connective tissue pad, however, separates the posterior lobes of the two kidneys.

Histologically, the kidneys are made of a compact mass of much coiled narrow *uriniferous*

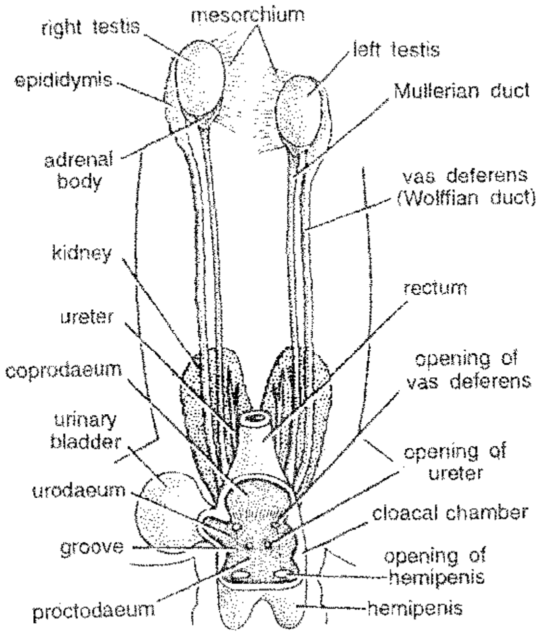


Fig. 21. *Uromastix*. Male urinogenital system.

tubules, embedded in connective tissue containing blood capillaries, muscle fibres and nerves. All the tubules of a kidney open into a common urinary duct, the *ureter*.

2. Ureters. A metanephric duct or ureter originates ventrally from each kidney. It is a short, narrow and delicate duct partly embedded in the kidney. Both the ureters run backwards to open dorsally into the middle chamber of cloaca called urodaeum. Their openings lie upon small papillae.

3. Urinary bladder. It is a small thin-walled sac opening into the urodaeum of cloaca ventrally in the region of the sphincter between the coprodaeum and the urodaeum.

4. Physiology of excretion. The reptiles are *urecotelic*, that is, their excretory waste is in the form of uric acid and urates which are not much soluble in water. They leave the kidneys with a small amount of water forming a yellowish urine. It is carried by ureters into urodaeum from where it passes into the urinary bladder to become stored. Much water is reabsorbed in the urodaeum and the bladder. As a result the excretory waste discharged is in a semi-solid state composed largely of uric acid.

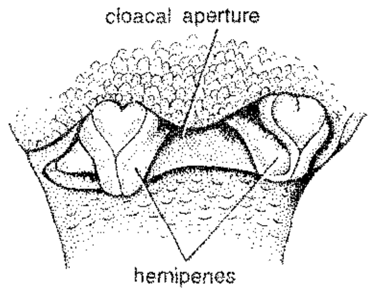


Fig. 22. *Uromastix*. Hemipenes of a lizard projecting through cloacal aperture.

[II] Male reproductive system

The male reproductive organs include one pair each of testes, vasa deferentia and hemipenes. (Figs. 21–22).

1. Testes. The testes are two white oval bodies. They are attached to the dorsal bodywall much ahead of the kidneys in the body cavity. They are placed asymmetrically, the right testis somewhat anterior to the left testis. Each testis is suspended from the dorsal bodywall by a peritoneal fold called *mesorchium*. A ductless gland, called *adrenal body*, is attached posteriorly to each testis.

The internal structure and functions of testes follow the general vertebrate pattern. Their main mass is formed by numerous coiled *seminiferous tubules*, the epithelial lining of which undergoes spermatogenesis to produce spermatozoa.

2. Vasa deferentia. The seminiferous tubules of each testis unite to form bigger vessels called *vasa efferentia*. These form a thick convoluted mass, called *epididymis*, closely applied to the outer posterior surface of the testis. A narrow convoluted duct, the *vas deferens* or *sperm duct*, runs posteriorly from epididymis, along the dorsal bodywall. It passes over the ventral surface of the kidney of its side and opens dorsally into the urodaeum of cloaca, independent of the ureter. The openings of vasa deferentia in the urodaeum lie in front of the openings of ureters.

The vasa deferentia are also known as the *Wolffian ducts*. A white strand, representing the vestigial *Mullerian duct*, also runs parallel to the vas deference of each side from the testis to the urodaeum.

3. Hemipenes. A pair of hollow, nodule-like eversible *copulatory sacs*, the so-called *hemipenes*, are present mid-ventrally behind the cloacal aperture at the base of the tail. These are made of highly erectile vascular tissue. Normally they lie contracted, but during copulation, they become erect and everted into the proctodaeum. The mechanism of eversion depend in part on the action of propulsor and retractor muscle and in part on engorgement of blood sinuses in the tissues of hemipenis. An everted hemipenis is a subcylin rical organ made of a hard proximal pedicel, bearing a distal head. The pedicel bears a groove, the *sulcus*, for con ucting t e spermatozoa during copulation. The groove originates from the opening of vas deferens into urodaeum and terminates on the head of hemipenis. The two hemipenes work independently and usually one of t em ecomes inserted into the cloaca of the female for the discharge of spermatozoa, during copulation. This however, depends upon the side, male happens to be during copulation.

[III] Female reproductive system

The female reproductive organs consist of one pair of ovaries and one pair of oviducts (Fig. 23).

1. Ovaries. The two ovaries are found in the abdominal cavity, slightly posterior to the position of testes in male. The right ovary is somewhat anterior to the left one, and each suspended to the dorsal bodywall by a double fold of peritoneum, the *mesovarium*. The ovaries are irregularly oval in shape and yellowish-white in colour. Their outer surface is raised into several rounded elevations, or *follicles*, each containing a single *ovum*. The ova are in different stage of development.

Histologically, the ovary is made of several lobules, lined by genital epithelium, the cells of which undergo oogenesis to form the ova. The ripe ova released by the rupture of follicles, float in the coelomic fluid of the body cavity.

2. Oviducts. The two oviducts are long, thin-walled and much pleated or folded tubes independent of the ovaries. They are kept in position and attached to the dorsal body wall by a fold of peritoneum, the *broad ligament* or *mesotubarium*. The broad anterior end of each oviduct is called the *oviducal funnel*. It opens into the body cavity by a large externally directed openings, the *ostium*, with ciliated margin. The mature ova floating in the fluid of the body cavity enter the oviducts through their ostia by ciliary action. Fertilization of ova takes place in the anterior part of the oviducts. The two oviducts run posteriorly. While passing over the ventral surface of the kidneys, each oviduct dilates to form a *shell gland* or *ovisac*, where the fertilized eggs are retained and provided with egg shells. Eggs of *Uromastix* are large, measuring 20×30 mm in size. About 15 eggs are said to be laid by a single female. The terminal part of oviduct, called *vagina*, opens dorsally into the urodaeum of cloaca. The openings of the oviducts are anterior to and independent of the openings of ureters.

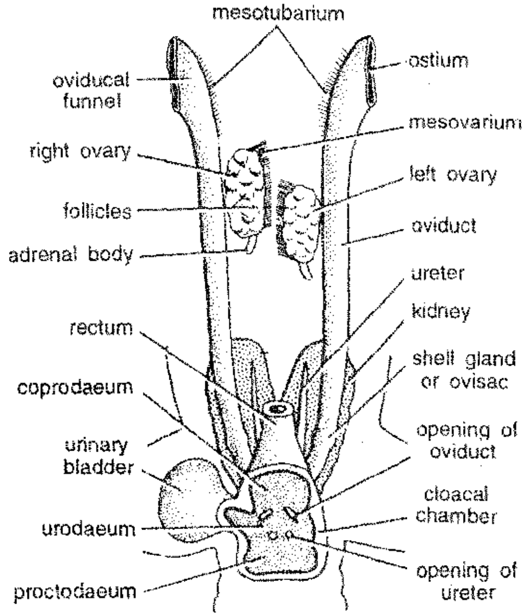


Fig. 23. *Uromastix*. Female urinogenital system.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the habit, habitat and external features of the spiny-tailed lizard.
2. Describe the digestive system of a lizard. How these are suited to their feeding habits ?
3. Give description of a reptilian heart. Explain the course of circulation through it.
4. Describe the arterial and venous system of *Uromastix*.
5. Give an account of brain of *Uromastix*.

» *Short Answer Type Questions*

1. Describe the urinogenital system of *Uromastix*.
2. Write short notes on — (i) Ductus caroticus, (ii) Foramen of Panizzae, (iii) Jacobson's organ, (iv) Preanofemoral pores.

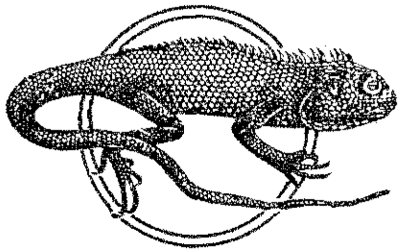
» *Multiple Choice Questions*

1. The body of *Uromastix* is divisible into :
(a) Head, neck, trunk and tail
(b) Head, trunk and tail
(c) Head, neck and trunk
(d) Head, neck and tail
2. *Uromastix* is commonly known as :
(a) Girgit (b) Spiny tailed lizard
(c) Flying lizard (d) Wall lizard
3. Shedding of scally covering periodically in flakes is :
(a) Moulting (b) Metamorphosis
(c) Ecdysis (d) Pupation
4. Lips guarding mouth in *Uromastix* are :
(a) Thin and movable (b) Fleshy and movable
(c) Thin and immovable (d) Fleshy and movable
5. In *Uromastix* pharynx leads to oesophagus through an aperture the :
(a) Gullet (b) Glottis (c) Nares (d) Cloaca
6. In *Uromastix* liver is attached to the body wall by a peritoneal fold called :
(a) Mesogaster (b) Hepatic omentum
(c) Pyloric sphincter (d) Temporal fossae
7. In *Uromastix* cloaca is divided into :
(a) Coprodaeum and Urodaeum
(b) Coprodaeum and Proctodaeum
(c) Coprodaeum, Urodaeum and Proctodaeum
(d) Urodaeum and Proctodaeum
8. Walls of larynx are supported by :
(a) Arytenoid cartilage
(b) Cricoid cartilage
(c) Coracoid cartilage
(d) Arytenoid and cricoid cartilage
9. Right and left systemic arches communicate through :
(a) Foramen of Panizae (b) Foramen of Monero
(c) Foramen magnum (d) Fenestra ovilis
10. Fertilized egg is provide with shell I :
(a) Oviducal funnel (b) Ovisac
(c) Ostium (d) Vagina

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b)

23



Type 9. *Calotes versicolor* : The Garden Lizard

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Division	Gnathostomata
Superclass	Tetrapoda
Class	Reptilia
Subclass	Diapsida
Order	Squamata
Suborder	Lacertilia
Family	Agamidae
Type	*Calotes versicolor* (Garden lizard)

Natural History

Distribution. *Calotes*, the common garden lizard is known as 'girgit' in North India. It is often called a "blood sucker," because of the red colour of throat. The most commonly distributed Indian species is, *Calotes versicolor* which is dissected as a type of Lacertilia in most South Indian universities.

Habits and habitat. *Calotes* is a common *arboreal* lizard of fields and gardens. It is *diurnal*, often seen during day, sitting on tree branches, shrubs and hedges. It is mainly *insectivorous* but is also told to feed on smaller lizards, frogs, crabs and earthworms. It runs swiftly on ground and even swims in water. Sexes are separate and difficult to distinguish externally. It breeds from May to November, when it can change its colour like a chamaeleon. It often lives in crevices and lays eggs there or in debris. Development is direct and the young resemble the parents.

External Features

Shape, size and colour. Body is elongated, slender, lizard-like and clearly divisible into 4 parts —*head, neck, trunk* and *tail*. Male is brightly coloured, golden yellow with a greenish tinge. Throat is scarlet red, often with a black transverse

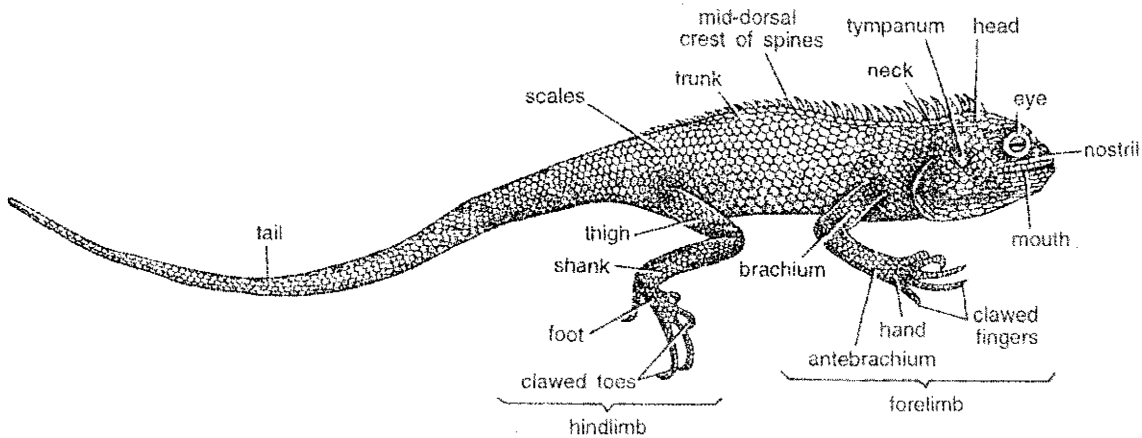


Fig. 1. *Calotes versicolor*. External features.

bar. Female is not so brightly coloured. The male is stronger and larger than female and measures about 35 cm in length including tail (Fig. 1).

Head. The large head is pyramidal in shape with a short conical *snout*, bearing a wide slit-like transverse terminal *mouth* and a pair of small oval apertures, the *external nares*. Lips are absent. The lower jaw of male shows a characteristic curve not present in female. Each *eye* is shielded by movable eyelids and a nictitating membrane. Behind each eye is a shallow *external ear opening* provided with a tympanum at its bottom.

Trunk. A short neck connects the head with an elongated trunk which is compressed laterally but flattened ventrally. Between trunk and tail mid-ventrally opens a transverse slit-like *vent* or *cloacal aperture*. A large *cloacal plate* is fond at front of the cloacal aperture. The trunk bears 2 pairs of limbs, the hind limbs being longer than the forelimbs. Each *forelimb* comprises antebrachium, brachium, manus and 5 clawed fingers; while each *hind limb* comprises femur, crus, pes and 5 clawed toes.

Tail. Tail is cylindrical, tapering like a whip and two and a half times longer than the head and trunk. In adult male the base of tail just behind the cloacal aperture becomes markedly swollen due to hemipenes. The tail shows alternate dark and light annuli.

Skin and exoskeleton. The entire body is covered by rough epidermal horny, imbricate and backwardly directed *scales* of unequal size. On the head, a prominent shield covers the parietal foramen and 2 spines are present above each ear opening. On head and trunk, along mid-dorsal line, is a characteristic *frill* or *crest* of larger spine-like movable scales pointed backwards and gradually diminishing in size posteriorly. Scales are shed periodically in *ecdysis*. Skin is dry and devoid of glands; femoral pores on thighs are absent in females. In males, these glands become functional during breeding seasons.

Calotes skin first develops as a simple cuboidal ectoderm. Subsequently it differentiates into outer *periderm* and inner *basal germinativum* layer. Later it becomes stratified due to addition of outer layers composed of an inner layer of columnar cells, *stratum germinativum* (=*malpighian layer*), which is found on *basement membrane*. The outermost layer is made of dead cells called *stratum corneum*. Between the two a transitional layer is also present.

Scales and claws form the exoskeleton of most of the reptiles including *Calotes*.

Scales. Scales form a continuous cover over the body of *Calotes*, but become thinner in the grooves between the scales. Scales on the body of *Calotes* are of two types viz., *large scales* and *small scales*. Sensory devices in the form of bristles are present on both the scales called *prototrichus* (plural of *protothrix*). It is believed to evolve into hair in mammals, during the course of evolution. Scales are epidermal in origin, develop from malpighian layer. Each scale is a plat. lik. structure support... by .. *bony plate* or *ossicle*.

Claws. Tips of the digits of *Calotes* are provided with shar- claws. Each made u- of a dorsal and ventral scale like horny plate. Dorsal plate is called *unguis* and ventral one is called *subunguis*. The latter is flattened. Both these plates are derived from the malpighian layer and placed in such a way, that they converge to form a sharp claw. Cellular structure of skin is similar to that of *Uromastix*.

Endoskeleton

Endoskeleton of *Calotes* is very much similar to that of *Varanus* or monitor lizard. The latter is more convenient for study because of its larger size. The same has been described in a separate chapter (38) in the section on "Vertebrate Osteology".

Digestive System

The digestive system of *Calotes* consists of alimentary canal and digestive glands (Fig. 2).

[I] Alimentary canal

Alimentary canal is a coiled tube between mouth and cloaca.

1. Mouth. The anterior terminal mouth is a wide transverse slit bounded by upper and lower jaws bearing teeth. The *teeth* are small, similar (*homodont*) and simple cones attached to the inner lateral sides of jaw bones (*pleurodont*). Each teeth has an *enamel* cap externally and an inner *orthdentine*. Latter encloses a large pulp cavity. Size of teeth varies in different regions of the jaws. They are curved posteriorly and not used for mastication.

2. Buccal cavity. Mouth leads into a narrow buccal cavity which widens posteriorly. In its roof open two small openings of *internal nares*, while on its floor lies a median, muscular, protrusible *tongue*. Its posterior end is attached while the anterior free end is slightly notched.

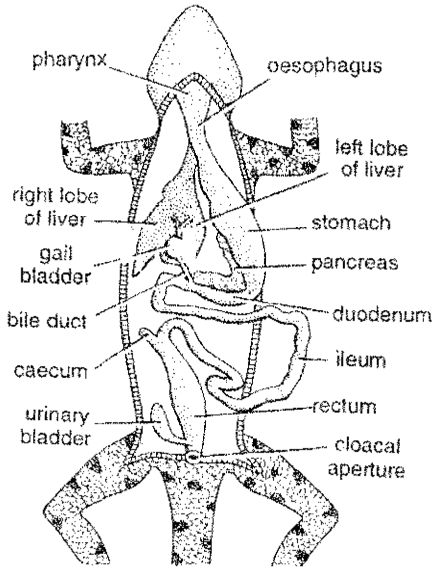


Fig. 2. *Calotes*. Digestive system.

3. Pharynx. The pharynx shows the usual mid-ventral slit-like *glottis*, the lateral paired *openings of eustachian tubes*, and the posterior wide opening of *gullet* leading into *oesophagus*.

4. Oesophagus. The straight, narrow tubular oesophagus passes down the neck, dorsal to trachea to join the stomach.

5. Stomach. The stomach is an elongated, wide sac-like tube, with little distinction between anterior *cardiac* stomach and posterior *pyloric* stomach.

6. Small intestine. Stomach leads through a pyloric sphincter into small intestine which is a long, narrow and coiled tube. Its small anterior U-shaped part, or *duodenum*, receives the bile and pancreatic ducts. The longer posterior and much coiled *ileum* leads into the large intestine. At the junction of the two arises a small blind *caecum*.

7. Large intestine. The large intestine or *rectum* is a small, wide, thick-walled tube opening straight into cloaca by a sphinctured *anus*. A colon is lacking.

8. Cloaca. The small tripartite cloaca comprises an anterior *coprodaeum*, a middle *urodaeum* and a posterior *proctodaeum*. The latter opens to the exterior by the *cloacal aperture*.

Entire alimentary canal is held in position, within the body with the help of folds of peritoneum. Stomach is attached with the body wall with the help of *mesogaster*, the ilium by *mesentery* and rectum by *mesorchium*.

[II] Digestive glands

Digestive glands include salivary and mucous glands, gastric glands, liver, pancreas and intestinal glands. The massive, brownish and bilobed *liver* is situated dorsal to stomach, behind the heart. The upper margin of the liver and tip of the ventricle are connected with each other with the help of *gu ernaculum cor is*. A small roun e *gall bladder* is embedded in its right lobe. The alkaline *bile* secreted by liver and stored by gall bladder is poured into duodenum through a small *bile duct*. Inner wall of stomach is provided with large number of unicellular glands viz., *parietal glands* and *gastric glands* which secrete hydrochloric acid and digestive enzymes respectively. *Pancreas* is an elongated, whitish structure lying in the mesentery between stomach and duodenum. Its alkaline pancreatic juice is drained into duodenum by a separate duct.

Respiratory System

[I] Respiratory passage

As in *Uromastix*, the respiratory tract includes the external nares, nasal chambers, internal nares, glottis, larynx, trachea and bronchi (Fig. 3).

[II] Respiratory organs

True respiratory organs are a pair of elongated, fusiform, thin-walled, elastic sac-like *lungs*. These lie in the thoracic cavity one on either side of the heart. Right lung is a little larger than the left one. Inner surface of each lung is raised into a network of incomplete ridges or *septa*, enclosing small chambers, the *alveoli*, within which gaseous exchange occurs. The distal part of lung is without alveoli and therefore, non-respiratory. The alveoli and walls of a lung are richly supplied with blood capillaries.

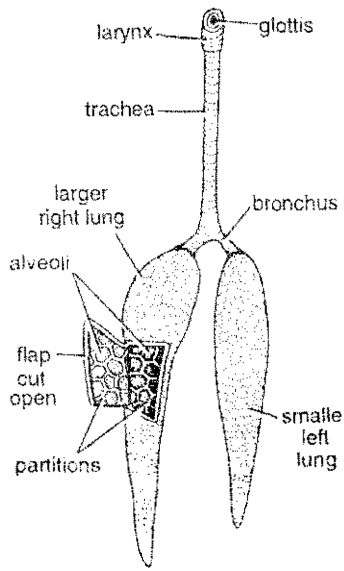


Fig. 3. *Calotes*. Respiratory system. Right lung partly cut open to show internal partitions and alveoli.

[III] Respiratory mechanism

The breathing movements in inspiration and expiration are similar to those already described in *Uromastix*.

Blood-Vascular System

[I] Heart

1. External features. Heart of *Calotes* is essentially similar to that of *Uromastix*. It lies mid-ventrally in the anterior part of thoracic cavity at the level midway between the forelimb and ventricle, extending slightly beyond the axillae enclosed by the 2-layered, transparent *pericardium*. Heart is a triangular, red-coloured and 3-chambered muscular organ. This, slight anterior location of the heart indicates a little lower grade of organization also seen in *Sphenodon*. The anterior two *auricles* are clearly marked off from the posterior single *ventricle* by a transverse *auriculo-ventricular groove*. A *truncus arteriosus* is lacking. The thin-walled *sinus venosus*, reduced and unequally bilobed by a constriction, lies transversely and dorsally upon the auricles. Its smaller left lobe is formed by left precaval, while

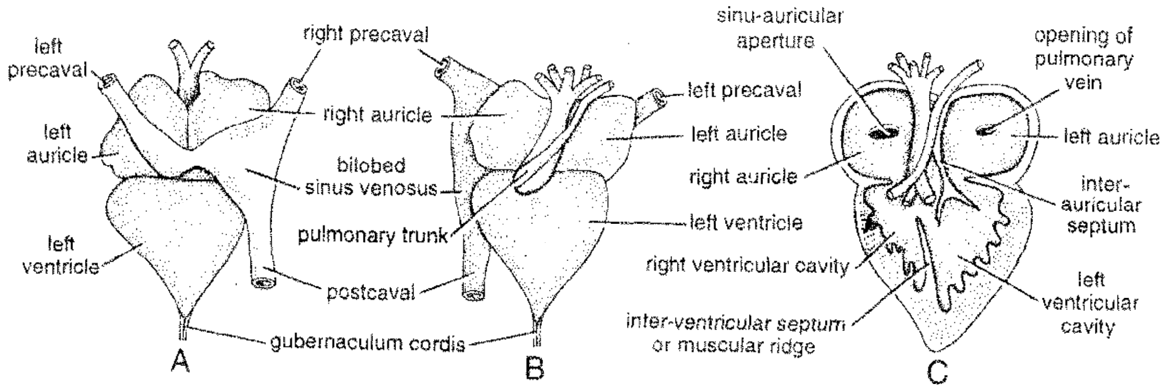


Fig. 4. *Calotes*. Structure of heart. A—Dorsal view. B—Ventral view. C—Internal structure in diagrammatic ventral view.

its larger right lobe by the union of right precaval and postcaval veins. The posterior apex of ventricle is connected to liver by a thin, white cord of tissue, the *gubernaculum cordis*.

2. Internal structure. Internally the two auricles are separated by a thin, muscular and vertical *interauricular septum. Right auricle* is larger and darker. Its thicker wall is raised internally into small ridges, the *musculi pectinati*. Sinus venosus opens into its dorsal wall by a large semicircular *sinuauricular aperture*, guarded by two flap-like valves. *Left auricle* is smaller, thin-walled and its roof receives a small circular and valveless common *pulmonary aperture* of pulmonary veins (Fig. 4C).

Ventricle has thick, spongy muscular walls internally projecting into interlacing ridges, called *columnae carneae*. The two auricles open into ventricle through right and left *auriculo-ventricular apertures* guarded by *auriculo-ventricular valves*. The flaps of these valves are attached to columnae carneae by thread-like muscles, the *chordae tendineae*. An incomplete *interventricular septum* or *muscular ridge* divides the lumen of ventricle incompletely into a right chamber, *cavum pulmonale*, and a left chamber, *cavum dorsale*. Three arches, *right* and *left systemic* and *pulmonary*, arise from ventricle. Each arch has paired semilunar valves at its base to check return of blood. The walls of the heart are provided with three layers viz., *tunica intima, tunica media* and *tunica adventitia*, out of these tunica media is made of *cardiac muscles* and is innervated with *cardiac branch* of 10th cranial nerve.

Working. In *Calotes*, the course of circulation of blood through heart is exactly similar to that already described in *Uromastix*.

[II] Arterial system

As already mentioned, 3 aortic arches arise from the ventricle—1 pulmonary and 2 systemic—, all united together at the base by a fibrous connective tissue (Fig. 5).

1. Pulmonary arch. It arises from the right side of ventricle (*cavum pulmonale*) and soon divides into two pulmonary arteries carrying deoxygenated blood to lungs.

2. Systemic arches. Right systemic arch arises from left side of ventricle and carries pure blood. Left systemic arises from right side of ventricle and carries mixed blood. Just in front of auricles, the two systemic arches cross each other to go to their respective sides, curve around the oesophagus and then unite posterior to the heart mid-dorsally to form the *dorsal aorta*.

(a) Innominate. Right systemic gives off in front a very short *innominate* or *common carotid artery*. It soon bifurcates into *right* and *left carotid arteries* which run parallel to the systemic arch of that side. Each carotid artery further divides into *internal* and *external carotid* arteries supplying oxygenated blood to head region. The internal carotid is connected to the systemic arch of its side by a small *ductus caroticus*. It represents the remnant of embryonic lateral aorta.

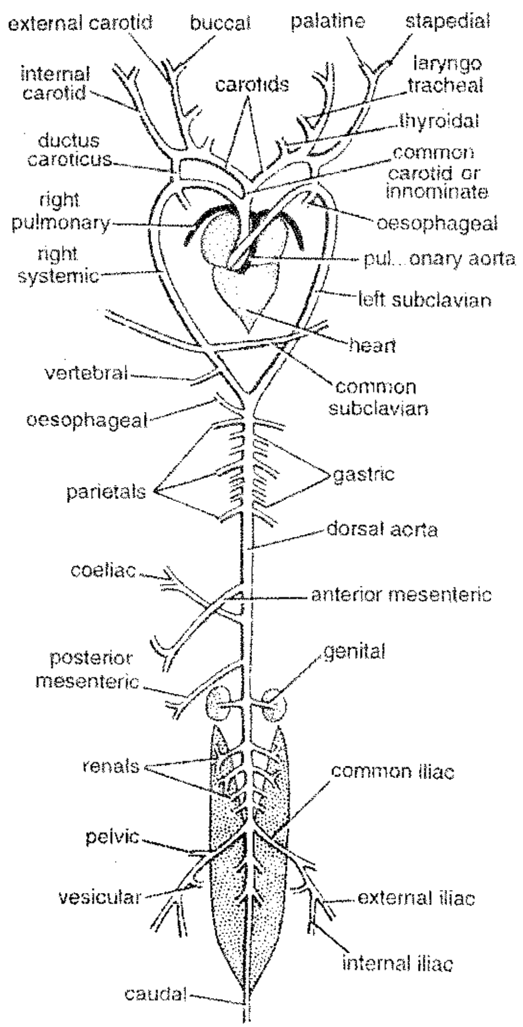


Fig. 5. *Calotes*. Arterial system.

(b) Subclavian. The common subclavian arising from right systemic divides into *right* and *left subclavian arteries* supplying the two forelimbs.

(c) Vertebral. It is given off from right systemic arch to vertebral column.

(d) Oesophageal. 3 of them arise from right systemic and 4 from left systemic to supply oesophagus.

3. Dorsal aorta. Dorsal aorta, running straight backward mid-dorsally, gives off the following branches :

(a) Parietal. Several pairs throughout to dorsal muscles and vertebral column.

(b) Anterior oesophageal. To oesophagus.

(c) Gastric. 4-8 pairs to stomach.

(d) Anterior mesenteric. To small intestine.

(e) Coeliac. To stomach, pancreas, spleen.

(f) Posterior mesenteric. To rectum.

(g) Genital. 1 pair to testes or ovaries.

(h) Renal. 3 or more pairs to kidneys.

(i) Iliac. 1 pair to hind limbs. Each sends a *pelvic* branch to pelvic girdle and breaks into *internal* and *external iliacs* to leg.

(j) Caudal. Posterior continuation of dorsal aorta into tail.

[III] Venous system

Veins bringing deoxygenated blood from body back to the heart fall under the following 4 categories (Fig. 6) :

1. Pulmonary veins. Two pulmonary veins from each lung join together into a *common pulmonary vein* which opens into the left auricle.

2. Caval veins. Sinus venosus receives blood by 3 large caval veins—two anterior or *precavals*, and one posterior or *postcaval*.

Each *precaval* is formed by the union of 3 veins —*internal* and *external jugular* from head and *subclavian* from forelimb. Right precaval also gets an *azygos vein* from ventral thoracic wall.

The *postcaval* is formed by the union of two *right* and *left efferent renal veins* which collect blood from kidneys. Before union each receives *genital veins* from gonad. The postcaval receives two stout *hepatic veins* from liver, before it enters the posterior angle of sinus venosus.

3. Renal portal system. A median *caudal vein* from tail bifurcates over kidneys into two *pelvic veins*. Each pelvic sends an *afferent renal portal vein* into kidney where it breaks into capillaries. The pelvic vein now receives a *femoral* and a *sciatic vein* from the hind limb of its side. The two pelvic veins now unite in front of kidneys to form a median *anterior abdominal vein* which ultimately enters liver to break up into capillaries.

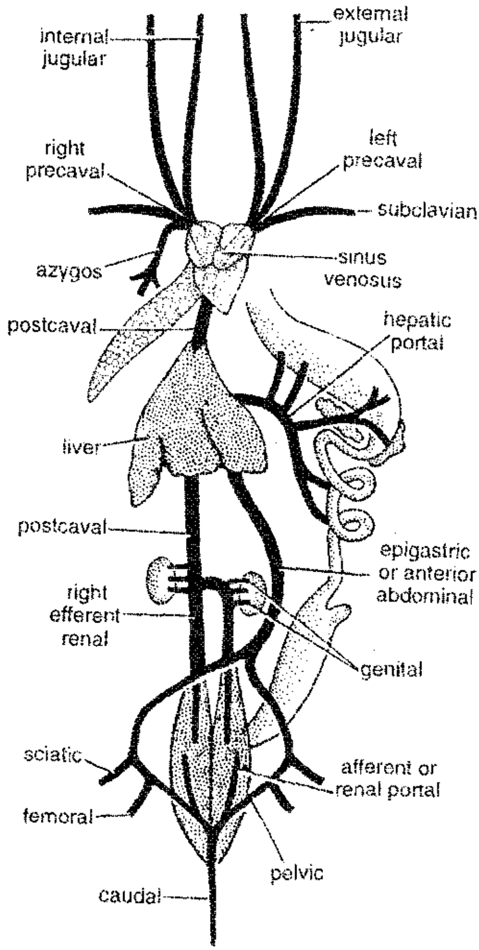


Fig. 6. *Calotes*. Venous system.

4. Hepatic portal system. A stout *hepatic portal vein* is formed by branches from stomach, intestine, pancreas, etc. It enters liver to break up into capillaries.

[IV] Blood

Blood of *Calotes* is similar in structure and function to that of frog.

Nervous and Sensory Systems

The nervous system (brain, cranial nerves) and sensory system (olfactory sacs, Jacobson's organs, eyes, ears) of *Calotes* are similar to those of *Uromastix*, which have already been described in detail in the previous chapter.

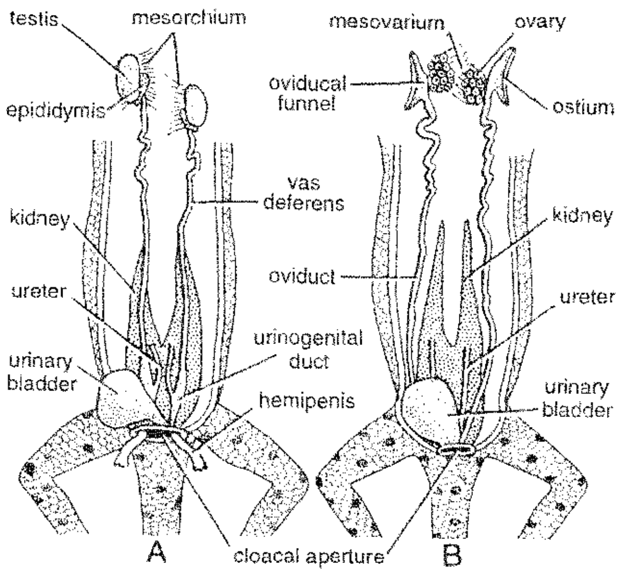


Fig. 7. *Calotes*. A—Male urinogenital system. B—Female urinogenital system.

Urinogenital System

As in all other vertebrates, the *excretory* and *reproductive* organs are closely associated forming the *urinogenital system*. Basically, it is similar to that of *Uromastix* (Fig. 7).

[I] Excretory system

The two metanephric *kidneys* are elongated, dark-red, flattened and lobed, lying in posterior region o a ominal cavity attac e , to orsal bodywall. Their narrower anterior ends remain free but broader posterior ends united forming a V-shaped structure. Histological structure of kidneys is identical with those of frog. From each kidney arises a short narrow duct, the *ureter*. In female it opens dorsally into urodaeum of cloaca independently. In male the ureter joins the vas deferens of its side to form the urinogenital duct. A thin-walled *urinary bladder* allantoic in origin, opens mid-ventrally into urodaeum of cloaca. *Calotes* is also *uricotelic* like *Uromastix*.

Periodic shedding of scales, the *ecdysis* is a feature of *Calotes*. It is seen that some nitrogenous metabolic wastes are also removed during ecdysis thus, ecdysis is also a process of excretion.

[II] Male reproductive system

A pair of oval white *testes* are situated quite ahead of kidneys, each suspended from dorsal bodywall by a peritoneal fold, the *mesorchium*. Right testis is somewhat larger and anterior in position. Histological structure is similar to those of frog. On the inner side of each testis is attached a long and much coiled tube, the *epididymis*, which receives *vasa efferentia* from testis. Epididymis is continued behind as a narrow and spirally twisted duct, the *vas deferens*. It joins with the ureter of its side forming the *urinogenital duct* before opening into cloaca. At the base of tail behind cloaca are present a pair of eversible and erectile copulatory sacs. During copulation, they protrude through the cloacal aperture as grooved *hemipenes* meant to transfer sperm of male into the cloacal cavity of female.

[III] Female reproductive system

The two whitish and irregularly lobulated *ovaries* remain attached to dorsal bodywall by peritoneal folds called *mesovaria*. The two *oviducts* are long, thin-walled tubes. Anteriorly, each oviduct opens into body cavity by a broad, ciliated *oviducal funnel*, and posteriorly into cloaca in front of the opening of ureter. The walls of oviducts are glandular and secrete albumen and shell of the eggs.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Describe the distribution, habitat, and external features of *Calotes versicolor*.
2. Give an account of arterial and venous system of *Calotes*.

» ***Short Answer Type Questions***

1. Describe the urinogenital system of *Calotes*.

» ***Multiple Choice Questions***

1. Which of the following is not a name of *Calotes* :
   (a) Wall lizard (b) Garden lizard
   (c) Girgit (d) Blood sucker
2. Teeth in *Calotes* are :
   (a) Hetrodont and monodont
   (b) Homodont and pleurodont
   (c) Hetrodont and acrodont
   (d) Hetrodont and thecodont
3. The precavals are formed by the union of :
   (a) Pulmonary veins
   (b) Azygous vein and juglar vein
   (c) Internal and external juglar and subclavian vein
   (d) Caudal vein and subclavian vein
4. In *Calotes* tunica media of heart is made of :
   (a) Ligaments (b) Skeletal muscles
   (c) Visceral muscles (d) Cardiac muscles

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d)

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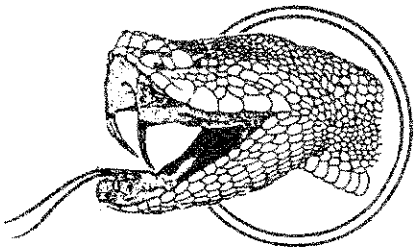

Snakes : General Account

Superstitions

Reptiles are probably the most misunderstood and universally disliked animals in the world since times immemorial. Snakes in particular are hated by all because these slippery, creeping creatures, dispatch man to his heavenly abode within seconds. It is true that bite of poisonous snakes is sometimes fatal, but most of them are harmless and even beneficial to man. Unfortunately, most of our fears about snakes are based on sheer ignorance and baseless superstitions. An interesting fallacy is regarding 'Ichhadhari' snakes who can transform into humans and vice versa at will, as often picturized by Indian cinema. It is also wrongly believed that image of the person killing a snake (cobra) is imprinted on the retina of dead snake, so that the living partner of snake can easily recognize the murderer and take revenge. It is also said that by performing certain rituals, the snake who had previously bitten a person, can be forced to appear physically and suck its own venom from the body of the victim who will recover at once. Even the americans believe in a mysterious hoop snake or 'whip snake' who keeps the end of its tail into mouth to become a ring or wheel that can roll after a person and stab in the back. It can chase a person even on a stair. Another snake is reputed to milk cattle. Some snakes are supposed to hypnotize birds. It is needless to emphasize that none of these superstitions is based on facts.

Locomotion

Snakes are limbless reptiles. Girdles and limb musculature have also disappeared along with the limbs. While all species are able to swim, they employ 4 types of locomotion of land (Fig. 1).

1. Lateral undulations. It is also called *curvilinear* or *serpentine locomotion*. Body is thrown into a series of lateral, horizontal curves which follow in the exact pathway. Swimming is also accomplished, as in fishes, by lateral undulation of body.

2. Rectilinear motion. It is used primarily by heavy-bodied snakes. Body undulates dorso-ventrally from head backward and snake

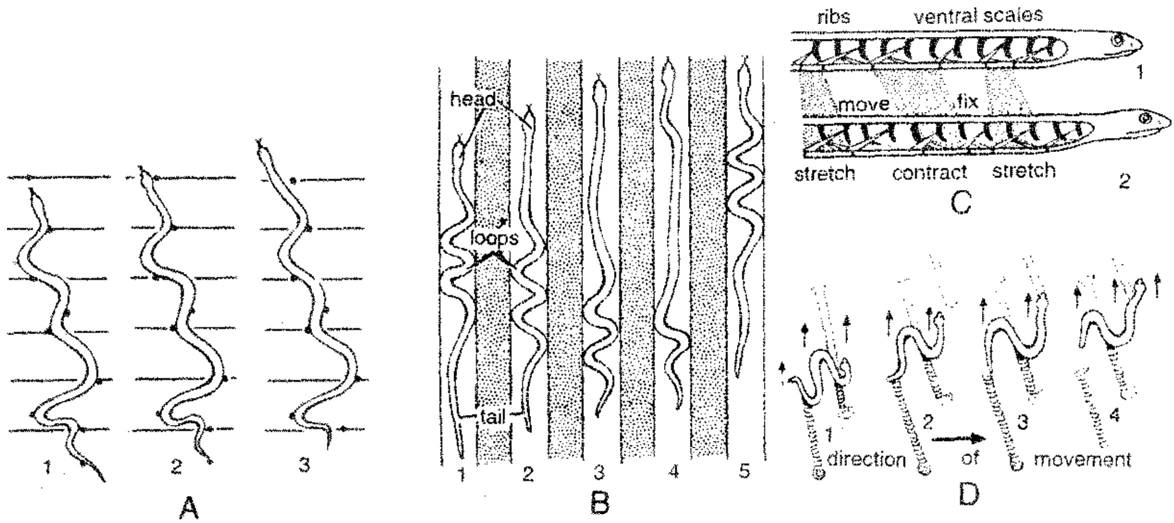

Fig. 1. Snakes. 4 common methods of locomotion. A—Serpentine movement. B—Concertina movement. C—Rectilinear or caterpillar crawl. D—Sidewinding.

moves forward in a straight line. Body is pulled forward in sections by well developed cutaneous muscles that originate on the ribs and insert on the broad ventral scales or scutes. The ribs serve as a series of internal legs while the ventral scales used in clinging like setae of an earthworm.

3. Concertina motion. It is used in a narrow place such as a rodent burrow. Tail is anchored to ground and body drawn into a series of S-loops. Body is pushed forward by straightening it, forming new loops and drawing the tail forward.

4. Sidewinding. It is used by snakes living in sand, such as the sidewinder (*Crotalus cerastes*), by a curious looping of body at right angles to its direction of travel.

Hearing

In sanskirit, snakes are known as चक्षुश्रवा meaning they can hear through eyes, which is however not correct. As they have no external ear openings, tympanic membranes, eustachian canals and middle ear cavities, they probably cannot hear air-borne sounds. The so-called dancing of a cobra to the tune of snake charmer's flute probably shows simple defensive posture against the movements of the charmer and his instrument. The ear of snakes includes an *internal ear* and a *columella auris*. Inner end of columella auris, plugs fenestra ovalis while outer end is attached to the middle of *quadrate* bone. This makes snakes sensitive to earth borne vibrations such as made by foot-steps. Sound-vibrations seem to travel along the jaws, quadrate, columella auris, fenestra ovalis and ultimately reach the perilymph of internal ear.

The tongue of snakes is slender, deeply-forked and lodged in a sac in the floor of mouth. It usually protrudes, even when mouth is closed, through an opening formed by the notches in two jaws. Besides a tactile olfactory organ, the tongue of snakes probably also serves as an auditory organ for picking up sound vibrations from earth.

Feeding Mechanism

Snakes do not chew their food but swallow it whole. They differ from lizards most notably in being capable to swallow animals larger than their own bodies. Several structural adaptations make this possible. (i) The two rami of lower jaw are loosely connected anteriorly by an elastic ligament which permits lateral expansion. (ii) The lower jaw is also loosely attached posteriorly to the quadrate bones which in turn are loosely attached to skull. (iii) Bones of the palate are also movable. These features allow the mouth to expand several times the diameter of the snake itself. (iv) The pectoral girdle is absent and (v) there is no sternum so that

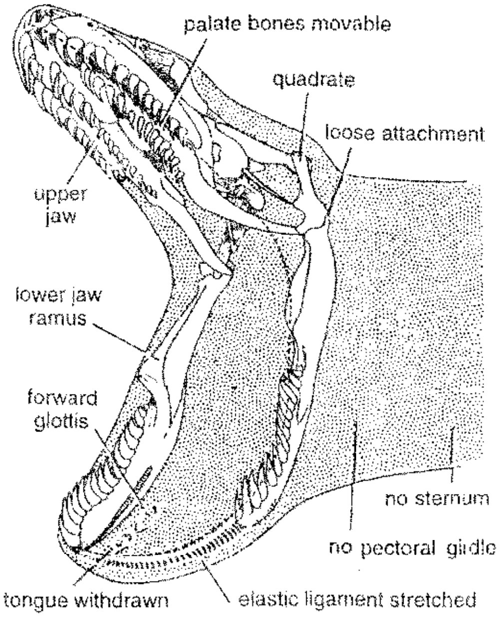

Fig. 2. Snake. Mechanism of swallowing large objects.

ribs are free ventrally. As a result the throat and body are also capable of great distention. (vi) The glottis is located far anterior in the floor of mouth, opening just behind the lower front teeth. Thus, breathing is not interfered with while swallowing. (vii) The cartilages of trachea prevent it from being closed so that air passage remains open for breathing while swallowing (Fig. 2).

During swallowing, their sharp teeth which curve inward prevent the prey from slipping forward. By moving the two sides of jaws alternately, the snake gradually pushes the prey down into its oesophagus through which it passes by peristaltic movements into stomach.

Poison Apparatus

All the poisonous snakes have *poison apparatus* in their heads, which is not found in non-poisonous snakes. This apparatus includes (i) a pair of poison glands, (ii) their ducts, (iii) fangs and (iv) muscles.

1. Poison glands. Two sac-like poison glands are situated one on either inner side of the upper jaw, below the eyes and somewhat behind them. These are possibly the modified *superior labial* or *parotid glands*. The glands may be small and oval (sea snakes) or large and tubular (vipers) depending on species. Poison gland is held in position with the help of ligaments. Anterior ligament attaches anterior end of the gland with maxilla and the posterior ligament runs between the gland and quadrate. Each gland is thickly encapsulated with fibrous connective tissue and mostly covered by a fan-shaped *constrictor muscle*, often referred to as *temporal* or *masseter*. Its stretching during biting squeezes poison from gland into its duct.

2. Poison ducts. A narrow poison duct leads anteriorly from each poison gland to the base of a poison fang to enter its groove or canal.

3. Fangs. Fangs are certain specialized teeth attached to maxillary bones. They are long, curved, sharp and pointed. They serve as hypodermic needles for injecting poison into the body of victim. When a functional fang is lost or

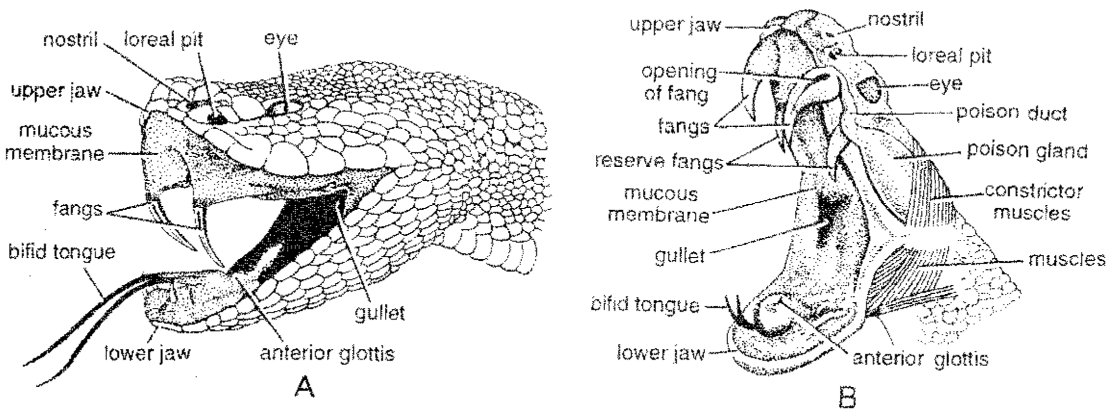

Fig. 3. Pit viper. A—Head of *Lachesis muta* (undissected). B—Head of rattle snake, *Crotalus*, dissected to display poison apparatus.

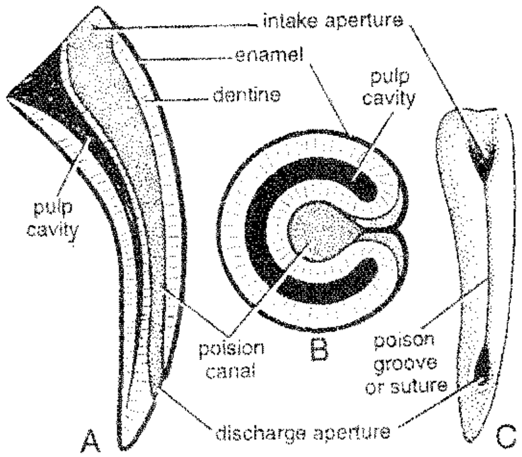

Fig. 4 Fangs. A—Solenoglyphous fang in L.S. B—Solenoglyphous fang in T.S. C—Entire grooved fang.

damaged, it is replaced by one of the reserved fangs. On the basis of structure and position 3 types of fangs occur in poisonous snakes :

(a) ***Solenoglyphous.*** In vipers and rattle snakes, a large functional fang occurs on the front of each maxilla. Its base is covered on all sides by a sheath containing a few reserve and developing fangs. The fangs are movable and turned inside to lie close to the roof of mouth when it is closed. A hollow poison canal, lined with enamel runs through the fang opening at the tip (*solen*, pipe + *glyph*, hollowed) (Fig. 4).

(b) ***Proteroglyphous.*** In cobras, kraits, coral snakes and sea snakes, fangs are small, at the front of maxillae and permanently erect. Each fang is grooved all along its anterior face (*protero*, first).

(c) ***Opisthoglyphous.*** In some poisonous snakes, in family Colubridae, fangs are small, lie at the back of maxillae and each grooved along its posterior border (*opistho*, behind).

Biting Mechanism

The skull and jaw bones of poisonous snakes are very flexible. They are loosely or movably articulated thus allowing a considerable degree of adjustment during the act of swallowing or striking. In cobras, the fangs are permanently erect. But in vipers, the large fangs lie against the roof of mouth when cl sed. T ere re, ec anis for biting serves two main purposes—(i) erection of fangs and (ii) injection of poison into the victim's body (Fig. 5).

When a viper wants to strike, a series of movements occur in a chain. Contraction of *digastric muscles* lowers the *mandible* so that mouth opens and lower end of *quadrate* thrusts forward. This in turn, pushes forward the *pterygoid*. This is also aided by the contraction of *sphenopterygoid muscles*. The forward pull of pterygoid in turn pushes the *transverse* or *ectopterygoid* upwards. This causes, the *maxilla* bearing fangs to rotate through 90° at the hinge-joint with lacrimal. As a result, the *fangs* become vertically erect and in the most effective position to strike. A simultaneous stretching of *constrictor muscles* around the poison gland, forces its poison through poison duct into the canal or groove of fang to be injected into the victim. When mouth is closed by the contraction of *temporal muscles*, the above movements are reversed. The fangs embed in the prey which is drawn into the mouth. At the same time the vertical fangs rotate to become horizontal.

Snake Venom

Snake venom or poison is secreted by certain poison glands found in the head of snakes and injected in the body of bitten prey through the fangs, serving as hypodermic needles. There is no doubt that venom evolved in snakes as an aid to capturing and subduing prey. It is a clear sticky liquid of faint yellow or greenish colour. It is tasteless and odourless and acidic in reaction. It is a complex mixture of enzymes and specific toxins and is a good digestive juice. It is fatal only when mixed in blood. It can be swallowed and if there is no scratch in mouth or alimentary tract, it will pass out with faeces without doing any harm. It is precipitated in reagents such as silver nitrate and potassium permanganate. It can be dried and kept indefinitely, retaining its poisonous properties. It can be dissolved in water, salt solution or glycerine when it is equally poisonous. Most snake venoms consist of both neurotoxic and haemotoxic

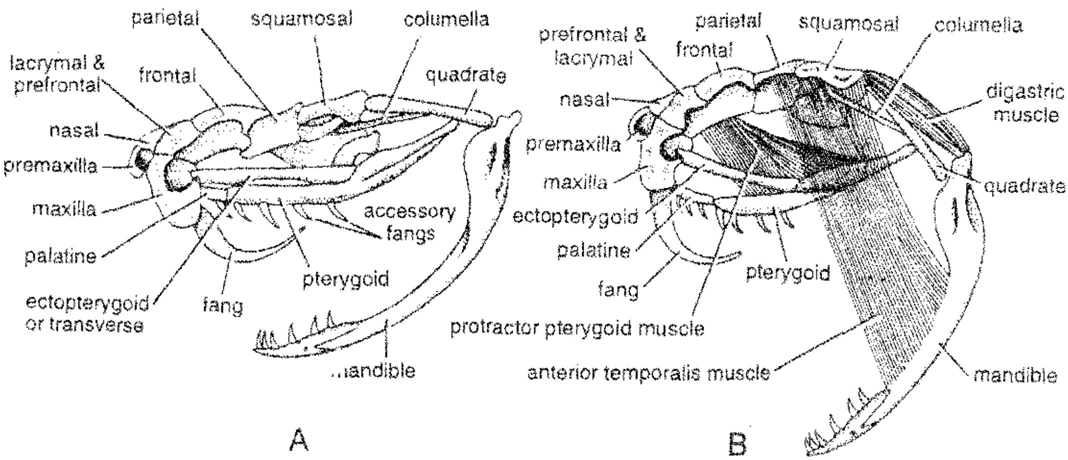

Fig. 5 Skull of a viper showing biting mechanism. A—Mouth closed at rest. B—Mouth opened when striking.

factors. In some, one of the factors predominates. The venom of viper contains an *endotheliotoxin* (*haemorrhagin*) which damages the capillary endothelium and produces haemorrhages in various tissues and also some toxin which leads to failure of peripheral circulation with marked fall in blood pressure by paralysing the neuromuscular junction of the vasoconstractor muscles. It also contains a *thromboidnase* which causes intravascular clotting if it happens to enter directly into the vein during the bite. The venom of debsia contains an enzyme which helps in the formation of *lysocythin* which causes extensive local damage. A *cardiotoxin* has also been isolated in snake venom which causes damage to the heart. In general the venom of vipers acts principally on the vascular system while the venom of cobras acts upon nervous system. A class of enzymes Hyabronidases help in the rapid absorption of venom. Proteases cause local inflammation, necrosis and damage to vascular epithelium.

Symptoms of Snake Bite (Effect of Venom)

The venom of different snakes has its own characteristic effect. Degree of virulence differs not only in different snakes but in the same snake under different circumstances. The bitten person may die or recover depending upon the amount injected and its virulence. It is customary to regard two categories of snake venoms—neurotoxic and haemotoxic. *Neurotoxins* are typical of elapids (cobra, krait) and sea snakes. They cause death by paralysis of respiratory muscles and asphyxiation. *Haemotoxins* are typical of vipers. They cause tissue destruction and widespread haemorrhage. The effects of venom or symptoms of snake bite in case of 3 most common poisonous snakes of India are as follows :

1. Cobra bite. Poison of cobra is most virulent. It is a neurotoxin, attacking nerve centres and causing paralysis of muscles, especially those of respiratory muscles. Symptoms include piercing pain and burning sensation, ending in numbness of bitten part which turns bluish or blackish. Person suffers from giddiness, weakness in legs, high pulse rate, speechlessness, drooping of saliva and eyelids, contraction of pupils, vomiting (nausea) and laboured breathing. Death results within a few hours due to failure of respiration (asphyxia) or of heart activity.

Late Prof. K.N. Bahl described cobra poisoning by the word CO-BRA, indicating that spinal cord (CO) and brain (BRA) are affected. Coagulation of blood (COB) is reduced (R) so that wound bleeds for hours and death occurs by asphyxia (A) as respiratory centres of brain are destroyed.

2. Krait bite. Kraits are most commonly found and dangerously poisonous snakes because their bite injects a very large quantity of poison (three times more than cobra's). Symptoms are very similar to those of cobra bite, except that the victim complains of unbearable abdominal pain due to internal haemorrhage. Destruction of RBC (*haemolysis*) and paralysis of trunk and limbs occur followed by death within 6 to 24 hours.

3. Viper bite. Venom of viper is mainly a haemotoxin affecting the circulatory and nervous systems more severely. Symptoms include local welling and discolouration of bitten part with acute burning pain. A red fluid, oozes out from wound due to massive tissue destruction (*necrosis*) which frequently necessitates amputation. Pupils dilate, pulse rate increases, profuse vomiting occurs and person loses consciousness. Death may result due to paralysis of vaso-motor centres and exhaustion from profuse bleeding.

Antivenin (Cure of Snake Bite)

The best cure for snake bite is an *antivenom serum* or *antivenin* which is injected into the body of the victim to counteract snake venom. Different antivenins are required against different snakes due to differences in the qualities of their venoms. An antivenin is prepared by injecting a horse with gradually increasing doses of a snake venom until the horse becomes fully immunized to any amount of venom injected. Now blood serum of horse is collected and preserved. This is antivenom serum or antivenin which has developed sufficient antibodies to neutralize the effect of that particular snake venom.

First-aid Treatment of Snake Bite

First aid treatment includes emergency care of the victim of snake bite before complete medical or surgical treatment can be secured. The following first aid methods are recommended by experts :

1. Psychological. The fright or fear due to snake bite may cause heart failure and death even if the snake was non-poisonous. Therefore, the victim should first of all be treated psychologically with reassuring and encouraging words.

2. Torniquet. A torniquet or ligature should be immediately tied on the bitten limb towards heart by any suitable available material such as a handkerchief, piece of cloth, rubber tube, cord, etc. This prevents or delays circulation of poison in the body. However, the torniquet must not be applied very tightly and should be removed for a few minutes in between.

3. Care of wound. Wound should be washed with clean water. Application of potassium permanganate to wound should be avoided. An incision, about 1 cm deep, should be made near the wound with a clean sterilized blade or knife. This will let out some poison with blood. Poison may also be sucked out by a suction cup and not by mouth. X-shaped cuts should be avoided as they require longer time for healing. Some experts do not recommend incision which may lead to infection. The bitten part should be cooled with ice to slow down blood circulation and spread of poison.

4. Care of person. Anything causing excitement or exertion to the victim should be avoided. Alcoholic beverages should be avoided. Instead, the victim may be served with hot milk, coffee or tea. The victim should be shifted immediately to a hospital or a qualified doctor for treatment with an antivenin injection.

Distinction Between Poisonous and Non-poisonous Snakes of India

Most of the Indian snakes are non-poisonous and harmless creatures. Of 330 Indian species only 69 are poisonous comprising 29 species of sea snakes and 40 species of land snakes. The poisonous snakes have a poison apparatus in head and a pair of larger teeth or fangs in upper jaw. When they bite, there may be two large circular punctures made by the fangs on the skin of the victim. But non-poisonous snakes have neither poison

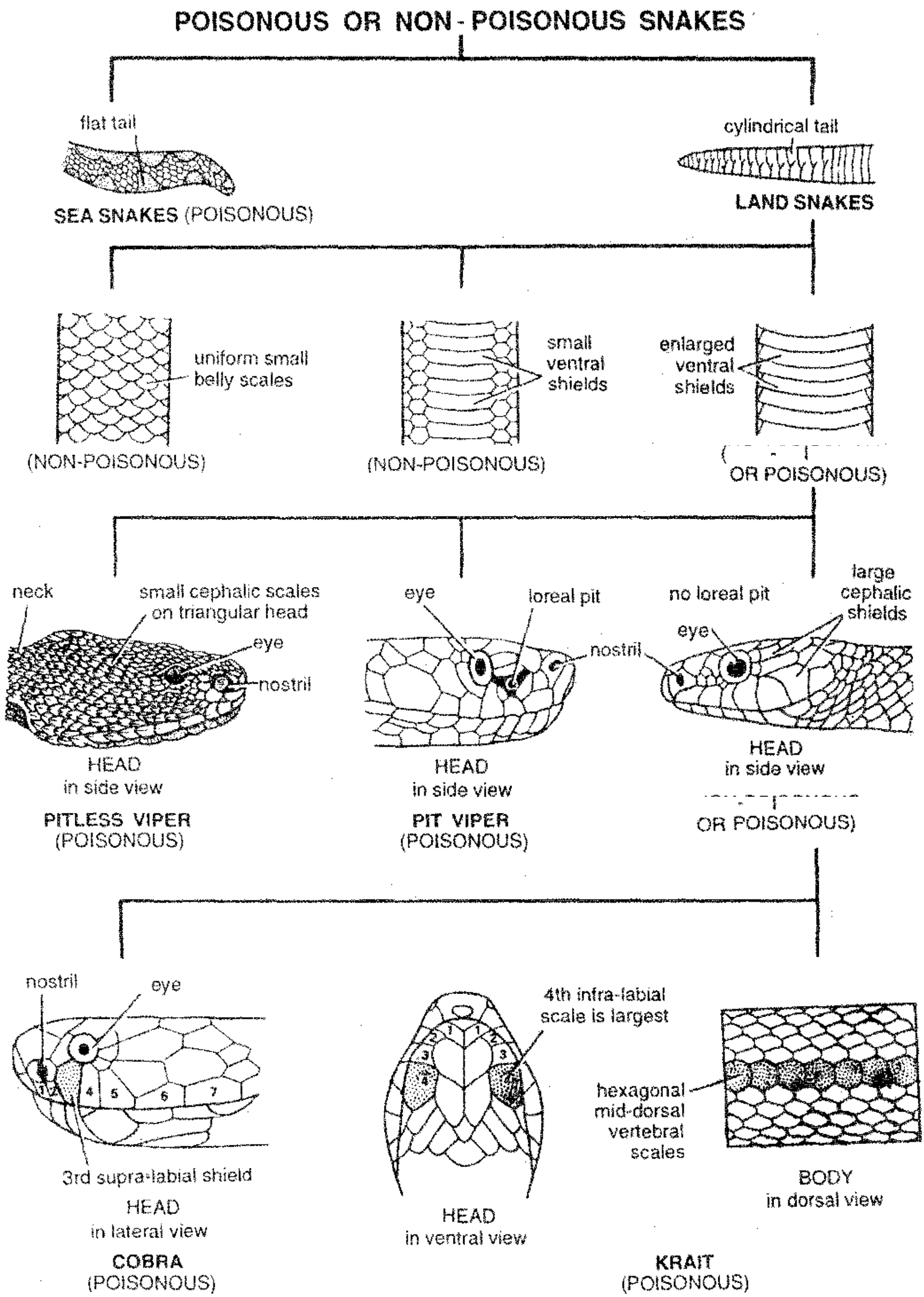

Fig. 6. Diagrams for identification of poisonous and non-poisonous snakes.

Table 1. Key to Identify Poisonous from Non-poisonous Snakes of India.

Structures		Characters	Nature	Snakes
1. Tail	(a)	Tail laterally compressed, oar-like	**Poisonous**	Sea snakes *Hydrophis, Enhydrina*
	(b)	Tail cylindrical, tapering	Poisonous or nonpoisonous Examine further	Land snakes
2. Belly scales or ventrals	(a)	Belly scales small, continuous with dorsals	Non-poisonous	
	(b)	Ventrals not fully broad to cover belly	Non-poisonous	Pythons
	(c)	Ventrals broad, fully covering belly	Examine further	
3. Head scales, loreal pit, sub-caudals	(a)	Head scales small. Head triangular. No loreal pit	**Poisonous**	Pitless vipers
		(i) Subcaudals double	"	*Vipera russelli*
		(ii) Subcaudals single	"	*Echis carinata*
	(b)	Head scales small. A loreal pit present between nostril and eye	**Poisonous**	Pit vipers *Lachesis, Ancistrodon*
	(c)	Head with large shields. No loreal pit	Examine further	
4. Vertebrals, 4th infralabial, 3rd supralabial	(a)	Vertebrals enlarged, hexagonal 4th infra-labial largest	Poisonous	Krait, *Bungarus*
	(b)	Vertebrals not enlarged. 3rd supra-labial touches eye and nostril	Poisonous	
		(i) Neck with a hood and spectacle mark	"	Cobra, *Naja*
		(ii) Hood absent. Coral spots on belly	"	Coral snakes, *Callophis*
	(c)	No such characters	Nonpoisonous	

apparatus nor fangs. When they bite, they leave many small pricks only. Some of the most common Indian poisonous snakes are cobras, kraits, pitvipers, vipers and sea snakes. It is easy to distinguish them from non-poisonous ones on the basis of the shape of their *tails* and the size and arrangement of *scales* and *shields* on their body. A simple and workable key for identification of Indian poisonous and nonpoisonous snakes is given in the Table 1 (Fig. 6).

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Describe the biting mechanism of a poisonous snake. How is a snake able to swallow animals much larger than the normal size of its mouth ?

» ***Short Answer Type Questions***

1. Differentiate between a poisonous and a non-poisonous snake.
2. Give zoological names and characters of poisonous snakes of your locality.

» *Multiple Choice Questions*

1. Lateral undulation are used by snakes in :
   (a) Serpentine locomotion
   (b) Forward locomotion
   (c) Locomotion in burrows
   (d) Locomotion in sand
2. Snakes are sensitive to :
   (a) Noises made by birds
   (b) Earth borne vibrations
   (c) Thunder
   (d) Air borne vibrations
3. Which of the following is incorrect for snakes :
   (a) The two rami of the lower jaw joined together by elastic ligament permit lateral expansion
   (b) Bones of palate are movable
   (c) Pectoral girdle is present
   (d) Ribs are free ventrally
4. Solenoglyphous is found in :
   (a) Family Colubridae
   (b) Cobras and Kraits
   (c) Coral snakes and sea snakes
   (d) Viper and rattle snake
5. Which is not true for COBRA
   (a) A = Altered
   (b) CO = Spinal cord
   (c) BRA = Brain
   (d) COB = Coagulation of blood

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a)

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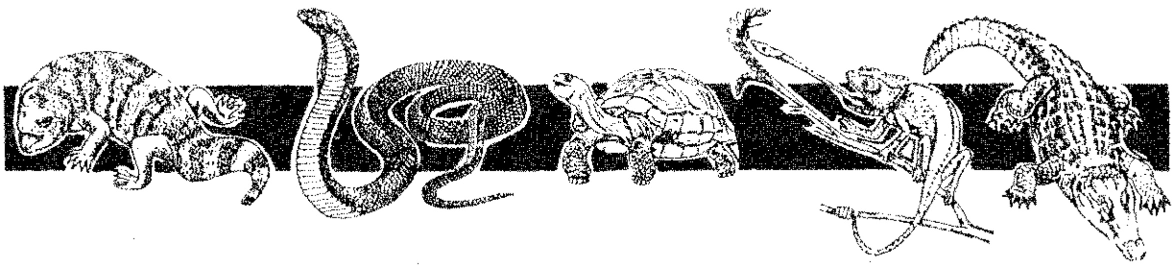

Class 7. Reptilia

General Characters

Reptiles represent the first class of vertebrates fully adapted for life in dry places on land. They have no obvious diagnostic characteristics of their own that immediately separate them from other classes of vertebrates. The characters of reptiles are in fact a combination of characters that are found in fish and amphibians on one hand and in birds and mammals on the other. The class name refers to the mode of locomotion (L., *repere* or *reptum*, to creep or crawl), and the study of reptiles is called *Herpetology* (Gr., *herpeton*, reptiles).

1. Predominantly terrestrial, creeping or burrowing, mostly carnivorous, air-breathing, cold-blooded, oviparous and tetrapodal vertebrates.
2. Body bilaterally symmetrical and divisible into 4 regions—head, neck, trunk and tail.
3. Limbs 2 pairs, pentadactyle. Digits provided with horny claws. However, limbs absent in a few lizards and all snakes.
4. Exoskeleton of horny epidermal scales, shields, plates and scutes.
5. Skin dry, cornified and devoid of glands.
6. Mouth terminal. Jaws bear simple conical teeth. In turtles teeth replaced by horny beaks.
7. Alimentary canal terminates into a cloacal aperture.
8. Endoskeleton bony. Skull with one occipital condyle (monocondylar). A characteristic T-shaped interclavicle present.
9. Heart usually 3-chambered, 4-chambered in crocodiles. Sinus venosus reduced. 2 systemic arches present. Red blood corpuscles oval and nucleated. Cold-blooded.
10. Respiration by lungs throughout life.

11. Kidneys metanephric. Excretion uricotelic.
12. Brain with better development of cerebrum than in Amphibia. Cranial nerves 12 pairs.
13. Lateral line system absent. Jacobson's organs present in the roof of mouth.
14. Sexes separate. Male usually with muscular copulatory organ.
15. Fertilization internal. Mostly oviparous. Large yolky meroblastic eggs, covered with leathery shells, always laid on land. Embryonic membranes (amnion, chorion, yolk sac and allantois) appear during development. No metamorphosis. Young resemble adults.
16. Parental care usually absent.

Classification

According to Bogert, there are more than 7,000 living and several extinct species of reptiles, grouped into approximately 16 orders of which only 4 are living. The class Reptilia is first divided into 5 major groups or *subclasses* on the basis of presence or absence of certain openings through the posterolateral or temporal region of the skull (Fig. 1).

Subclass I. Anapsida

Primitive reptiles with a solid skull roof. No temporal openings.

Order 1. Chelonia or Testudinata
(Gr., *chelone*, turtle; L., *testudo*, turtle)

1. Body short, broad and oval.
2. Limbs clawed and/or webbed, paddle-like.
3. Body encased in a firm shell of dorsal carapace and ventral plastron, made of dermal bony plates. Thoracic vertebrae and ribs usually fused to carapace.

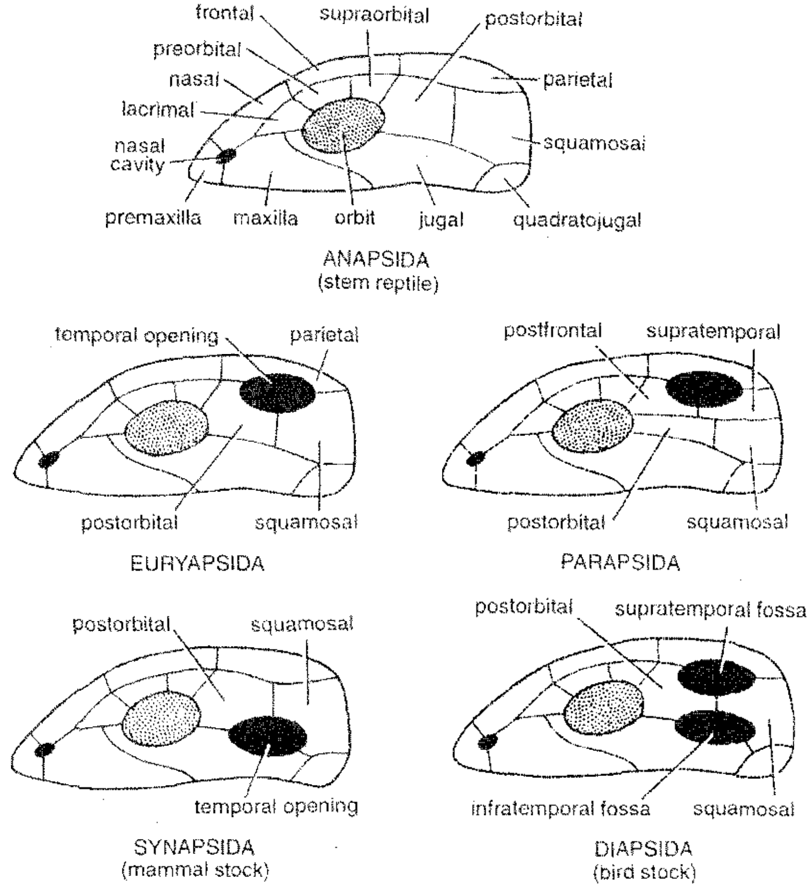

Fig. 1. Five types of skulls in lateral view in 5 subclasses of reptiles.

4. Skull anapsid, with a single nasal opening and without a parietal, foramen. Quadrate is immovable.
5. No sternum is found.
6. Teeth absent. Jaws with horny sheaths.
7. Cloacal aperture a longitudinal slit.
8. Heart incompletely 4-chambered with a partly divided ventricle.
9. Copulatory organ single and simple.
10. About 400 species of marine turtles, freshwater terrapins and terrestrial tortoises.

Examples : *Chelone, Chrysemys, Testudo, Trionyx, Dermochelys.*

Subclass II. Euryapsida (extinct)

Skull with a single dorso-lateral temporal opening on either side, bounded below by postorbital and squamosal bones.

Subclass III. Parapsida (extinct)

Skull with a single dorso-lateral temporal opening on either side bounded below by the supratemporal and postfrontal bones.

Subclass IV. Synapsida (extinct)

Skull with a single lateral temporal opening on either side bounded above by the postorbital and squamosal bones.

Subclass V. Diapsida

Skull with two temporal openings on either side separated by the bar of postorbital and squamosal bones.

Order 2. Rhynchocephalia

(L., *rhynchos*, snout + Gr., kephale, head)

1. Body small, elongated, lizard-like.
2. Limbs pentadactyle, clawed and burrowing.
3. Skin covered by granular scales and a mid-dorsal row of spines.
4. Skull diapsid. Nasal openings separate. Parietal foramen with vestigeal pineal eye present. Quadrate is fixed.
5. Vertebrae amphicoelous or biconcave. Numerous abdominal ribs present.
6. Teeth acrodont. Cloacal aperture transverse.
7. Heart incompletely 4-chambered.
8. No copulatory organ in male.

Example : Represented by a single living species, the "tuatara" or *Sphenodon punctatum* of New Zealand.

Order 3. Squamata

(L., *squama*, scale or *squamatus*, scaly)

1. Advanced, small to medium, elongated.
2. Limbs clawed, absent in snakes and few lizards.
3. Exoskeleton of horny epidermal scales, shields and spines.
4. Skull diapsid. Quadrate movable.
5. Vertebrae procoelous. Ribs single—headed.
6. Teeth acrodont or pleurodont.
7. Heart incompletely 4-chambered.
8. Cloacal aperture is transverse.
9. Male with eversible double copulatory organs (hemipenes).

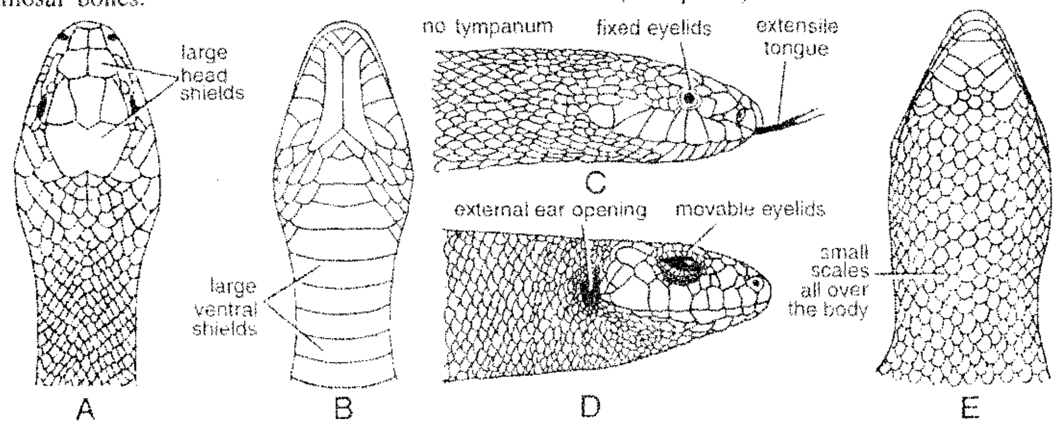

Fig 2. Comparison of snakes and lizards. Head of a snake in dorsal (A), ventral (B) and lateral (C) views. Head of a lizard in lateral (D) and ventral (E) views.

***Table 1.* Differences between Snakes and Lizards.**

	Suborder 1. Lacertilia or Sauria (Lizards)		Suborder 2. Ophidia or Serpentina (Snakes)
1.	Body elongated, lizard-like.	1.	Body slender, narrow, snake like.
2.	Limbs and girdles usually well-developed.	2.	Absent, vestigial hind limbs and pelvic girdle in boa, python, etc.
3.	Eyelids movable. Nictitating membranes present.	3.	Eyelids fixed. Nictitating membranes absent.
4.	Ear openings and tympanum present.	4.	Auditory openings and tympanum lost.
5.	Maxillae, palatines and pterygoids fixed.	5.	These skull bones freely movable helping in biting mechanism.
6.	Two rami of mandible firmly united anteriorly. Mouth non-expansible.	6.	Mandibular rami joined by an elastic ligament and can be widely separated during swallowing of large prey.
7.	Sternum, episternum and urinary bladder usually present.	7.	These are absent.
8.	Premaxillae bear conical teeth.	8.	Premaxillae are toothless.
9	Tongue rarely notched or extensile.	9.	Tongue slender, bifid and extensile.
10.	Caudal autotomy with regeneration in some.	10.	Caudal autotomy does not occur.
11.	Both lungs equally developed.	11.	Left lung greatly reduced.
12.	About 3,800 living species.	12.	About 3,000 living species.
13.	Single occipital condyle.	13.	Occipital condyle distinctly triple.
14.	Jugal bone present.	14.	Absent.
15.	Cerebral hemispheres are short.	15.	Extremely elongated and project between the eyes.
16.	Cranial nerves 12 pairs.	16.	10 pairs only.
	Examples : *Hemidactylus, Calotes, Uromastix, Varanus, Chamaeleon, Draco, Heloderma, Iguana, Ophisaurus*, etc.		Examples : *Typhlops, Python, Boa, Lycodon, Eryx, Naja, Bungarus, Vipera, Hydrophis, Crotalus*, etc.

10. About 6,800 species of lizards and snakes. These are divided into 2 distinct suborders—Lacertilia and Ophidia—with contrasting characters, as shown in the Table 1.

Order 4. Crocodilia

(G., *krokodeilos*, Crocodile)

1. Large-sized, carnivorous and aquatic reptiles.
2. Tail long, strong and laterally compressed.
3. Limbs short but powerful, clawed and webbed.
4. Skin thick with scales bony plates and scutes.
5. Skull diapsid. Quadrate immovable. No parietal foramen. A pseudopalate present.
6. Ribs bicephalous. Abdominal ribs present.
7. Teeth numerous, thecodont, lodged in sockets.
8. Heart completely 4-chambered.
9. Cloacal aperture is a longitudinal slit.
10. Male with a median, erectile, grooved penis.

Examples. *Crocodylus, Gavialis, Alligator.*

Other Reptilia

[I] Turtles and tortoises

The names 'turtles' and 'tortoises' are often used interchangeably. However, the term *turtle* is usually applied to the aquatic or semiaquatic forms and *tortoise* to land forms, whereas *terrapin* is reserved for some edible freshwater species. They are ancient reptiles that have remained relatively unchanged for 175 million years since Triassic. They show the greatest departure from the typical reptilian plan. However, they are easily identified by their armoured *shell* of bony plates consisting of a dorsal *carapace* and a ventral *plastron*. Their limbs are heavy as required for carrying about the unusually heavy body. When the animal is threatened with danger, the head and neck, limbs and tail are withdrawn into the shell. Teeth are absent in all turtles being replaced by a horny beak-like structure. Although they breathe by

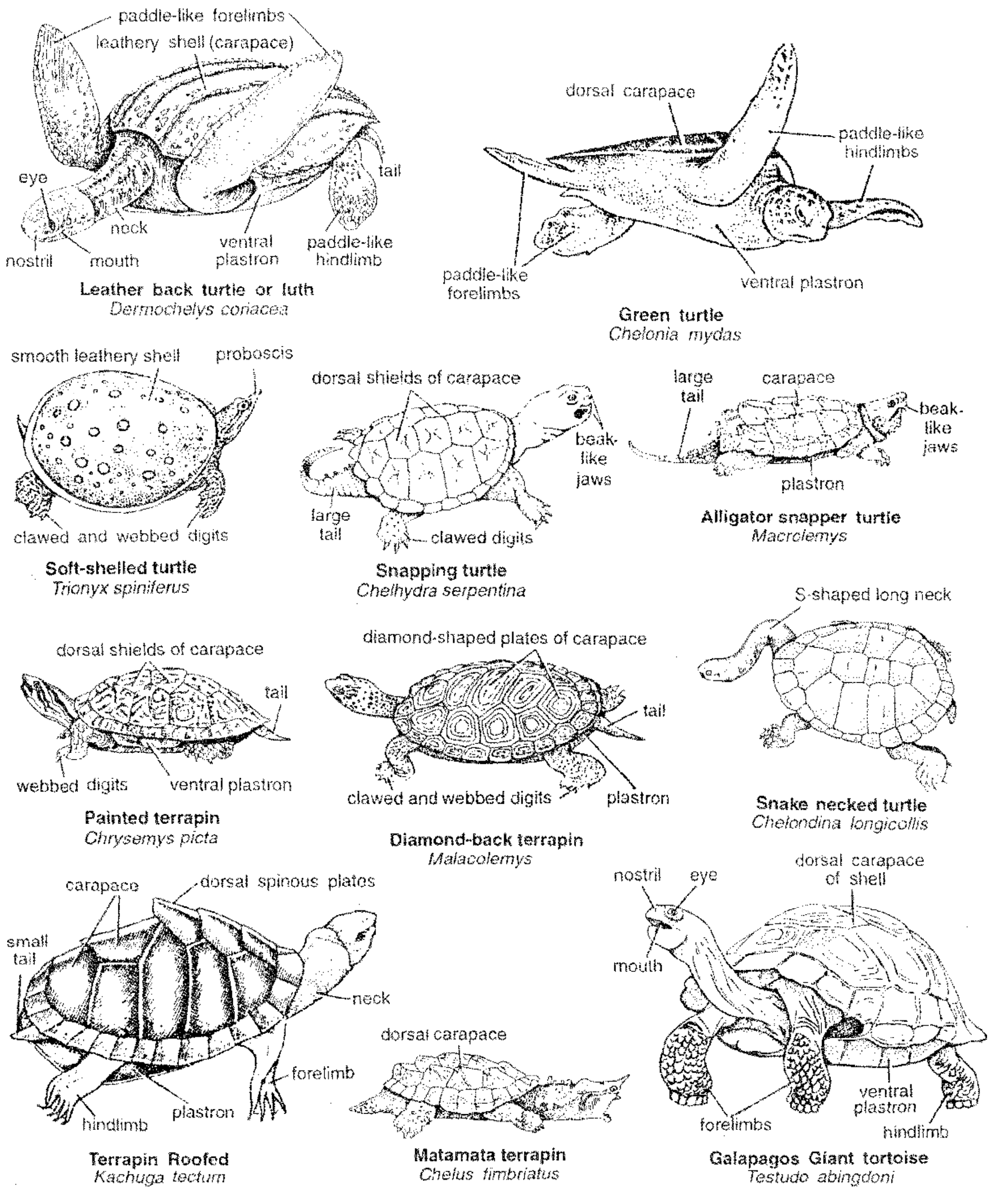

Fig. 3. Turtles and tortoises (Order Chelonia).

lungs, they may remain under water for a considerable time. Air is pumped into lungs by movements of neck and legs. Some aquatic forms (*Emys*) have vascular thin-walled cloacal sacs for aquatic respiration when submerged. In temperate climates, all turtles hibernate during colder days but in tropical countries, they aestivate during hotter months. All turtles are oviparous and the eggs, nearly spherical with calcareous shells, are deposited in nests in ground. Aquatic forms have reduced shells and limbs modified as flippers or paddles without claws for swimming. Sea turtles also reach a large size due to buoyant character of environment. The leatherback turtle, *Dermochelys coriacea*, also found along the coast of Kerala, is the largest of all. It may reach a length of 2.5 meters and attain a weight of 600kg. The green or edible sea turtle, *Chelonia mydas*, also common in Bay of Bengal, may grow to 1.2 meters and weigh 200 kg. It is greatly prized for soup. The aquatic soft-shelled turtles (*Trionyx, Amyda*) also have smooth leathery shells without shields. Their snout forms a short proboscis. *Trionyx gangeticus* is common in the rivers of N. India, while *T. leithi* in S. India. The snapping turtles (*Chelhydra serpentina*) and alligator turtles (*Macrolemys*) are carnivorous predators feeding on fish, frogs, waterfowls, etc. with powerful jaws. They are dangerous to handle for they strike with lightening speed and hold on with fierce tenacity. The painted turtle or terrapin (*Chrysemys picta*), with bright yellow, black and red colours, feeds on insects near the surface of water in ponds. The diamond-back terrapin (*Malaclemys*) is famous as food for man. It derives its common name from the markings on its shell. In *Kachuga* represented by several species in Indian rivers, the carapace bears spinous plates. The snake turtles have extremely long necks. In the side-necked turtle of Australia (*Chelodina longicollis*), the neck is folded in a lateral S-shaped bend. The matamata (*Chelus*) of America and Africa is the most bizarre side-necked freshwater turtle. A common land tortoise is *Testudo*. The giant land tortoise (*Testudo abingdoni*) of Galapagos Islands in Pacific Ocean and Islands of Indian Ocean weighs over 100kg and attains an estimated age of 200 to 400 years.

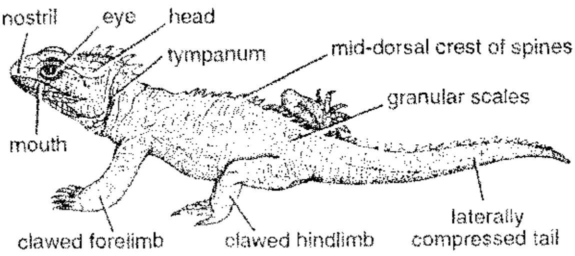

Fig. 4. *Sphenodon punctatum*, the Tuatara.

[II] Rhynchocephalia (*Sphenodon*)

Distribution. The order Rhynchocephalia, which has many fossil forms, is represented by a single living species, *Sphenodon punctatum* of New Zealand, commonly called 'Tuatara' or 'Hatteria' by the native maories. It was formerly found throughout New Zealand, but the advent of man and his associates—cats, dogs, rats, sheep and goats, pigs, etc.—exterminated it in the main Islands. This 'living fossil' is now restricted to some small neighbouring islands, in the Bay of Plenty, North Island. It is regarded to be the oldest known living reptile as fossils identical to tuatara can be traced back to the Jurassic or Permian. While all its relatives are long since extinct, it has survived in isolation due to absence of natural enemies in its present home (Fig. 4).

Habits and habitat. *Sphenodon* is burrowing, carnivorous and nocturnal in habits. It lives in small holes or burrows in rocks associated with petrels (birds) or in water. It feeds largely on invertebrates (worms, insects, spiders, molluscs) and fish, with an occasional gecko or baby seabird for variety. It is sluggish and crawls about slowly, stopping frequently to look around. During the day it basks in the sun to raise its body temperature. About 10 eggs, with hard white shells, are laid in spring in holes in ground and require more than a year to develop and hatch. Life span in captivity is 50 years. To prevent their total extinction, tuatara are strongly protected under law by the Government of New Zealand.

External features. Elongated lizard-like body measures about 70cm in length. It weighs upto 1 kg. If bears a long, bilaterally compressed and crested tail and 2 pairs of rather weak, pentadactyl, clawed limbs. If lost the tail can regenerate like lizards, but power of regeneration is slow. Colour is dull olive green with yellow spots above and white below. The upper surface is covered by small granular scales and bears a mid-dorsal crest or frill of spines. Lower surface is covered by large squarish plates, arranged in transverse rows. Eyes are large, dark-brown and with vertical pupil. Cloacal aperture is transverse and male is without copulatory sacs.

Pineal or parietal eye. An interesting feature of *Sphenodon* is the presence of a *pineal* or *parietal* or *third eye*. On the forehead, in the centre of a rosette of scales occurs a transparent scale, below which exists a small eye, lodged in the parietal foramen of skull. It has a lens, pigmented retina and supplied by a nerve from brain. Some lizards possess a similar median eye but without nerve supply. In all other living vertebrates, the pineal eye is vestigeal. It is believed to have functioned in types now extinct.

Lacertilian characters. Tuatara *resembles* a lizard in (i) general body form, (ii) elongated compressed tail, (iii) clawed pentadactyl limbs, (iv) pineal eye, (v) single-headed ribs, (vi) chevron bones in caudal vertebrae, and having (vii) similar heart, lungs and brain.

But it differs from lizards in having (i) an extra temporal vacuity (postemporal) in skull, (ii) mandibular rami united by an elastic ligament, (iii) immovable quadrate, (iv) amphicoelous vertebrae, (v) proatlas between skull and atlas, (vi) persistent notochord, (vii) uncinate processes on ribs, (viii) abdominal ribs, (ix) ten bones in carpus, and (x) in the absence of pecten in eye and copulatory sacs in male.

Crocodilian characters. Tuatara *resembles* crocodiles (also Chelonia and dinosaurs in most features) in the possession of (i) palate, (ii) immovable quadrate, (iii) proatlas, (iv) uncinate processes, (v) abdominal ribs, and (vi) chevron bones.

On the other hand, it *differs* from them in the absence of (i) thecodont teeth, (ii) procoelous vertebrae, (iii) 4-chambered heart, (iv) pecten in eye, (v) copulatory organ, and (vi) in the presence of clavicles.

Systematic position. *Sphenodon* is appropriately referred to as a 'living fossil' because it has retained many primitive characteristics of fossil or stem reptiles belonging to the Permian period and has changed little through the past 200 million years. Some of these *primitive characters* are : (i) median pineal eye, (ii) widely roofed mouth, (iii) three temporal bridges in skull, (iv) forward extension of pterygoid to meet vomer as in stegocephalians, (v) amphicoelous vertebrae with persistent vestiges of notochord, (vi) abdominal ribs, (vii) emergence of 3 aortic arches from a short common trunk comparable to conus arteriosus of Amphibia, (viii) retention of ductus caroticus as well as ductus arteriosus, and (ix) absence of copulatory organs in male.

Inspite of its primitiveness, *Sphenodon* is neither a degenerate nor an ancestral form. Rather, it is a highly modified type that has persisted from earlier times (Permian) as such. It resembles as well as differs from orders Squamata and Crocodilia in many respects. Therefore, it is quite reasonable to place it under a separate order of its own, the *Rhynchocephalia*.

[III] Lizards

The order Squamata includes the modern lizards and snakes. The lizards are the most typical of the modern reptiles, showing the least modification in body form. They usually have an elongate body, a long tail and 4 well-developed clawed pentadactyl limbs adapted for running, climbing and digging. The skin is usually covered with small scales. The tail of most lizards is easily broken off when threatened or seized by a predator. This ability is known as *autotomy*. A new tail is soon regenerated which, however, does not possess vertebrae. The fact that tail breaks up easily is of great survival value. While the predator is attracted to and eats

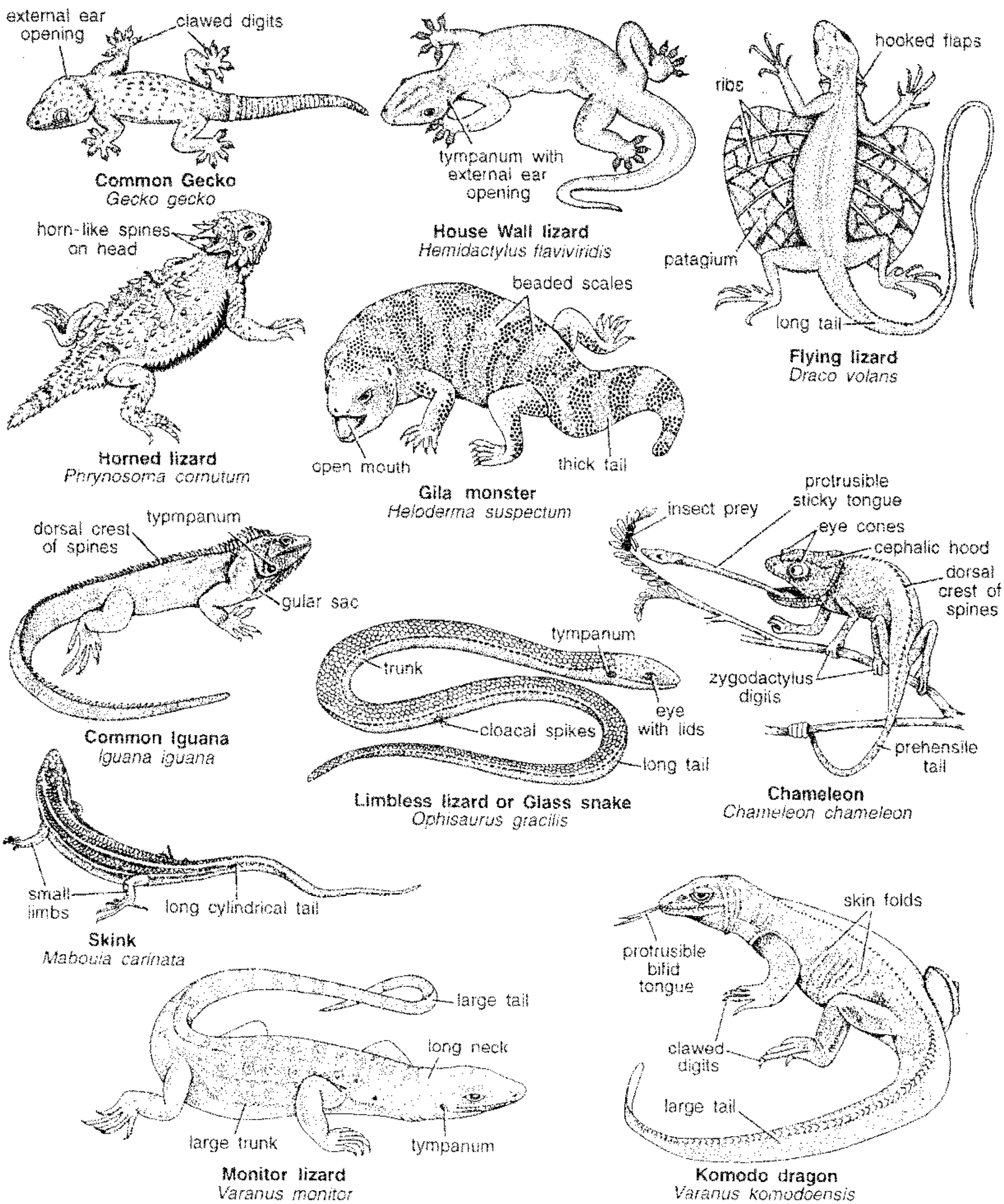

Fig. 5. Some common and interesting lizards (Suborder Lacertilia).

the wriggling tail, the lizard quietly escapes. The majority of lizards are carnivorous, feeding largely on insects, worms and other small animals. Most lizards are oviparous. Their eggs, protected by thin shells with little lime, are laid on land. Lizards are extremely diversified and some common and interesting examples are as follows (Fig. 5) :

1. *Hemidactylus.* Common house or wall lizards are known as geckos. These are small lizards, about 30 cm in length having tails shorter than head and trunk. Eyes lack movable lids and tongue is sticky and protrusible. The underneath of fingers and toes have adhesive lamellae which aid in climbing vertical surfaces or walking across ceilings by creating suction by vacuum. Unlike most lizards some geckos are vocal, making clicking and peeping sounds. Common North Indian gecko is *Hemidactylus flaviviridis*, while *H. brooki* and *H. giganticus* occur in South India.

2. *Draco.* *Draco* is the Indo-Malayan genus of the so-called flying dragons. It is a small brilliantly coloured lizard with a very long tail and well-developed limbs for running and climbing. Either lateral side of body has a thin semicircular membranous parachute-like fold of skin, or *patagium*, supported by 4 or 5 pairs of extended ribs. It can be spread out and used for gliding from tree to tree, and folded when not in use. A vertical narrow gular pouch hangs down from the middle of throat. *D. dussumieri* is common in the forests of Kerala.

3. *Phrynosoma.* The horned-lizard *Phrynosoma* is erroneously named the 'horned-toad'. It is a flat spiny lizard of U.S.A. and Mexico, showing desert adaptations. Its grotesque spines give it a formidable appearance with 2 enlarged horns on head, but it is quite harmless and makes an interesting pet. It feeds primarily on ants.

4. *Mabouia.* Skinks are common small, slender lizards living in holes and crevices. Tail is long, cylindrical and limbs or toes often reduced. Scales covering body are thin, smooth and polished. They are viviparous. Body of *Mabouia carinata* is brown above and pale below, while tail is blood-red in colour.

5. *Chameleon.* Chameleons from Africa, Madagascar and India are highly specialized for arboreal life. Body is compressed, skin granulated and head with a prominent helmet or hood formed by squamosal and occipital bones. Feet are zygodactylus (*zygo*, jointed + *dactyl*, digits) with digits arranged in groups of 2 and 3 to grasp branches firmly. Additional security is provided by a prehensile tail. The very large tongue can be projected forward with great speed to capture insects, which stick to its sticky clubbed tip. The eyes are elevated in small cones and move independently. Chameleons are famous to change their body colours rapidly to blend with their surroundings.

6. *Heloderma.* The only poisonous lizard in the world is the gila monster, measuring 30 cm in length commonly called the 'beaded' lizard because its scales resemble beads. It is represented by two species, *Heloderma suspectum* and *H. horridum*, found in drier regions of North and Middle America. It is a stout, plump, depressed, sluggish and highly coloured creature with alternate stripes of brownish black and orange-red. Its diet consists of birds, nestlings, lizards and eggs. With gooved teeth in lower jaw, it passes its neurotoxic poison into its prey by chewing movements. Its bite rarely, if ever, fatal to man.

7. *Iguana.* *Iguana* is a large herbivorous and arboreal inhabitant of tropical south and central America, reaching a length of 2.5 meters. Another iguanid, *Amblyrhynchus*, is the only existing marine lizard from Galapagos Islands. It dives 10 meters or more below tide mark to browse on seaweed. Iquanids are favourite article in the native diet.

8. *Varanus.* The monitor lizards (*Varanus*) show relatively little morphological variation. The most commonly found Indian monitor lizard is *Varanus monitor* about 50 cm long. It is characterized by a large trunk, long neck and tail, large pleurodont teeth and long protrusible and deeply bifid tongue. They are active predators, feeding on a variety of invertebrate and vertebrate animals. Its dark brown body bears black spots dorsally. It is a good climber on trees as well as a good swimmer in water.

The largest living lizard in the world is the ferocious dragon, *Varanus komodoensis*, found on some of the Islands of Malaya Archipelago. It may reach a length of 2.5 metres and weight over 100 kg. It is capable of killing adult water buffalo, but it normally preys upon wild pigs, goats, deer, etc.

9. *Ophisaurus*. Rarely limbs are absent in lizards. This is true of the so-called glass-snakes (*Ophisaurus*), slow worms or blind-worms (*Anguis fragilis*) and the worm-lizards (*Rhineura*) of Europe, America and Asia. The glass-snake *Ophisaurus* derives its name from its ability to break off its tail when seized. The tail, which constitutes about two-thirds of the animal's length, fragments into many pieces that wriggle about attracting attention, while the lizard moves away quietly. Limbless lizards move by lateral undulations as most snakes do. They can be distinguished from true snakes by the presence of movable eyelids and external ear openings which snaks lack. Further, they have small overlapping scales on the ventral side of body instead of transverse scutes that most snakes possess. The North Indian species *Ophisaurus* (= *Pseudopus*) *gracilis* differs from American glass snake in the total absence of the rudimentary hindlimb spikes on cloacal aperture. A limbless lizard from South India is *Barkudia*.

[IV] Snakes

Snakes with their limbless elongated form represent one of the most specialized groups of animals in the world. They are found in almost every kind of habitat. While snakes resemble lizards in many anatomical features, they differ from them in several ways (Table 1). A notable difference is the ability of snakes to swallow preys several times larger than their own diameter. The long slender body of snakes is highly muscular with internal organs arranged along the narrow cylindrical trunk. There is little or no external evidence of paired limbs. The scales on the head are so regular that they are used in their taxonomy. The large ventral scutes are used in locomotion. The scaly epidermis of skin is periodically shed usually in one piece. The process is termed *moulting* or *ecdysis*. Their long, slender and bifid tongue is sensitive both to odours and vibrations so that it is protruded out of mouth as a sense organ. Most snakes are not poisonous to human. Rather they are of definite value as destroyer of harmful rodents, insects and so forth.

A. Non-poisonous snakes

1. *Typhlops*. It is a small burrowing snake blackish or brownish in colour and 175-180 cm long. It looks like earthworm, hence the name *worm snake*. Tail is blunt and is either conical or end in spine. Body scales are small, uniform and semicircular. Blunt snout is covered with large shields. Eyes are vestigial and hidden beneath shining scales, hence the common name *blind snake*. Teeth are absent in lower jaw. It is harmless and feeds on insect larvae and termites. *T. braminus* and *T. thurstoni* are common in India.

2. *Uropeltis*. It is similar to blind snake but the short tail ends in a large flat rough shield as if severed by a knife, hence the name *rough-tailed snake*. Teeth are found in both jaws. It is viviparous. Common example is *Uropeltis grandis*.

3. *Ptyas* (=*Zamenis*). *Ptyas mucosus* is the most common Indian rat snake called "dhaman". Colour is olive or greenish above and whitish below. Head is distinct from neck and head shields are regular. Eyes are large. Tail forms more than one-third of body, which may attain a length of 2.5 meters. It is an active and alert snake, moving about usually during day. It feeds on mammals, birds and frogs and often enters human dwellings in search of rats and mice.

4. *Tropidonotus*. It is the common pond or grass, snake. It frequents freshwaters to feed on frogs, toads, fish etc. Body is stout, cylindrical and 1 meter long. Back is rough due to keeled scales. Colour is yellow or brown with black spots. In *T. quincunciatus*, two black streaks run behind from each eye. It looks like a cobra but is harmless.

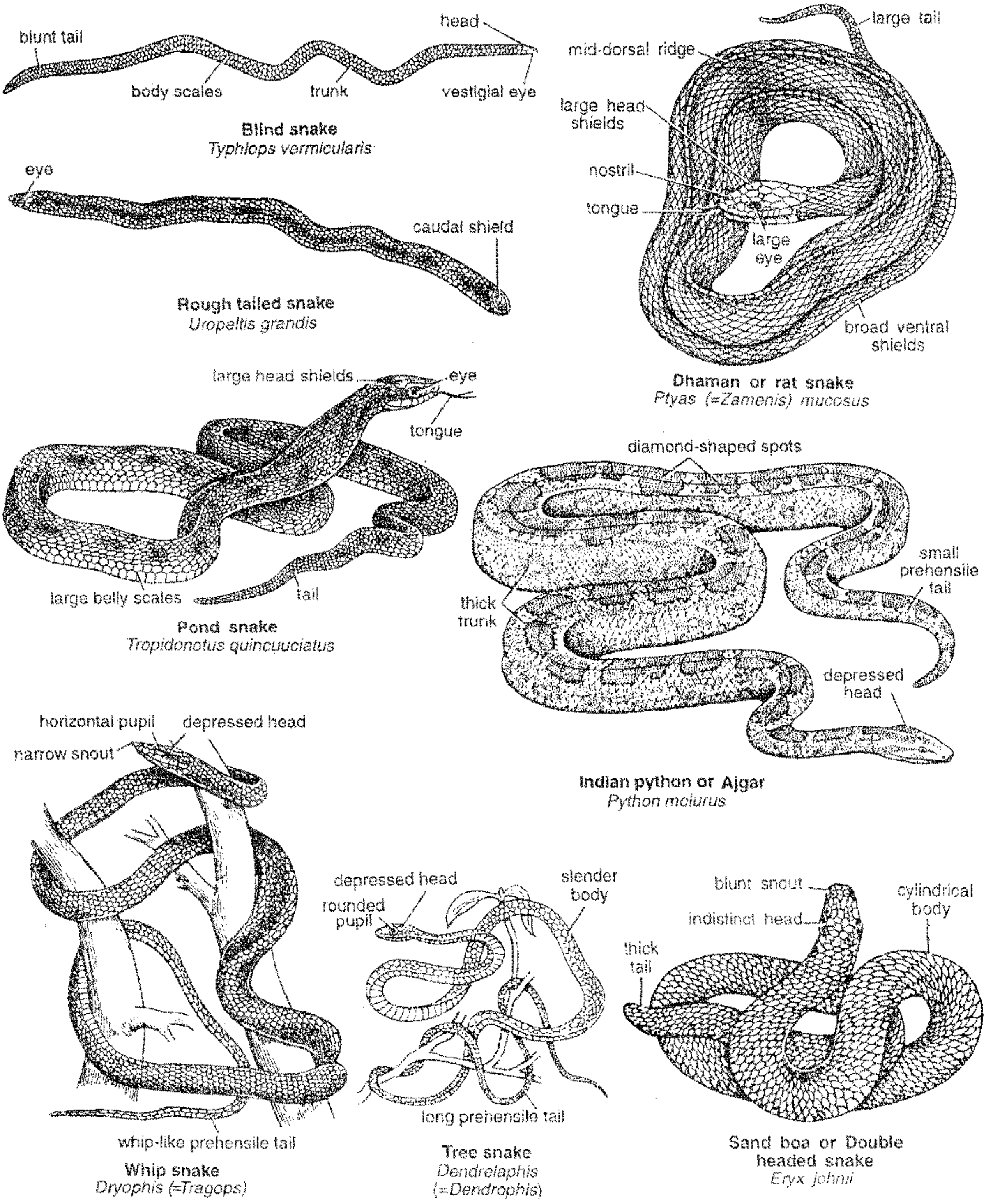

Fig. 6. Some non-poisonous Indian snakes (Suborder Ophidia or Serpentes).

5. ***Lycodon.*** The wolf snake grows to about 60 cm. A slight ridge runs along the sides of abdomen and tail. It feeds almost entirely on skinks. Maxillary fangs are not grooved but admirably adapted for catching these slippery lizards. Colour is brown above with white cross bars all over the body. In colouration it mimics the poisonous krait, but is non-poisonous. There are about 20 kinds of wolf snakes, of which 9 are found in India. The most common Indian wolf snake is *Lycodon aulicus*.

6. ***Dendrophis.*** The body of tree snake is very elongated, slender, compressed and about 2 meters long. Head is depressed, snout obtuse, pupil rounded and nostrils separate. Vertebral scales are enlarged. It is diurnal and feeds on lizards and frogs. Posterior maxillary teeth are not grooved.

7. ***Dryophis.*** The whip snake has excessively slender body like the cord of a whip, and a prehensile tail. Head is narrow, long with a tapering snout. Pupil is horizontal. Posterior fang-like maxillary teeth are grooved. Colour is green. It is viviparous and feeds on small reptiles and birds. Although non-poisonous, its saliva is weakly poisonous which can kill small animals.

8. ***Python.*** The largest non-poisonous snakes belong to the family Boidae. Pythons are oviparous and boas ovoviviparous. The largest species, *Python reticulatus* of south east Asia grows to over 10 metres. A close second is the water boa or Anaconda (*Eunectes murinus*) of South America reaching 8 metres. The Indian python, *Python molurus*, commonly called 'Ajgar', may grow upto 6 metres. It lives upon trees in forests. Body is plump and sluggish. Head is depressed with truncated snout. Tail is short and prehensile. Pupil is vertical. Adult has a claw or spur on either side of cloaca, representing vestigial hind limbs. Dorsally, the anterior half of head bears shields, the posterior half scales. Diamond-shaped dark brown and green spots mark the body. A brown spear-like mark is present over head. It feeds exclusively on birds and mammals which are suffocated in its coils.

9. ***Eryx.*** The sand boa or *Eryx johnii* burrows in dry sandy plains and hills in India. The cylindrical body is about 1 meter long with indistinct head and a blunt snout. Tail is small, non-prehensile, thick and bearing a false resemblance to head, hence the common name *double-headed snake* or *Dumuhi*. Colour is brown and head and body covered with small scales. A conical prominence in a groove on either side of cloaca represents a rudimentary hind limb. *Eryx johnii* is non-poisonous and feeds on rats, mice and squirrels which it kills by constriction and swallows. Another Indian species is *Eryix conicus*.

B. Poisonous snakes

Common poisonous snakes are *cobras, kraits, pit less vipers, pit vipers, sea snakes* and *coral snakes*. All have poison glands and some of their maxillary teeth modified into fangs. Their tails are cylindrical, except in sea snakes. Heads are covered with shields (not scales) and ventral shields cover the entire width of belly. Their other special characteristics are as follows (Fig. 7) :

1. **Cobras.** The common Indian cobra is *Naja naja* or *Naja tripudians*. It is the most common and deadly poisonous snake of India. Length is about 2 metres and black or brown colour variable. Head is small and indistinct. Pupil is round. Neck can dilatate into a hood supported by ribs and may bear spectacle marks dorsally. The 3rd supralabial shield of upper lip touches eye and nasal shield. Subcaudal shields are in 2 rows. Fangs are anterior, grooved and permanently erect. It feeds on small birds, rats, frogs, lizards, etc. Its chief enemies are the jungle fowls which destroy its young brood, and the mongoose (*Herpestes*) that kills it.

One of the largest and deadliest venomous snakes is the king cobra or hamdadryad *Ophiophagus hannah*, also known as *Naja hannah* or *Naja bungarus*. It lives in deeply forested areas and grows to about 4 metres. It feeds mainly on monitor lizards and other snakes, hence the name king cobra.

2. **Kraits.** Kraits occur all over India. The common krait, *Bungarus caeruleus*, grows to a length of 1.2 metres. Vertebrals are large and hexagonal. 4th infralabial is the largest. Subcaudals

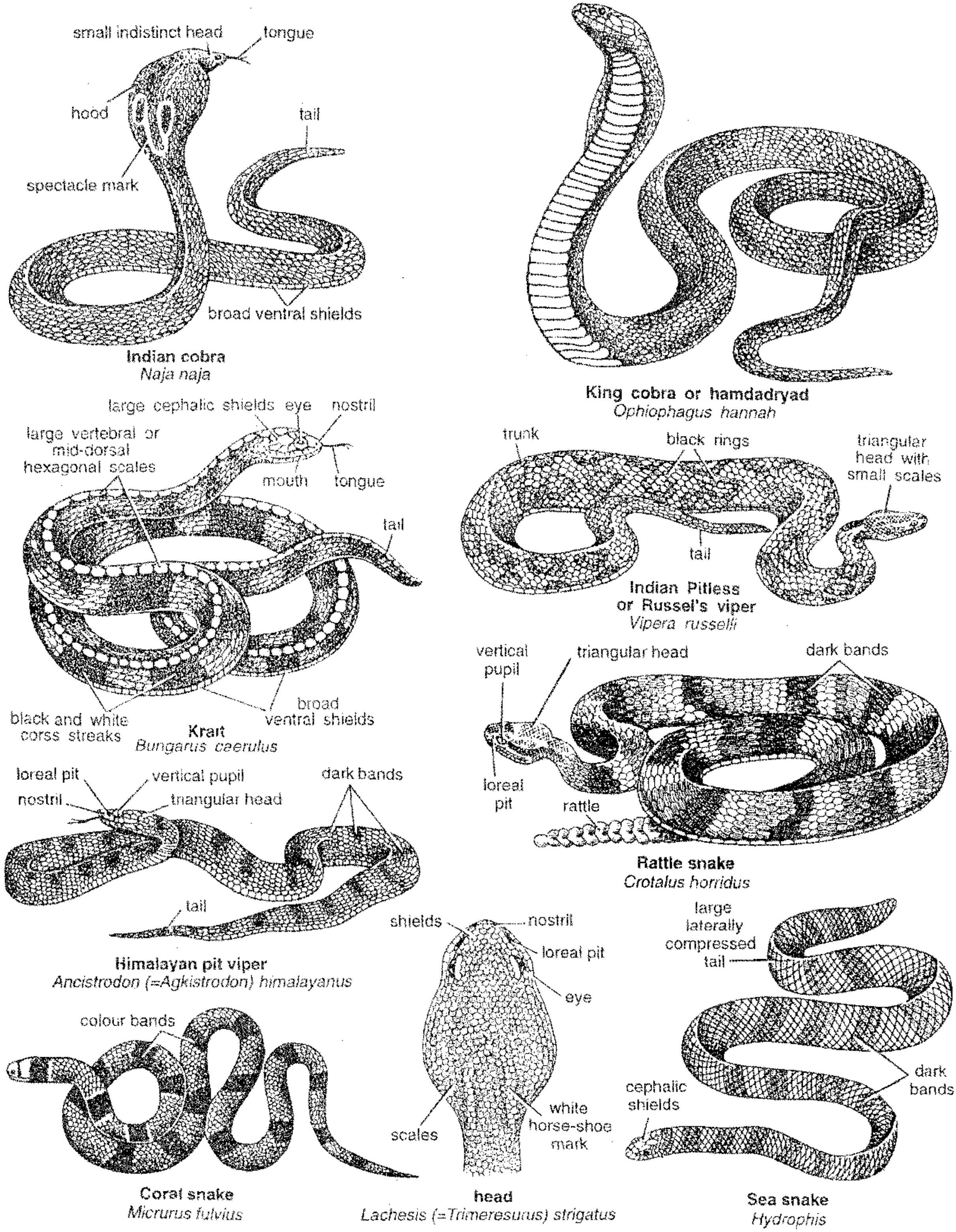

Fig. 7. Common poisonous snakes of India.

are single. Ventral surface is white. Dorsal surface is bluish or brownish black with narrow white cross streaks. Their fangs are small and wounds inflicted superficial, but poison is three times as virulent as that of cobra. It is a terrestrial and diurnal snake, feeding on small amphibians, lizards, snakes and mammals. The banded krait, *Bungarus fasciatus*, is more restricted to northern India. Its body is marked with alternate broad black and yellowish rings imparting a beautiful but dreadful appearance.

3. True or pitless vipers. The largest Indian pitless viper is the Russel's viper or *Vipera russelli*. It is about 1.5 metres long. Its head is distinct, triangular, flat and covered with small scales. Nostrils are lateral, oblique and very large. Upper surface of body shows three rows of large black rings appearing like chains, hence the common name *chain viper*. Head shows a yellow A -mark. Subcaudal shields are in 2 rows. Fangs are large, tubular (solenoglyph) and lie down when not in use. It marks a loud hissing sound when attacked. It is nocturnal, viviparous, thoroughly terrestrial and feeds chiefly on mice.

Another pitless viper from South India is *Echis carinata*. It lives in sandy areas with scant vegetation. It is small, about half a meter long, and with a single row of sub-caudals. Colour is green or brown with black and brown spots and a white belly. Back scales are strongly keeled and serrated, hence the common name, *saw-scaled viper*. In other features it resembles the russel's viper. Its bite is not fatal to man.

4. Pit vipers. Pit vipers differ from true or pitless vipers in having a *loreal pit* between the eye and nostril on either side. The loreal pits form heat sensitive organs. But they resemble pitless vipers in the possession of a robust body, triangular head with scales, broad ventrals, vertical pupil, solenoglyph fangs and viviparity.

Ancistrodon (= *Agkistrodon*) *himalayanus*, the brown Himalayan pit viper of India, is very common in eastern hills as well as Kashmir and grows to nearly 70 cm. Its head bears shields, subcaudals are in 2 rows and tail ends in a long spine—like scale. In *A. hypnale* of South India, snout is bossy and slightly turned upwards.

Lachesis (= *Trimeresurus*) *strigatus*, also common in South India, grows to about 45 cm. Its snout has shields, rest of the head bears scales. Slightly prehensile tail ends in a conical scale. Colour is brown with irregular dark spots. Neck bears a white horse-shoe mark. A dark brown band runs behind each eye.

The famous rattle snake (*Crotalus*) of North America is easily distinguished by the presence of a *rattle* at the end of tail. It consists of 10-12 horny hollow segments loosely held together. During locomotion, the rattle strikes ground producing a rattling sound. Before, striking the rattle vibrates producing a buzzing sound which serves as a warning.

5. Water snakes. In masshy waters or in the neighbourhood of water sources water snakes may be found which may be identified by rather short and stout body and a long tail. The fresh water snakes are all nonpoisonous, however, some sea snakes are poisonous. Water snakes, particularly the sea snakes have bright colours ranging from many shades of yellow to olive brown. The common fresh water snake is *Xanochrophis piscater* also known as 'checkered keel back' as it has the dorsal spots arranged in series forming a class board pattern, which can be identified by characteristics sound, pupils with speckled greenish golden area around them. Nostrils are placed high on the snout, which facilitate respiration in water. It feeds on small fishes and frogs. Flesh of water snakes is relished in many parts of the world.

Sea snakes inhabit tropical parts of Indian and Pacific Oceans. They pass their whole life in sea water and are highly poisonous. They look eel-like and are easily identified by their elevated and laterally compressed oar-like tails, suited for swimming. Their food consists of small fish. Head is small and shielded above. Eyes are small with rounded pupil. Nostrils are valvular and lie at the tip of snout to permit breathing while in water. Ventral shields are narrow, rudimentary or absent. All are viviparous. Most common Indian sea snake is *Hydrophis* with 20 or more species. Its lower jaw is not notched in front. In *Enhydrina*, the lower jaw is deeply notched in front.

6. Coral snakes. These are small snakes of cobra family (Elapidae) living in sandy areas near sea beaches. Although poisonous, they are not fatal to man. As in cobra, the 3rd supralabial touches eye and nostril, but hood and spectacle mark are absent. Common South Indian coral snake, *Hemibungarus nigrescens*, is 1.2 metres long, coloured black or brown above and red below. A black, mid-dorsal line runs throughout with black oval spots on either lateral side. *Callophis* is about 50 cm long. It is without longitudinal band but with about 40 narrow, equidistant, black white-edged rings. *Micrurus*, a poisonous coral snake of U.S.A. and tropical countries, is beautifully coloured with bands of black, red and yellow.

[V] Crocodilians

The crocodilians (crocodiles, alligators, gavials, caimans) include some of the largest living reptiles. These formidable and carnivorous lizard-like creatures, live mainly in tropical freshwater rivers. Their body is long, cylindrical, depressed and head elongated into a flat snout with nostrils at its tip. Massive tail is laterally compressed, forming a powerful swimming appendage. Limbs are short but strong, pentadactyle, clawed and webbed. Skin is thick, leathery, with horny scutes, those on back and

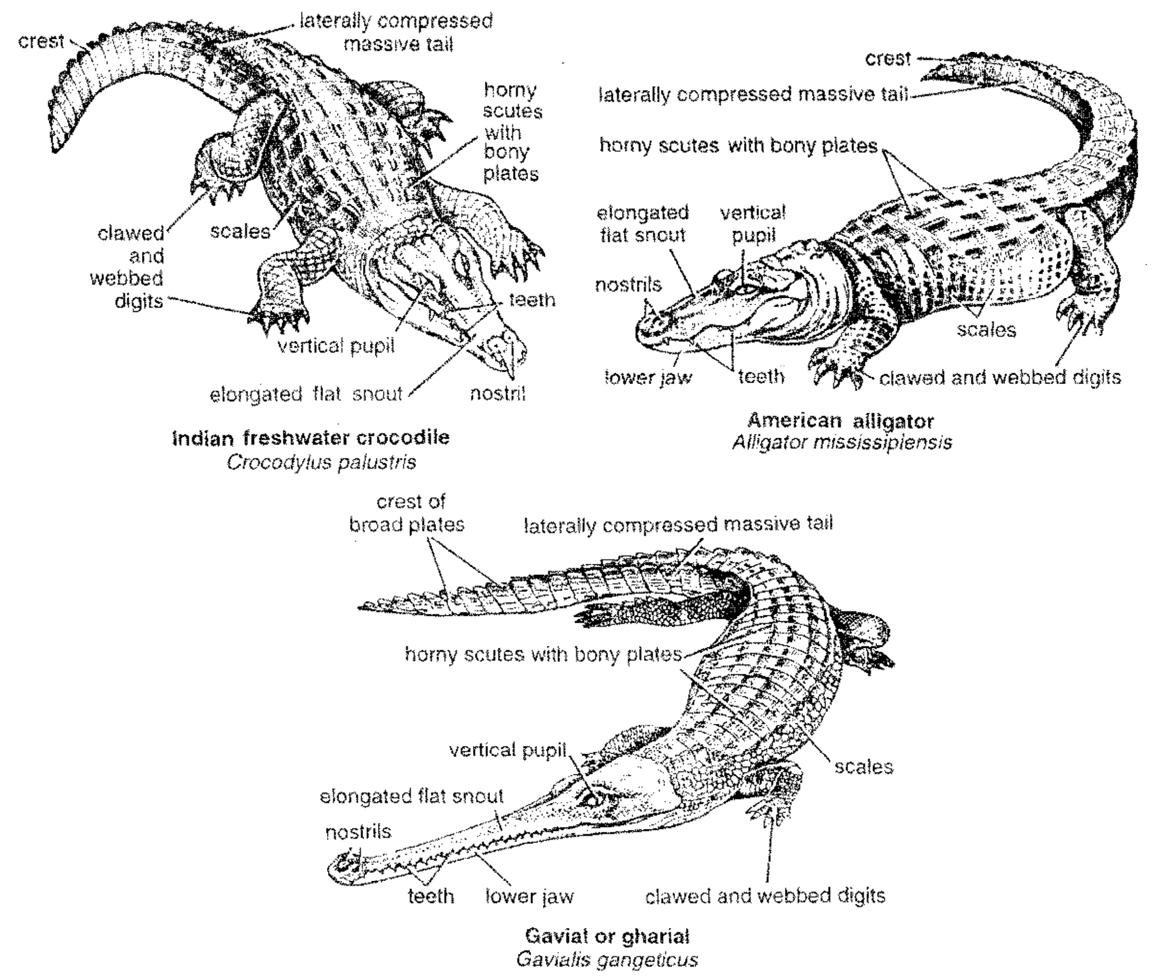

Fig. 8. Common crocodilians.

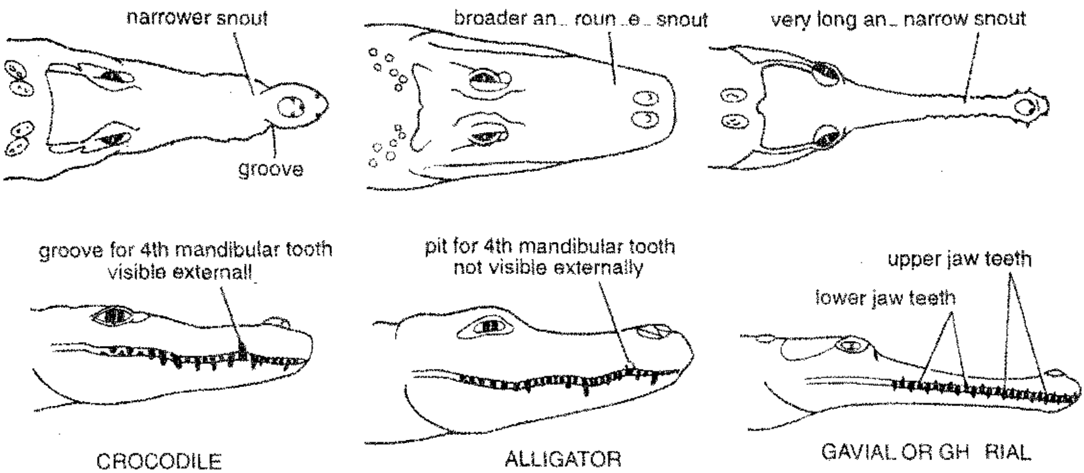

Fig. 9. Heads of crocodile alligator and gharial to illustrate their differences. Upper row shows shape of heads and width of snouts in dorsal view. Lower row shows arrangement of teeth in lateral view.

Table 2. **Distinction of Crocodylus, Alligator and Gavialis.**

	Characters	Crocodylus	Alligator	Gavialis
1.	Distribution	Central America, Africa, Asia, Malaya, Indonesia, North Australia. *Crocodylus palustris*	North America, China, *Alligator mississipiensis*	India. *Gavialis gangeticus*.
2.	Habits	More aggressive, dangerous to man	Less aggressive, attack when provoked	Can eat only fish because of narrow throat.
3.	Body length	8 metres	3 metres	6 metres
4.	Colour	Olive green with black spots or bands	Steel grey	Dark olive green
5.	Snout	Moderately long and pointed	Short broad and rounded	Very long and slender
6.	Mandibular rami	United upto 8th tooth	United upto 5th tooth	United upto 14th tooth
7.	Teeth	18-19/15, similar	17-22, slightly different	27-29, similar
8.	Fourth mandibular tooth	Fits into a maxillary groove and visible externally	Fits into a pit and not visible externally	—

belly rectangular and supported by dermal bony plates. Tail bears dorsally a crest of broad plates, double in the basal half but single in the distal half. Cloaca is a longitudinal slit. Two pairs of musk glands are present, one on throat and the other in cloaca. These large reptiles are well adapted for an aquatic existence. Nostrils, eyes and ear openings are placed high on the head and remain exposed even when the whole animal is immersed in water. Thus, breathing, seeing and hearing remain uninterrupted. When the animal dives, nostrils are closed by valves, nictitating membranes are drawn over yes and ear openings shut by skin flaps. A complete hard palate separates the nasal and oral cavities and an intranarial epiglottis closes the wind pipe at the back, so that animal can open its mouth under water to feed, at the same time breathing with its nostrils above water. Crocodilians differ from all other reptiles in having certain *advanced* characteristics, such as (i) thecodont teeth set in sockets, (ii) a relatively complete bony palate, (iii) lungs in pleural cavities, (iv) separated from the rest of body cavity by a muscular diaphragm, analgous to that of mammals, (v) completely 4-chambered heart and (vi) a simple but grooved copulatory organ in male. All crocodilians are oviparous. Usually 20 to 50 eggs are laid in a heap of dead vegetation or sand. The largest of all crocodilians (120 species) is the salt water or estuarine crocodile, *Crocodylus porosus*, of south eastern Asia. It grows to 8-9 metres and is very much feared. The freshwater crocodile *Crocodylus palustris*, known as 'maggar', is widely distributed in India and reaches a length of 5 metres. The single species of gavial or gharial, *Gavialis gangeticus*, lives in the Ganges and Brahmputra river systems and grows to 8 metres. There are 2 species of alligators—Chinese and American. The American alligator (*Alligator mississipiensis*) inhabits the south eastern parts of North America. Table 2 tabulates some of the distinguishing characteristics of *Crocodylus, Alligator* and *Gavialis*.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Classify Reptilia upto orders giving important characters and suitable examples.
2. Give principal anatomical peculiarities of *Sphenodon* and discuss its affinities.
3. Discuss that *Sphenodon* is the most primitive and the crocodilians the most advanced of all living reptiles.

» *Short Answer Type Questions*

1. State distinctive characters of class Reptilia.
2. Differentiate between — (i) Limbless lizard and snake, (ii) Limbless amphibian and snake, (iii) Lizard and snake, (iv) Lizard and salamander, (v) Crocodile, alligator and gharial, (vi) Turtle and tortoise.
3. Write short notes on — (i) Anapsida, (ii) *Chameleon*, (iii) Coral snake, (iv) Cobra, (v) *Draco*, (vi) *Heloderma*, (vii) Krait, (viii) *Python*, (ix) *Sphenodon*.

» *Multiple Choice Questions*

1. The study of reptiles is known as :
   (a) Herpetology (b) Ornithology
   (c) Icthyology (d) Osteology
2. Turtles have :
   (a) Homodont teeth (b) Horny beak
   (c) Hetrodont teeth (d) Pleurodont teeth
3. Interclavical in reptiles is :
   (a) H shaped (b) W shaped
   (c) T shaped (d) A shaped
4. Embryonic membranes present in reptiles are :
   (a) Amnion and chorion
   (b) Chorion and yolk sac
   (c) Yolk sac and allantois
   (d) Amnion, chorion, yolk sac and allantois
5. Turtles are included in the order :
   (a) Chelonia (b) Rhynchocephalia
   (c) Squamata (d) Crocodilia
6. Tuatara belongs to the order :
   (a) Chelonia (b) Rhynchocephalia
   (c) Cquamata (d) Crocodilia
7. Vestigeal hind limbs and pelvic girdle are present in :
   (a) Cobra (b) Krait (c) Boa (d) Turtles
8. Ophiosaurus belongs to :
   (a) Chelonia (b) Rhynchocephalia
   (c) Ophidia (d) Lacertilia
9. Heart in crocodiles is :
   (a) Completely 4 chambered
   (b) Incompletely 4 chambered
   (c) 3 chambered (d) 2 chambered

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a)

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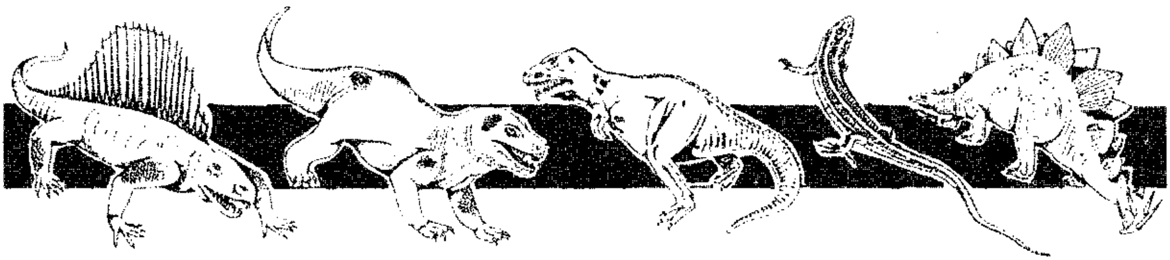

Reptilia : General Account

Origin of Reptiles

Amphibian origin. It is generally agreed that primitive reptiles originated from some primitive labyrinthodont Amphibia, in the beginning of Carboniferous period. The labyrinthodonts possessed characteristically folded or labyrinthine teeth, similar to their crossopterygian ancestors. They flourished through Carboniferous and Permian periods before extinction in the Triassic. We cannot however point to a single ancestor of reptiles. Probably they arose polyphyletically along a dozen or more independent lines.

Stem reptiles (Cotylosauria). During Carboniferous period of late Palaeozoic Era, about 250 million years ago, some labyrinthodont amphibians gradually took on reptilian characters. These earliest reptiles are called the *stem reptiles*. They belong to the order *Cotylosauria* of the subclass *Anapsida*. The transition was so gradual that often it is difficult to decide whether some fossil skeletons are those of advanced amphibians or primitive reptiles.

Seymouria. One of the members of the Cotylosauria was *Seymouria*, (Fig. 1) found in the Lower Permian of Texas (U.S.A.), perhaps 250 million years old. It was a lizard—like animal about 60 cm long, with a comparatively thick body, relatively small pointed head with dorsally placed nostrils, and a short tail. Structure of *Seymouria* was intermediate between the amphibians of that time and the early reptiles.

(a) Amphibian affinities. *Seymouria* resembled early Amphibia or Labyrinthodontia in many features. (i) Skull is flat with reduced ossification. (ii) An intertemporal bone is present. (iii) Palate is primitive. (iv) Teeth are labyrinthine and also found on vomers and palatines. (v) Position of fenestra ovalis below the basal level of brain is amphibian. (vi) There are traces of lateral line canals in head region. (vii) Vertebrae show little 'ifferentiation. 'viii) One pair of sacral ri's are present. (ix) Neck is short so that pectoral girdle lies close behind skull.

(b) Reptilian affinities. *Seymouria* had several characteristically reptilian features. (i) Limbs are ~us~ular and arise ~id-~entrall~. (ii) Sk~ll is anapsid and monocondylic. (iii) Pelvic girdle is attached to vertebral column by sacral vertebrae. (iv) Number of phalanges 2 : 3 : 4 : 5 : 3 or 4 is more reptile like.

(c) Conclusions. *Seymouria* leads us to certain logical conclusions. It is not directly ancestral to all reptiles. At the time it was living, the reptiles had already been present for some 50 million years. It is so perfectly intermediate between an amphibian and a reptile that its true position remains uncertain. Romer treats it as a reptile under the order Cotylosauria, whereas others classify it with primitive Amphibia under the order Seymouria-morpha. Perhaps *Seymouria* is a connecting link between Labyrinthodontia and Cotylsosauria.

1. *Limnoscelis.* Now *Seymouria* seems no longer to occupy the position which it has often graced in text books as the ideal primitive reptile. Another creature, *Limnoscelis* has special claims to attention. This was a genuine reptile from the late Carboniferous or early Permian of New Mexico. Romer (1946) critically studied it and suggested that *Limnoscelis*, a Captorhinomorph Cotylosaur is the primitive reptile. Although, it was also too late an arrival, on the geological scene, to have seen, the actual prototype of the reptilian evolution. *Limnoscelis* was about 5 ft in length, some half of which was made up by tail, with an elongated body, low slung on short stubby legs which sprawled outwards from the sides. Like *Seymouria*, it was also aquatic in habitat. The skull was anapsid type, compressed from side and dorsoventrally flattened. The otic notch present in Labyrinthodonts, had disappeared, leaving indication at back of the skull, in the region of its closure. The premaxillary teeth were enlarged and over hung the front teeth in the lower jaw, which

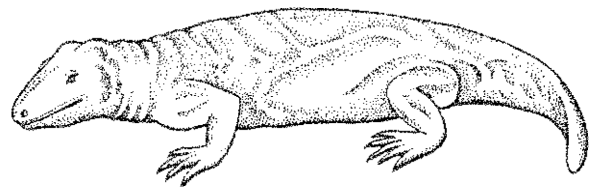

Fig. 1. A cotylosaur, *Seymouria* (ANAPSID).

is one of the most common specialization of early reptiles, but seldom seen in amphibians.

Diadectes. It was contemporary to *Limnoscelis*, but the didectomorphs represents different evolutionary line from *Limnoscelis*. The didectomorphs retained the otic notch at the back of skull. *Diadectes* had developed a specialized dentition. The front teeth were chisel shaped and back teeth had broad ridged crowns.

The first really large reptiles to make their appearance in the later Permian were the *Pareiasaurs*, related to *Diadectes*. These lumbering animals ran to spiny excrescences on the head and spiny armour of bony plates along back, which was presumably a defence against carnivorous mammals like reptiles.

From the foregoing discussion, it is clear that the Cotylosaurs were broadly speaking ancestral to all reptiles. Some workers including Watson believe that these Cotylosaurs separated into two divergent evolutionary lines. One of these lines is represented by Captorhinomorph (sub order) of which *Limnoscelis* was primitive member, led to mammal like reptiles and ultimately to mammals and has been termed as *theropsida*. The other line however, the Sauropsida is represented by Didectomorph Cotylosaurss, the remaining reptiles and birds. In this group, the otic notch tends to persist. Although, the authorities have not yet agreed, as at what prescise stage of evolution these two separated from one another. It seems clear therefore that the modern reptiles are not intermediate in the evolutionary sense between amphibians and mammals. And to find out a common ancestor for a creature like a lizard and a mammal, one has to go back to an ancient reptilian or possibly to an amphibian according to Watson.

Evolution and Adaptive Radiation

Evolutionary significance

Evolution of reptiles bears a special significance. They represent the first terrestrial vertebrates, adapted for life in dry places on land. The dryness of skin to prevent loss of moisture from body, method of reproduction including amniotic eggs capable of development on land, and the devices for economizing in the use of water, are some of the achievements in their terrestrial adaptations.

Generalized condition

The oldest fossils, clearly judged to be the most primitive reptiles, comprise a group of so-called *stem reptiles* or *Cotylosauria*. They range from the upper Carboniferous to the upper Triassic when they became extinct. They closely resembled the labyrinthodont Amphibia from which they had evolved. These primitive or generalized reptiles had thick body, small pointed head with dorsal nostrils, short tail and short muscular pentadactyl limbs. Two characteristics were common: the complete roofing of skull (*anapsid condition*), and the flattened plate-like pelvic girdle. The size ranged from 30 cm to 3 metres. From this generalized condition in the succeeding periods, arose several lines of radiation or specializations, some leading to the great array of reptiles, both extinct as well as living, and others to birds and mammals.

Adaptive radiation

Because of the competition for food and living space, a single ancestral species evolves into different forms which occupy different habitats. This is called *adaptive radiation* or *divergent evolution*. Perhaps reptiles have shown the greatest evolutionary diversity and adaptive radiation of all vertebrate groups. Their adaptive radiation took place twice, first in the Palaeozoic and secondly in the Mesozoic.

Palaeozoic radiation

During Palaeozoic, with no serious competetors on land, the ancestral reptiles or cotylosaurs multiplied rapidly, occupying all ecological niches available to them. Their radiation involved adaptations to different methods of locomotion and feeding. Distinct anapsid and synapsid forms dominated.

Mesozoic radiation

By the end of Palaeozoic, the ancestral cotylosaurs had disappeared, but their descendants produced a second and bigger radiation during Mesozoic. They dominated not only the land but also the sea and the air throughout the Mesozoic Era, which is truly called the *Age of Reptiles*. They lasted over a great span of time, about 130 million years. By comparison, man is no older than 2 to 4 million years. The extinct Mesozoic reptiles are represented by as many as 16 orders. Of these one led to the birds, one to the mammals and four to the modern reptiles. With the advent of Coenozoic Era, the vast hordes of the Mesozoic reptiles disappeared, leaving behind the representatives of only 4 living orders.

We shall not undertake to discuss the whole circus of the extinct reptiles but only the more notable lines, based on the morphology of the skull, such as anapsid, synapsid, euryapsid, parapsid and diapsid.

1. Anapsid line. The modern *Chelonia* (turtles and tortoises) represent a direct and an early offshoot of cotylosaurs retaining anapsid skull. They have remained virtually unchanged since Triassic, some 160 million years ago.

2. Synapsid line. The mammal—like reptiles or Synapsida had a single temporal cavity in skull ventral to postorbital and squamosal. Early *Pelycosauria* or *Theromorpha* were similar to cotylosaurs. Later *Therapsida* with differentiated dentition and improved locomotion were more mammal—like. Before disappearing in Jurassic they gave rise to ancestral mammals.

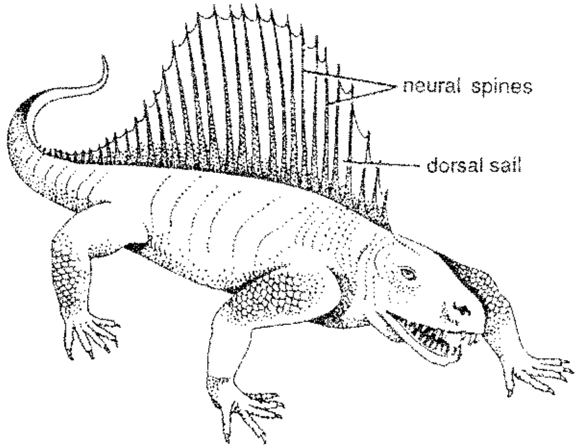

Fig. 2. A pelycosaur, *Dimetrodon* (SYNAPSID).

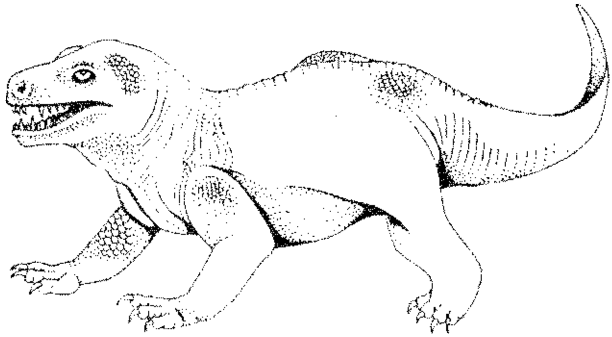

Fig. 3. A therapsid, *Cynognathus* (SYNAPSID).

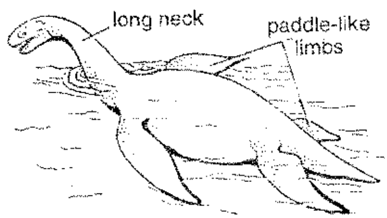

Fig. 4. A plesiosaur (EURY PSID).

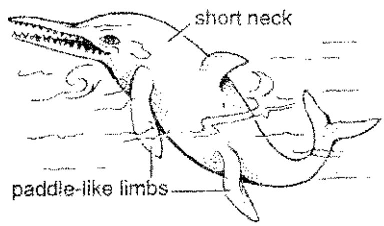

Fig. 5. An ichthyosaur (PARAPSID).

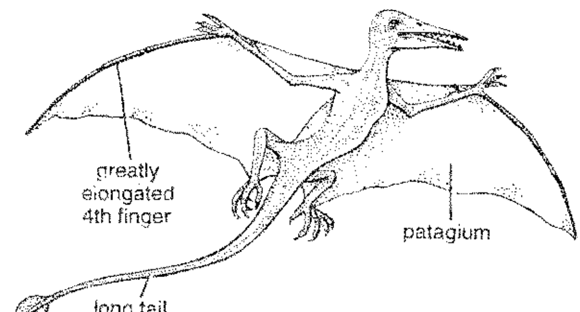

Fig. 6. A pterosaur, *Rhamphorhynchus*.

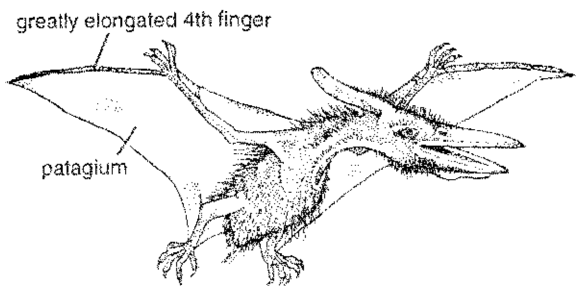

Fig. 7. A pterosaur, *Pteranodon*.

3. Euryapsid line. The euryapsids or *Plesiosaurs* (Fig. 4) had a single temporal fossa in skull above the joint of postorbital and squamosal. They were large, marine, turtle-like, heavy-bodied and long-necked creatures. They were obviously fish-eaters. All became extinct towards the end of Cretaceous.

4. Parapsid Line. There was another marine blind alley, like Euryapsida, represented by fish-like or porpoise-like *Ichthyosaurs*. They became extinct near the close of Mesozoic Era (Fig. 5).

5. Diapsid line. Most of the present-day reptiles are diapsid with two temporal openings on either side of skull separated by squamosal and postorbital bones. The earliest diapsids divided into two branches, Lepidosauria and Archosauria. The *Lepidosauria* were probably ancestral to modern *Squamata* (snakes and lizards) and *Rhynchocephalia* (*Sphenodon*). The *Archosauria* were the "ruling reptiles" dominating the Mesozoic Era. They represented the extinct *Pterosauria*, the extinct *Dinosaurs* and the modern

Crocodilia. They also gave rise to the modern birds.

(a) Pterosauria. The extinct flying reptiles called *Pterosauria* or *Pterodactyla* were of light built. Their forelimbs evolved into membranous wings or patagia. First 3 fingers were short, hooked and probably used for clinging to rocks. 4th finger was greatly elongated to support the edge of patagium. 5th finger was lost. *Rhamphorhynchus* of late Jurassic was a primitive *Pterosaur* with 1 meter wingspan, a long balancing tail and toothed jaws. *Pteranodon* of Cretaceous had a 9 meter wingspan but no tail. Its huge horny and toothless beak was balanced by a backward bony projection of head (Figs. 6 & 7).

(b) Dinosaurs. At the end of Triassic, *Thecodontia* or *Pseudosuchia*, the early descendants of Archosauria, gave rise to the most fantastic Mesozoic reptiles, the *dinosaurs*, which means 'terrible lizards' (Gr., *dinos*, terrible + *saurus*, lizard). They subdivided early into two orders, Saurischia and Ornithischia, depending on the structure of their pelvis (Figs. 8 & 9).

Saurischia means 'reptile hips'. They possessed a triradiate pelvis with pubis entirely separate and anterior to ischium. Suborder Theropoda included all flesh-eating and bipedal carnivores. Smaller Cretaceous ostrich-like forms, such as *Struthiomimus* and *Ornithomimus*, walked on 3 toes of large hindfeet. Their forelimbs also had 3 fingers, of which one was opposable like a thumb and used for grasping. Jurassic *Allosaurus*, a monster carnivore, was 10 metres long. But the largest and the most fearful predator that ever walked the face of earth was *Tyrannosaurus rex* from Cretaceous of North America. It was 15 metres long and stood 6 metres high. Its head was disproportionately great with large jaws armed with dagger-like teeth 15 cm long. The 3-toed massive hind legs were adapted for running, but extremely short forelimbs were almost useless. Suborder Sauropoda included large herbivorous quadrupedal dinosaurs. Some of them were the largest and heaviest of all terrestrial and amphibious vertebrates that ever lived. *Apatosaurus* (=*Brontosaurus*), *Diploducus*, and *Branchiosaurus* were enormous Jurassic reptiles each more than 25 metres long and weighing over 50 tons. They probably lived in swamps where their body would be supported partly by the buoyancy of water. They had long necks and tails, small heads with exceptionally small brains and weak jaws.

Ornithischia means 'bird hips'. They had a typical tetraradiate bird like pelvic girdle with pubis directed backwards parallel to ischium. They were all herbivorous. Bipedal *Iguanodon* (Lower Cretaceous) grew to 10 meters. Its sharp dagger-like thumb was probably used for defence. Quadrupedal *Stegosaurus* (Jurassic) measured 8 meters and weighed 10 tons. Forelimbs were much shorter than hindlimbs. Skull was small and brain much smaller than the lumbar swelling of spinal cord. It had a parapet of heavy triangular plates on its neck, back and tail. The tail was also furnished with formidable sharp spikes or spines. *Triceratops* (Late Cretaceous) was 6 meters long and stood 3 meters high. Its enormous head carried 3 huge horns projecting from a large bony frill or collar protecting the vulnerable skull.

Causes of extinction. After thriving and dominating the earth for 130 million years, the great dinosaurs and their contemporaries became suddenly extinct by the end of Cretaceous period. Various factors have been suggested for their total extinction such as catastrophism, epidemic, food

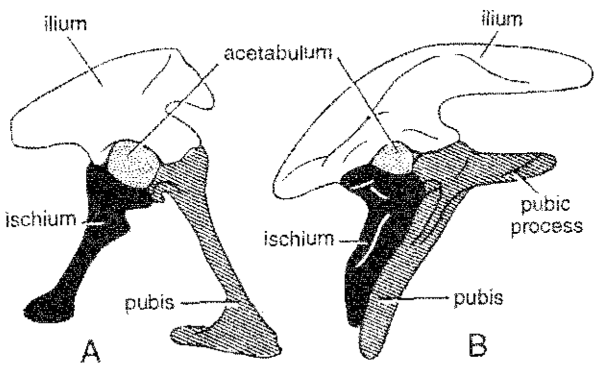

Fig. 8. Structure of pelvis in two orders of dinosaurs. A—Saurischia. B—Ornithischia.

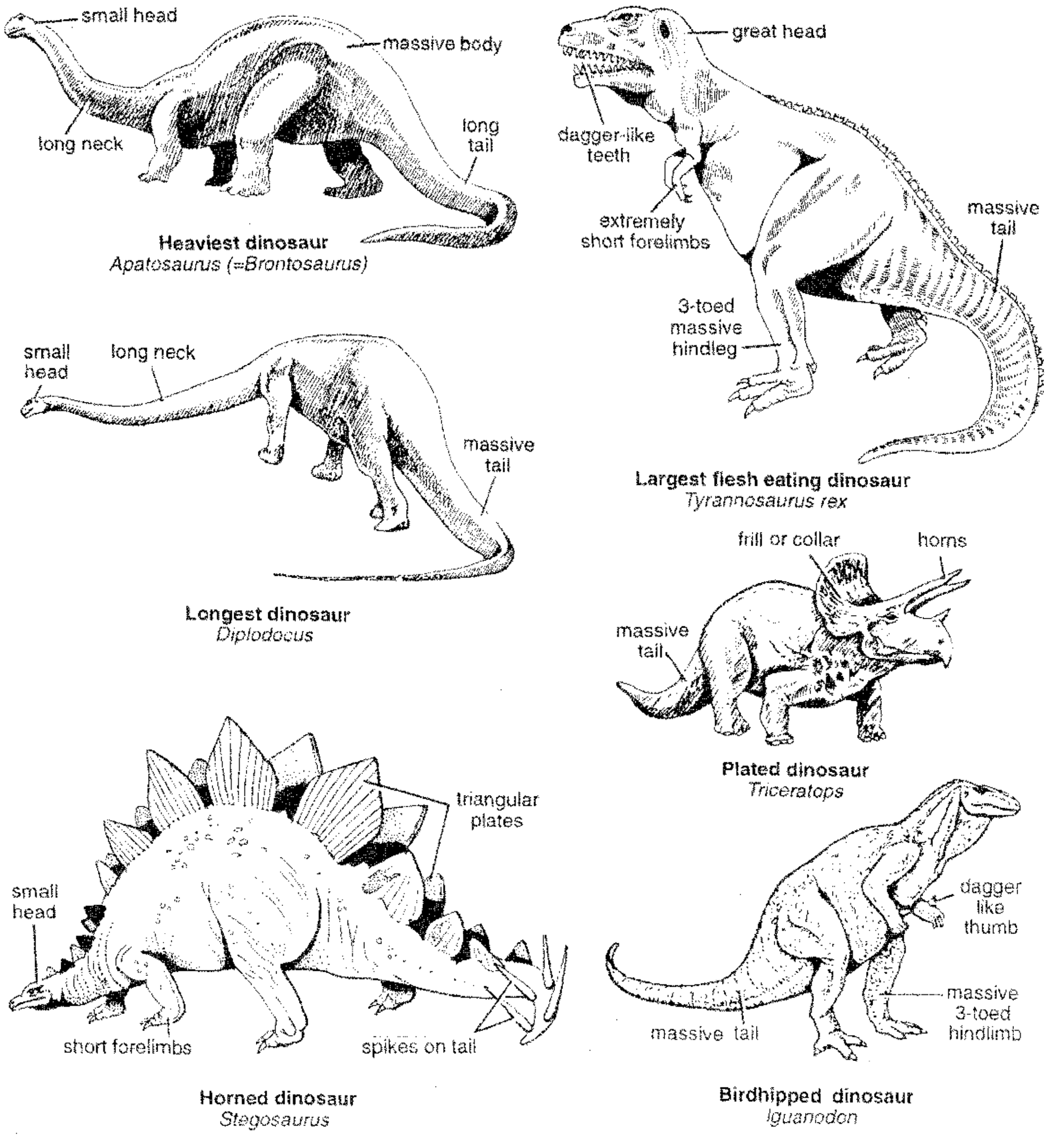

Fig. 9. Varied types of Mesozoic dinosaurs.

poisoning, racial senescence, climatic changes, overspecialization, interspecific warfare or competition with ancestral mammals. None of these has been accepted as being completely satisfactory. Probably a combination of several factors was responsible for their extinction.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Discuss the origin and evolution of reptiles.
2. Write an essay on adaptive radiation in reptiles.

» *Short Answer Type Questions*

1. Write short notes on — (i) Age of reptiles, (ii) Dinosaurs, (iii) *Seymouria.*

» *Multiple Choice Questions*

1. Which of the following is not true for *Seymouria* :
   (a) Skull is flat with high degree of ossification
   (b) An intertemporal bone is present
   (c) Palate is primitive
   (d) Traces of lateral line canals in the head region
2. Which of the following is not a reptilian character of *Seymouria* :
   (a) Muscular limbs arise midventrally
   (b) Skull flat with reduced ossification
   (c) Anapsid and monocondylic skull
   (d) Pelvic girdle attached to vertebral column by sacral vertebrae
3. The age of reptiles :
   (a) Palaeozoic era (b) Carboniferous era
   (c) Mesozoic era (d) Archeozoic era
4. Mammal like reptiles belong to :
   (a) Anapsid line of evolution (b) Euryapsid line
   (c) Parapsid line (d) Synapsid line

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d)

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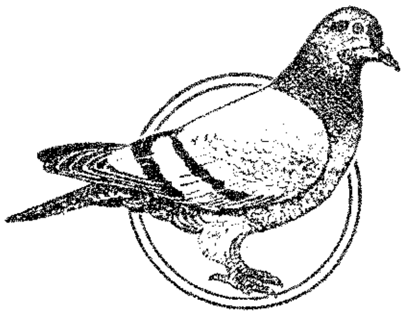

Type 10. *Columba livia* : The Common Rock Pigeon

Birds belong to the class Aves (L., *avis*, bird) of the superclass Tetrapoda. The most distinguishing feature of birds is the possession of feathers, which do not occur in other animals. Thus, a bird may be described as a feathered, bipedal, flying vertebrate possessing wings. The study of birds is termed *Ornithology* (Gr., *ornis*, bird), and that branch of Zoology that deals with the study of birds' eggs is called *Oology* (Gr., *oion*, egg). In general, people know more about birds than any other major group of animals. They attract attention because of their flight, colourful plumages, springtime songs, strange migrations, many fascinating habits and considerable economic value to man.

. Pigeons are quite familiar birds that we see everyday of our lives. They are best suited for type study because of their convenient size, harmless nature and easy procurement in large numbers.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Superclass	Tetrapoda
Class	Aves
Subclass	Neornithes
Superorder	Neognathae
Order	Columbiformes
Type	*Columba livia* (The blue rock pigeon)

Kinds of Pigeon

More than 500 species of pigeons have been described. Generally speaking, they fall under two categories, wild and domesticated. The common wild pigeon, known as the blue rock pigeon or rock dove, is *Columba livia*. The domestic pigeons differ from one another in size, proportion, colouration, details in the arrangement of feathers, etc. Some prominent varieties include *Girahbaz* (*carrier*), *Lotan* (*tumbler*), *Shirazee* and

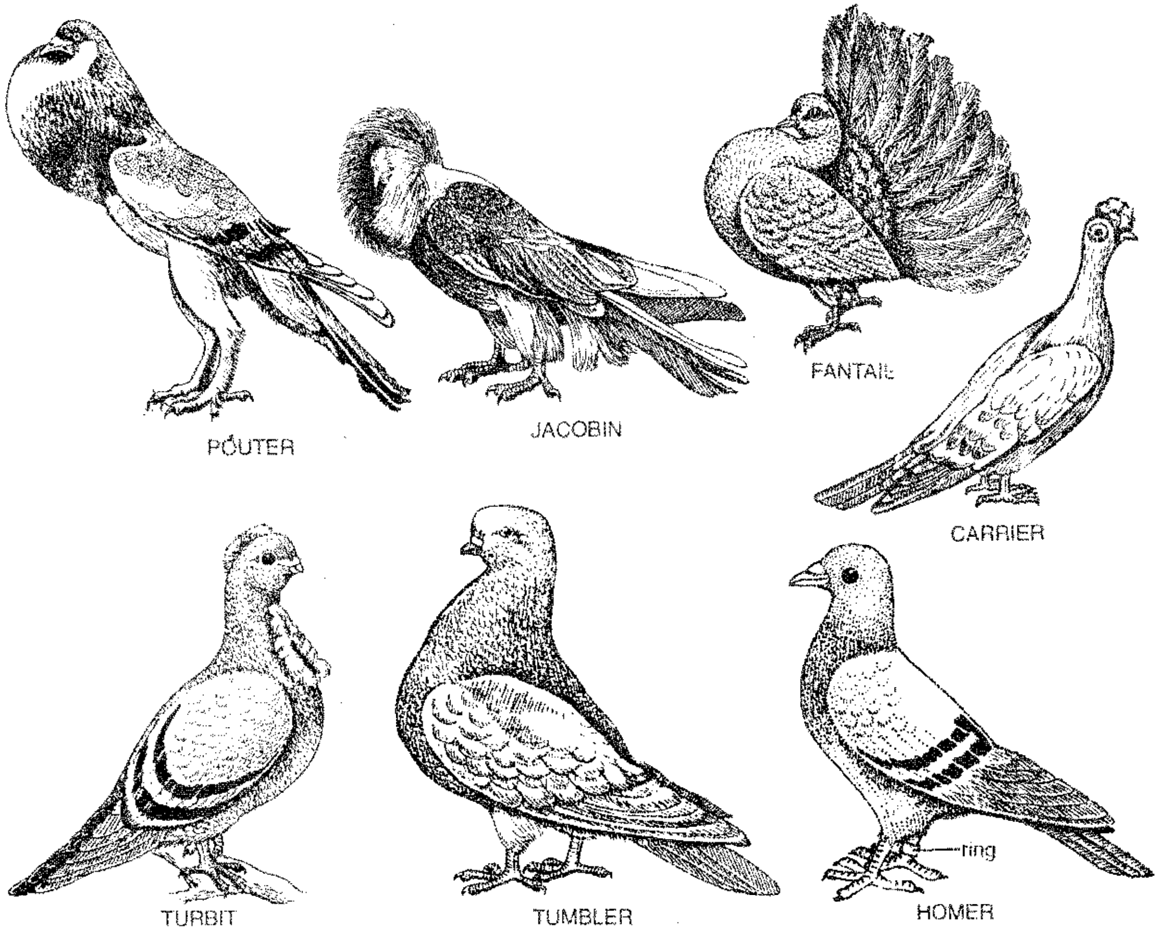

Fig. 1. Kinds of domestic pigeons.

Baghdadee, Mukhi, Lakka (fantail), pouter, etc. They have all descended from the wild pigeon by artificial selection. The following description is based on the blue rock pigeon, *Columba livia*, but is applicable to domestic pigeons as well (Fig. 1).

Natural History

Distribution. Blue rock pigeons are widely distributed in Asia, Europe and North Africa with several geographical races or sub-species. They are especially plentiful in Palestine (Israel), where they frequent the precipitous cliffs of soft limestone that are honeycombed in all directions with caves and fissures. At least two races are recorded from India. A larger and paler sub-species, *Columba livia neglecta*, is found upto 13,000 feet on the Himalaya. A smaller and darker race, *Columba livia intermedia*, is common throughout. The wild pigeon of India differs from that of Europe in having the rump or the lower part of the back ash-coloured instead of white.

Habitat. In its wild state, pigeon lives in perfect freedom in ledges, fissures and holes of rocks, forts, old crumbling buildings, and other inaccessible places, but never nests on trees. They often nest in houses tenanted by man. They can be seen in thousands in cities like Bombay and Delhi, where they get plentiful of house accommodation and are regularly fed on grains by pious Hindus. In some parts of the country they prefer holes in sides of wells.

Nature. Pigeons are the gentlest of all birds. Timid, inoffensive and harmless, they are considered living symbol of peace, harmony and happiness, all over the world. They are not afraid of man and if touched with hands will not fly away. They fly in flocks and roost together.

Food and feeding. Pigeons are vegetarian feeding on grains, pulses, seeds of fruits and grasses, etc. They have been reported sometimes to eat insects, snails and slugs, probably mistaken for food. They drink like horses and do not sip as other birds do. In mornings and evenings, they regularly leave their retreats and settle in large flocks to plunder the nearby fields.

Locomotion. Pigeons are provided with long, tapering and powerful wings, generally fitted for swift and strong flight. They do not leap with both feet together like sparrows. When traversing ground in search of food, they walk with considerable rapidity, moving their short legs alternately and the head backwards and forwards at every step. The mode of walking on two legs is called *bipedal gait.* When startled, they rise suddenly and by striking the ground with their wings produce a crackling sound.

Sound. Pigeons never sing, chirp or screech. Their voice is a plaintive moan or coo, verging sometimes on a mellow whistle. Their call notes resemble the syllables *gootur-goon, gootur-goon*, etc.

Family life. Pigeons lead a *monogamous* life. The male and female partners are very fond of each other and always remain together. Strangely enough their acts of love and courtship are very similar to those of men.

Reproduction. *Breeding season* lasts all the year round. *Fertilization* is *internal* and preceded by much *courtship* and *copulation*. Like most birds (Carinatae), pigeon has no copulatory organ. During copulation the male bird rides on the back of the female, their cloacae are closely apposed and the transfer of sperms effected quickly and directly into the urodaeum of female. Later, the sperms reach into the oviduct to fertilize ova. Reproduction is rapid so that generations overlap one another.

Nest. Pigeons take little interest in nest-building. Eggs are often laid and hatched on bare stone or plank. More often, they make a simple, flat and artless platform of small sticks and thin roots, etc., loosely heaped together at all sorts of places, where is some shelter from rain and sun, but never on a tree.

Incubation. The female lays usually two oval white eggs in a clutch at a time. An egg is about 2.5 cm long and 2 cm broad. Incubation is strictly regulated and both the sexes sit on eggs in turns. Eggs are incubated by the warmth of the sitting parent's body and hatching occurs after a fortnight.

Parental care. Pigeons are altricial, that is, the young are hatched naked, blind and helpless, requiring parental care till they are fully grown up. To feed them the parents regurgitate a fatty, curdy secretion, the *pigeon's milk*, manufactured in their crops by certain glands. Both sexes produce it. The nestlings grow rapidly and soon develop contour feathers.

Natural enemies. The common predators of pigeons include carnivorous animals such as wild and domestic cats, foxes, weasels, hawks, owls and snakes, etc. Man also preys on them for flesh and study. Various bird parasites, such as lice, worms, protozoans, bacteria and viruses also take their toll.

Homing instinct. If pigeons are sent by a rail in a closed basket to several miles away and there set at liberty, they will return to their loft which they can recognise without any mistake. Thus, they share with the rest of the migratory birds, a certain sense of orientation and homing instinct.

Economic importance. As already noted above, pigeons provide easy food to various predators, including men. Fruit pigeons or Green pigeons (*Crocopus phoenicopterus chlorogaster*) make excellent eating, especially if their tough skins have been removed before cooking. They form nice pets in the households and important animals for study in laboratories. From very early times, carrier pigeons have been trained and used as messengers in wars and love affairs. They were employed to carry written messages even during the First World War (1914-1919). It is said that Akbar, the great Moghul Emperor of India, kept a fleet of 20,000 pigeons, which regularly carried mail from one part of his kingdom to another. Pigeons are also prescribed in curing certain illnesses. On the other hand, pigeons can sometimes become pests in the houses and in the fields by consuming large quantities of grains.

External Features

The structure of pigeon does not differ a great deal from that of other birds (Figs. 2 & 3).

[I] Shape, size and colouration

The compact, fusiform or boat-shaped streamlined body is well adapted for rapid flight and offers minimum resistance to air. Blue rock pigeon is slightly smaller than the common house-crow and measures about 33 cm in length. Pigeon is a very beautiful bird. It is a slaty-grey bird with glistening metallic green and purple sheen on the upper breast and around the neck. Eyes and the feet are pink. Rump or posterior region of back is ash-coloured and not white as in *Columba livia* of Europe. There are two prominent black bars on the wings.

[II] Division of body

Body of a pigeon is distinctly divisible into four parts : head, neck, trunk and tail, invested in a close covering of feathers. All these parts are clearly recognised when the body is stripped of its feathers.

1. Head. Head is small in proportion to the body, somewhat rounded and mobile.

(a) Beak. Anteriorly, the head is drawn out into a short straight and pointed *bill* or *beak*, formed by the elongated upper and lower jaws. There are no teeth in the two jaws which remain covered with a horny sheath called *rhamphotheca*. The terminal slit-like *mouth*, bounded by the horny beaks, forms a wide gape.

(b) Nostrils. At the base of the upper beak, open the two slit-like *external nares* or nostrils. Each nostril is dorsally overhung by a small, whitish, swollen area of barren, soft and sensitive skin, the *operculum* or *cere*. It is considered some sort of a receptor organ, useful in lovemaking, but it has not been proved. The nostrils can apparently be closed by the cere.

(c) Eyes. Behind the cere are located a pair of large, lateral and rounded *eyes*. Each eye is guarded by an upper and a lower eyelid and transparent third eyelid, or the *nictitating membrane*, which can be drawn independently across the eyeball from the anterior upper corner of the orbit. The eyelids are bare, without eyelashes and eyebrows.

(d) Auditory apertures. A little below and behind each eye, is an external ear opening, or the *auditory aperture*, hidden under special *auricular feathers*. It leads into a short tube, the *external auditory meatus*, which is closed below by the *tympanic membrane*.

2. Neck. The long and cylindrical neck is made very flexible by the modified cervical vertebrae. It serves for handling food and compensates for the conversion of the forelimbs into wings.

3. Trunk. The trunk is compact, stout and spindle-shaped. It bears midventrally a prominent bony ridge, the *keel* or *carina*. A large and transversely elongated *cloacal aperture* opens ventrally at the hind end of the trunk.

The trunk can be further differentiated into an anterior thorax to which the wings are attached, and a posterior abdomen to which the legs are attached.

4. Tail. The small stumpy, conical projection of the trunk beyond the cloacal aperture forms the true tail or *uropygium*. It bears a fan-like group of elongated tail-feathers or *rectrices*, which constitute what is ordinarily termed the tail. Dorsally the base of the tail (rump) has a knob-like papilla, which bears the opening of a large *preen gland* or *uropygial gland*. It is the only cutaneous gland present and its oily secretion is used for lubricating or dressing the feathers and also probably for keeping the horny beaks from becoming brittle.

The tail is used as a rudder in flight, to suddenly check flight, and as a balancer in perching and walking.

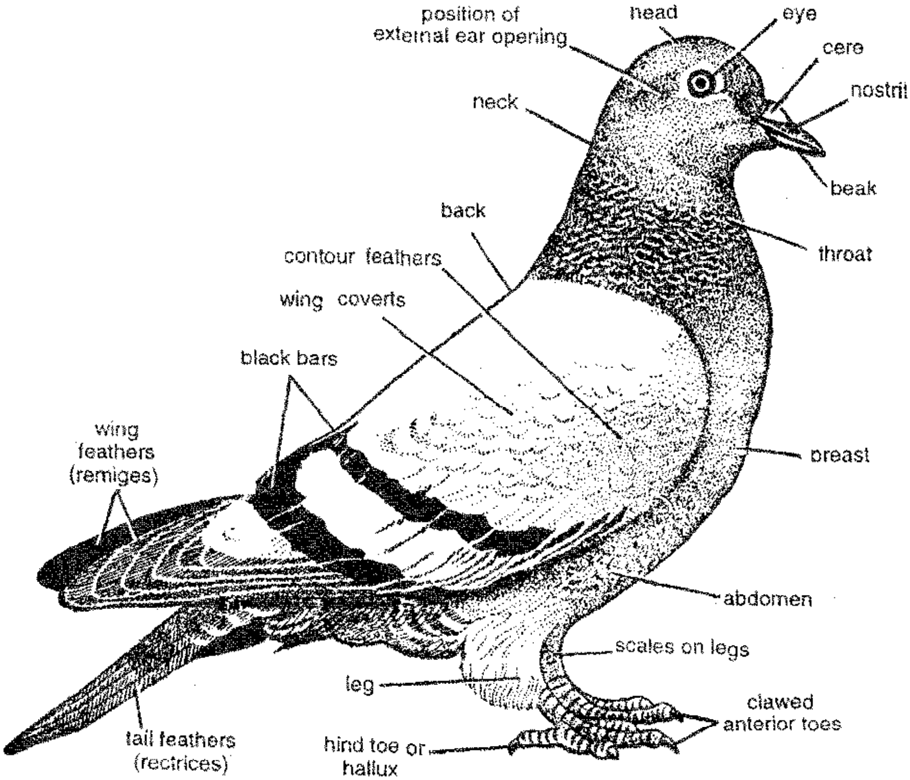

Fig. 2. *Columba livia.* Common rock pigeon. External features.

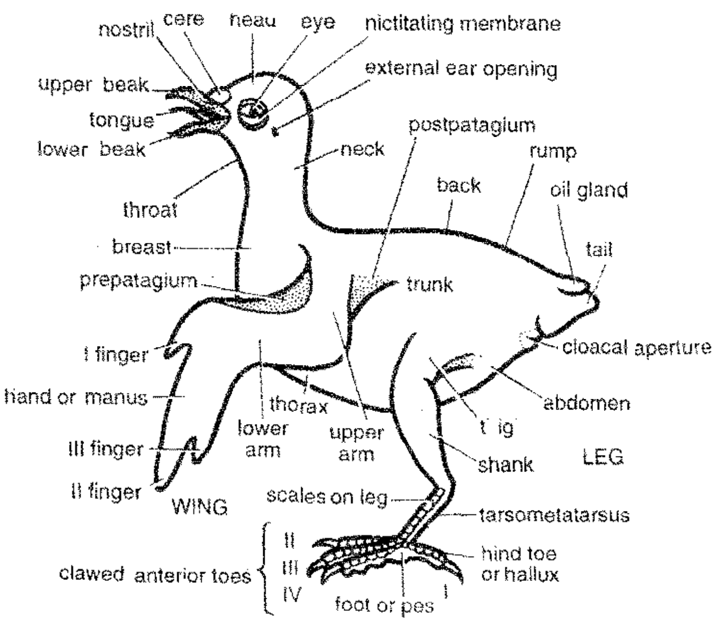

Fig. 3. Pigeon. Defeathered bird in left lateral view.

[III] Appendages

The limbs are two pairs : one pair of wings and one pair of legs, borne by the trunk.

1. Wings. The two forelimbs are modified into wings which are the chief organs of flight. They are attached high on the back, to the anterior or thoracic region of the trunk, and are very powerful when compared with the size and strength of the bird. Each wing is elongated, flattened and distally pointed with its longitudinal axis at right angles to that of the trunk. While at rest, it remains folded in the form of a Z. When extended the wing shows the three typical divisions : the upper arm or the *brachium*, the lower arm or the *antebrachium* and the hand or *manus*, all closely bound together by skin. The hand bears only three, imperfectly marked and clawless *digits*, of which the second is the largest. On the anterior or preaxial border of the wing, a fold of skin, called the *alar membrane* or *prepatagium*, stretches between the upper arm and the lower arm. A similar but smaller fold, *postpatagium*, is present posteriorly or postaxially between the upper arm and the trunk. The elongated flight feathers arising from the posterior margin of the wing are called *remiges*.

Wings provide broad surfaces for support in air. By vigorous downward strokes, they raise the body in air. Their various tilting and banking movements serve to alter the manner and direction of the flight.

2. Legs. The forelimbs being modified as wings, the hind limbs or legs spring somewhat anteriorly from the trunk in order to balance and support the entire weight of body at rest. Each leg is made of the usual three parts—thigh, shank and foot. The short and muscular *thigh* is directed downwards and forwards and closely bound to the trunk so that the knee is not visible. The long and muscular *shank* extends from the knee downwards and backwards. The foot or *pes* contains tendons but no muscles and remains covered by horny, epidermal *scales*, as in a lizard. Rest of the leg remains covered by feathers. Proximal slender part of foot is called *tarsometatarsus*. Distally, it bears four long and clawed digits or *toes*, of which the first or *hallux* is directed backwards and the remaining three, forwards. Feet are well adapted for perching with long toes and curved claws. Although slight in size, the legs are efficient organs of locomotion and the pigeons walk with considerable rapidity when traversing the ground in search of food. Walking on two legs provides *bipedal gait* to the bird.

Skin

Skin of pigeon is dry, loose, hard and thin. It consists of the typical two parts—outer *epidermis* and inner *dermis* (Fig. 4).

1. Epidermis. The epidermis is made of several layers. The outermost layer or *epitrichium* is composed of a single row of flattened delicate cells. The middle layer or *stratum corneum* is horny and protective and made of flat cornified cells. The inner layer called *stratum germinativum* or *stratum Malpighii* is made up of large, cylindrical and actively dividing cells.

2. Dermis. Dermis is mesodermal in origin and consists of muscle fibres, nerve fibres, blood capillaries and connective tissue. *Pigment* occurs in the scales and feathers only. *Cutaneous glands* are few or absent with the sole exception of a preen gland or *uropygial gland*, located dorsally at the base of the tail. Its only secretion is used to smear the beak and the feathers to make them waterproof and shining.

Exoskeleton

Exoskeleton of birds is purely epidermal and represented by horny claws, beaks, spurs, webs, scales and feathers.

1. Claws and beaks. Reference has already been made to the *claws* and *beaks* of pigeon. They are horny exoskeletal derivatives. They are variously modified in different birds. Beaks are used during ingestion, preening of feathers and fighting. Claws are used for perching and walking.

2. Spurs. *Spurs* are not found in pigeons. A spur is a bony projection of *tarsometatarsus* in the male of certain species of birds. It may be sharp and pointed and remains covered by a horny, scale like epidermal sheath. The spurs are best developed in the gallinaceous birds (e.g. fowls)

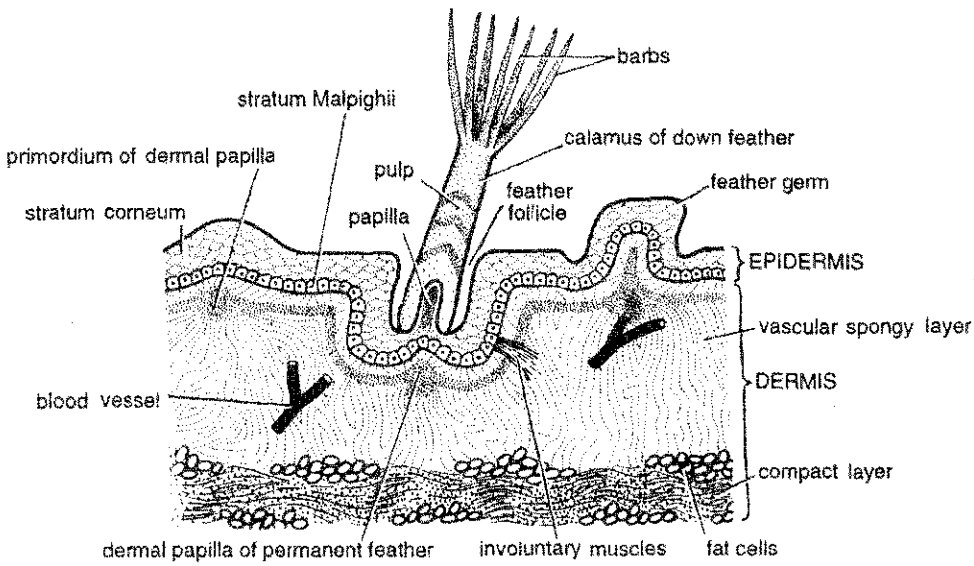

Fig. 4. Pigeon. V.S. of skin.

and used for fighting. Spurs may also occur on the wings (*carpometacarpus*) in certain birds.

3. Webs. *Webs* are modified folds of integument on the feet of aquatic birds, such as geese, swans and ducks. The skin forming webs is usually characteristically scaled.

4. Scales. The *scales* are confined to the feet or legs. They are not dermal scales, like those of fishes, but are epidermal scales of the reptilian type. They generally overlap and are formed in the same manner as those of snakes and lizards.

5. Feathers. A bird is often described as a feathered biped. The body of a bird is invested with a close covering of *feathers*, constituting the *plumage*. Feathers are supposed to be modified reptilian scales.

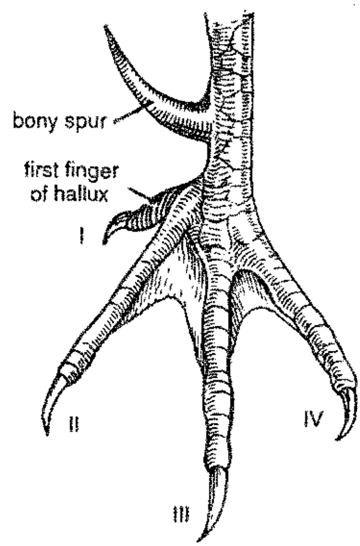

Fig. 5. Leg of male fowl (cock) showing spur. FEATHER TRACTS OR P ERY AE.

Feathers

The arrangement or distribution of feathers on the body is known as *pterylosis*. In flightless birds or Ratitae, feathers are uniformly distributed over the body. But in Carinatae, feathers are arranged in distinct patches or tracts, called *pterylae*, which remain separated by featherless interspaces, called *apteria*. The arrangement of pterylae varies in different orders, families and even species of birds. Principal pterylae found in pigeon are cephalic, cervical, humeral, spinal, ventral, alar, caudal, lumbar or femoral and crural (Fig. 6).

The feathers are characteristic of birds and do not occur in any other group of animals. They have been aptly designated the 'nature's masterpiece'. These unique structures are light, elastic, waterproof and most important in flight. The different colours of feathers are due to the

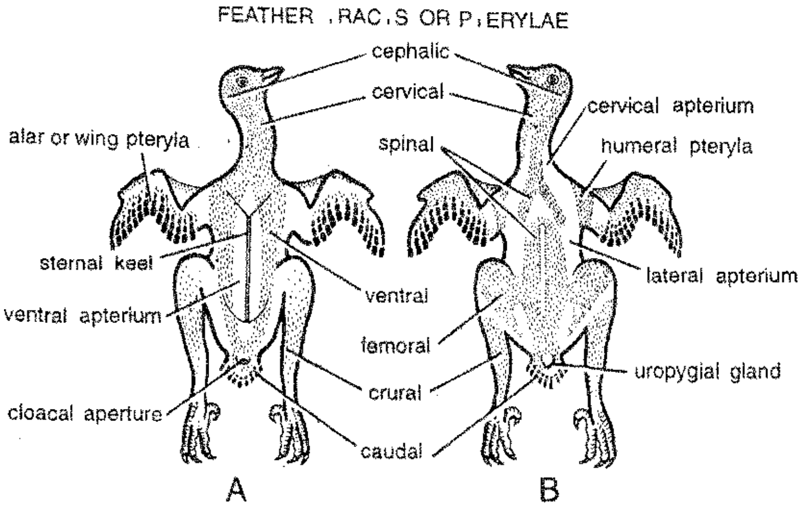

Fig. 6. Pigeon. Feather tracts (pterylosis). A—Ventral view. B—Dorsal view.

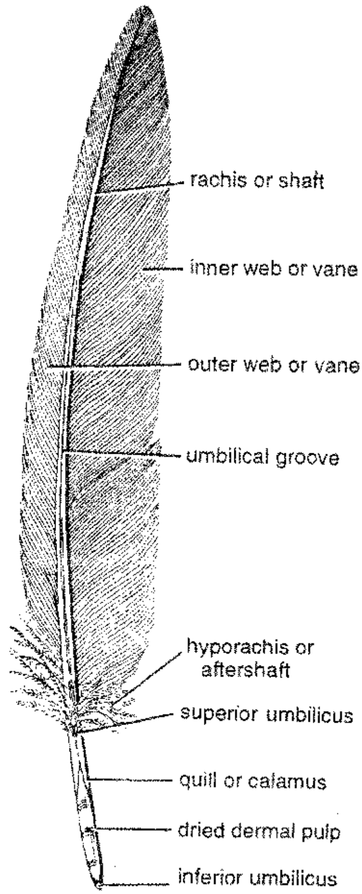

Fig. 7. Pigeon. Structure of a typical flight feather (remex) in ventral view.

presence of melanin of various shades as well as due to iridescence. They are variously modified in different birds to meet the diverse needs of these animated aeroplanes.

[I] Structure of a typical feather in pigeon

Any contour feather from the general body covering, or a flight feather present on wings or tail, provides the typical structure (Fig. 7).

A typical flight feather consists of a supporting central *axis* or *main stem*, and an expanded distal portion, the *vexillum* or *vane*.

1. Axis. The axis is divided in a proximal lower portion, the *calamus* or the *quill*, and distal upper portion, the *rachis* or the *shaft*.

(a) Calamus. The calamus or the quill is hollow, tubular in shape and semitransparent. The base of the calamus is inserted into a pit or epidermal *follicle* of the skin, from which muscle fibers pass to the feather and effect individual movements. At the lower end of the quill is a small opening, the *inferior umbilicus*, which receives a small conical nutritive papilla of the dermis, the *dermal papilla*, through which blood vessels enter to supply nutrients and pigments to the developing feather. A second minute opening, the *superior umbilicus*, occurs at the junction of the quill and the rachis on the inner or ventral side. In many birds, including some pigeons, a small tuft of soft feathers, called the *after-shaft* or *hyporachis*, arises near the superior umbilicus and covers it. In cassowary, emmu and extinct *Dinonris*, t e after-shaft is as long as the main feather, from which it arises. In the pigeon it is minute.

(b) Rachis. The rachis or the shaft forms the longitudinal axis of the vane. It differs from the calamus in being stiff, solid, opaque, roughly quadrangular in transverse section and filled with a closely packed mass of 'pith' cells. A longitudinal furrow, the *umbilical groove*, runs along the inner or ventral surface of the rachis throughout its length.

2. Vane. The expanded membranous part of the feather is called the *vane* or the *vexillum*. It is divided by the rachis into two unequal lateral halves and its distal end is narrower than the proximal end. The vane is formed by a series of numerous parallel and closely spaced, delicate, thread-like structures, the *barbs* or the *rami*. These arise somewhat obliquely from the two lateral sides of the rachis. The size of barbs gradually decreases towards the two ends of the rachis. Each barb in its turn gives rise to a double row of many extremely delicate, oblique filaments, the *barbules* or the *radii*. The barbules are of two types : *distal barbules*, directed towards the tip of the feather, and *proximal barbules*, directed towards the base of the feather. The lower edge of the distal barbules, is roduced into minute *hooklets, hamuli* or *barbicels*, while the upper edge of the proximal barbules is deeply curled or rolled forming a *groove* and *flange*. Owing to the oblique disposition, the barbules of the adjacent barbs, overlap and the hooklets of the distal barbules become interlocked with the curved edges or flanges of the proximal barbules (Fig. 8).

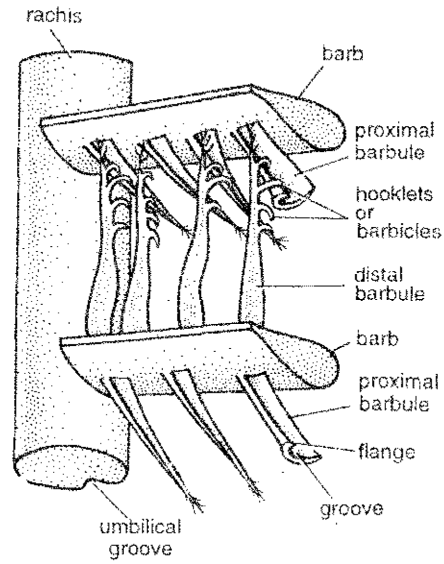

Fig. 8. A portion of vane highly magnified to show interlocking mechanism.

With this limited sliding interlocking arrangement, all the barbs and barbules are loosely held together, so that the vane forms a flexible, firm, wide, flat and continuous surface, ideal for striking the air in flight. These interlocking parts can be easily pulled apart, for, if the vane is stretched, it will first resist but eventually split. They can be slipped in place again and the original unity restored by drawing them through closed fingers. The birds repair such damaged feathers by preening or pulling them through their beaks.

The feathers of ostriches and kiwis, that have lost the power of flight, lack this interlocking mechanism and are very fluffy. After-shaft never possesses barbicles.

[II] Kinds of feathers in pigeon

From their varying forms, functions and locations, feathers are usually divided into several types. Of these, only quills, coverts, contours, filoplumes and down feathers are found in pigeon (Figs. 9 & 10).

1. Quills or flight feathers. The typical flight feathers or quills have a comparatively strong shaft. They are also characterized by the presence of barbules with an interlocking arrangement. They are further classified as given below :

(a) **Remiges.** Flight feathers of wings are termed *pinions, remiges* (singular, *remex*) or *wingquills*. Their inner or posterior half of the vane is slightly broader than the outer or anterior half. In pigeon, 23 remiges are attached to the hinder border of each wing. 11 of them attached to hand are called *primaries* or *manuals*. Of these first 4 attached to second digit are called *digitals*. 2 of these are *predigitals*, attached to distal phalanx and 2 *middigitals*, attached to proximal phalanx of second digit. The remaining 7 primaries attached to metacarpal region are called *metacarpals*, including 1 *addigital* connected with the third digit. The remaining 12 remiges connected with the forearm (ulna) are called *secondaries* or *cubitals*. A small but distinct tuft of feathers, called *ala spuria* or *bastard wing*, is attached to the pollex or thumb.

(b) **Rectrices.** In pigeon, 12 long *rectrices* (sing. *rectrix*) or *tail-quills* are arranged in a semicircle of fan-like manner on the tail. In them, the two halves of vane are almost equal in size. The rectrices help the bird as a brake and in steering the flight.

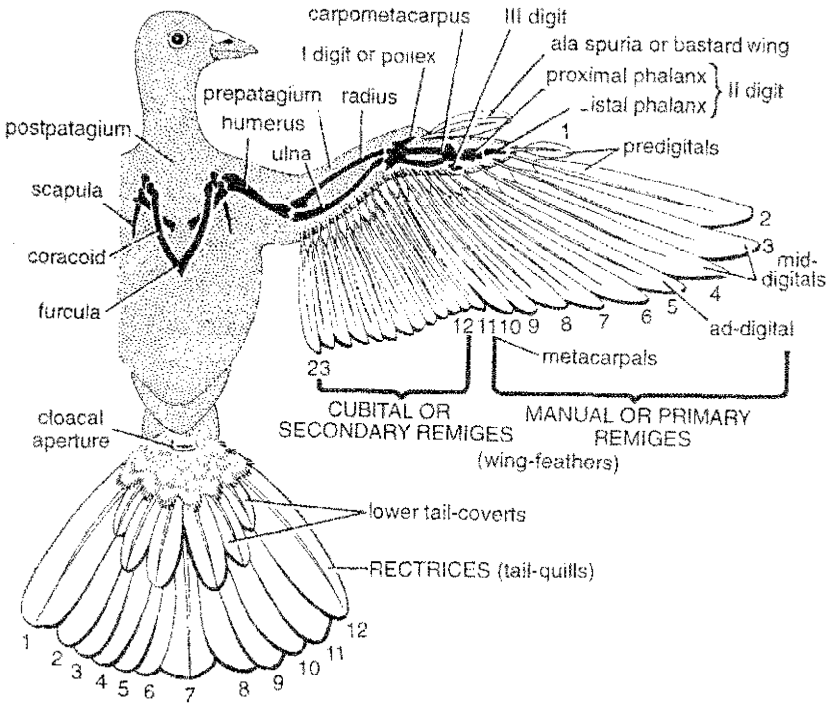

Fig. 9. Pigeon. Arrangement of flight feathers in ventral view.

(c) Coverts. Bases of wing-quills are covered by *upper* and *under wing-coverts* and bases of tail quills by *upper* and *under tail-coverts*. Coverts are smaller in size than the quill feathers to whom they are structurally similar. They close the interstices between quills of flight feathers, thus presenting a continuous area to oppose the buoyancy of air.

2. Contour feathers (pennae). These feathers, as their name implies, form the general covering of body. They are most typical in structure consisting of a central axis and a vane. They are smaller and woolly feathers, having poorly developed barbules, so that the barbs can be easily isolated. Contour feathers provide a smooth surfacing to body, reducing drag or frictional resistance to motion through air, give shape by overlapping of the vanes, and make a good heat-conserving layer.

3. Filoplumes (hair feathers or pin feathers). These are small, delicate and hair-like feathers of unknown function, which remain sparsely distributed over the body as seen in a plucked pigeon. A filoplume consists of a short calamus, and a long thread-like rachis with a few weak barbs and barbules at the free tip.

4. Down feathers (plumules). These are small, soft and woolly feathers which differ from contour feathers in the absence of a rachis. The barbs are long, flexible and with short barbules without hamuli and arising as a fluffy tuft from the top of the short calamus. They form the natal covering of the newly hatched birds providing excellent insulation. They are absent in the adult pigeon, being replaced by the permanent contour feathers.

[III] Other kinds of feathers in birds

1. Powder down feathers. These occur in many birds usually aggregated into special patches, such as the paired pectoral and pelvic yellowish patches on the skin of herons and bitterns and sometimes in scattered tracts and tufts as in parrots, rollers and the immature dammergeier. These are simply down feathers of which the tops never develop beyond the early stage and continually break down

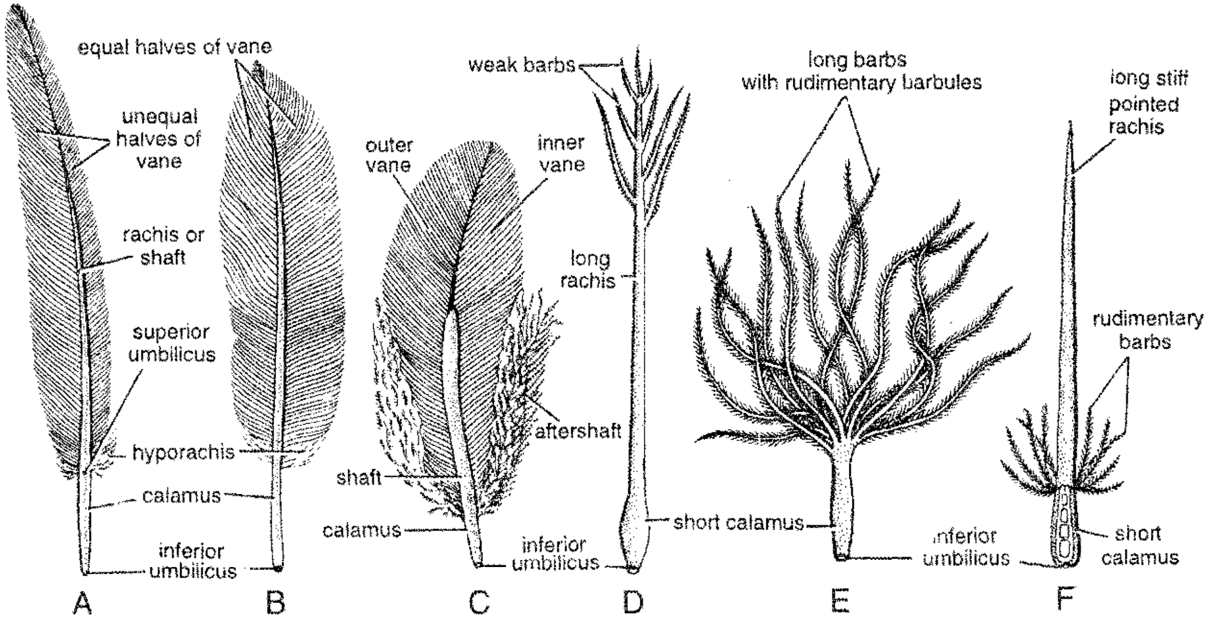

Fig. 10. Pigeon. Kinds of feathers. A—Remex. B—Rectrix. C—Contour. D—Filoplume. E—Down. F—Rictal bristle (not found in pigeon).

into a powdery substance. It has been suggested that they help to keep the plumage clean and in good condition—a sort of talcum powder.

2. Rictal bristles. Some birds have stiff hair-like feathers, believed to be modified filoplumes. Each bristle has a short calamus and a slender rachis with a few rudimentary barbs at its base. These are seen around the base of bill (rictus) of flycatchers, goat-suckers and whippoorwills.

3. Other types. *Tactile feathers* or *vibrissae* occur at the root of beaks or round the eyes and are best developed in nocturnal birds. Some of the peculiar feathers, such as the bristles at the gape of Night jars, *eye lashes* of Horn-bills, *wires* of Birds of Paradise, and *ornamental plumes* of many species may be derived from the contour feathers.

[IV] Development of feather

The feathers sprout from the bird's skin very much in the same way as hairs or scales do in mammals and reptiles.

1. Development of a down feather. Feather arises as a slight *dermal papilla* or *pimple*, about the 5th or 6th day of incubation, on the delicate and still semitransparent skin of the embryo. Each papilla is produced by an inner cluster of dermal cells, externally covered by epidermis. As the papilla grows, it takes the shape of a cone with its apex directed backwards. The base of the papilla then sinks into a gradually increasing *moat* or *feather follicle*, from which it projects as an elongated *feather germ* (Figs. 11 & 12).

Malpighian layer, covering the distal part of feather germ, forms a series of vertical radiating ridges, which later separate from one another converting into the *rami* or *barbs*. The lower part of feather germ remains intact, becomes uniformly thickened and forms the *quill*. The horny epidermal layer or *stratum corneum* forms a transparent and coherent cylindrical sheath, called *periderm*, which encloses the growing feather. The soft central dermal mass forms the *pulp*, which is the nutritive organ of the whole feather. It contains blood vessels which supply nutrients and colour pigments to the growing feather. As the feather grows and expands, the temporary horny sheath splits and peels off liberating the barbs, lying almost parallel with one another, yet slightly divergent. Apparently by secondary splitting, the barbs develop the *radii* or the *barbules*. In this manner, a rudiment of a *down feather* or *plumule*

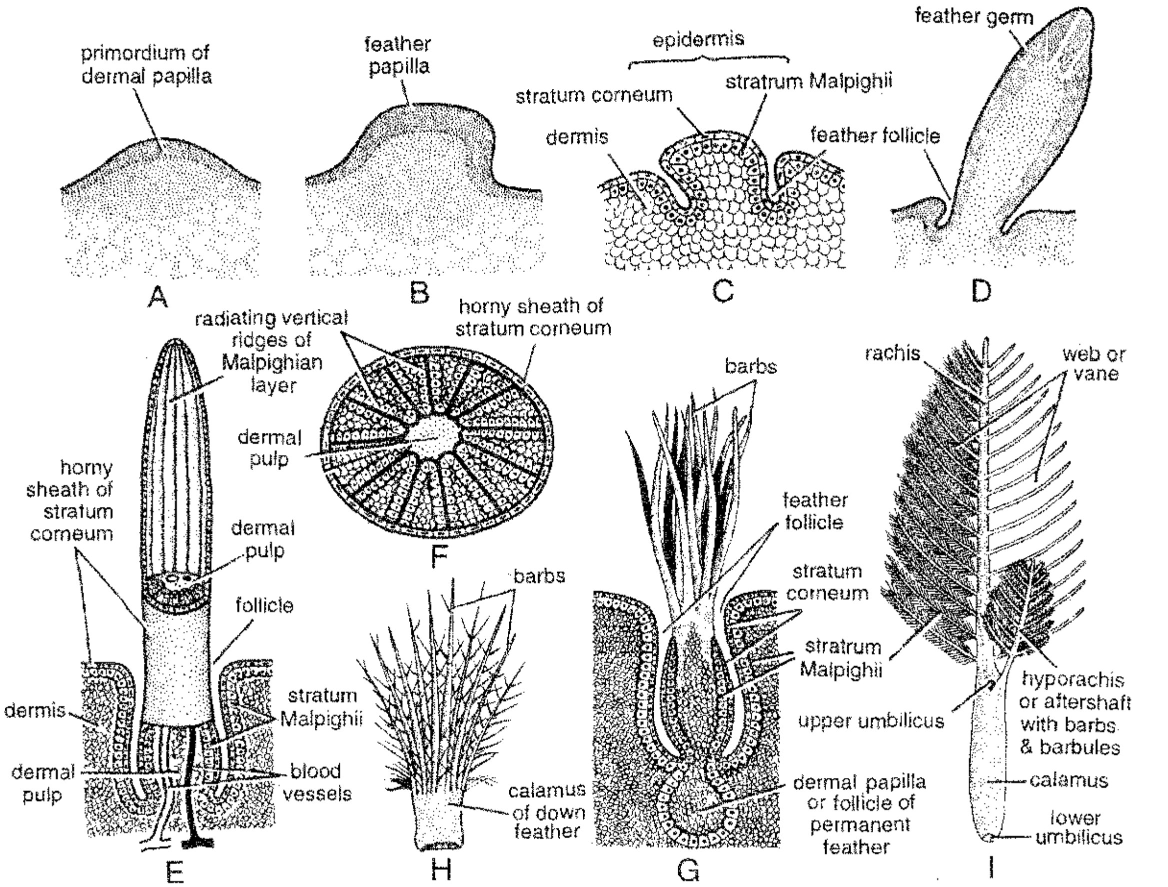

Fig. 11. Stages in the development of a contour feather. A—Dermal papilla. B—Feather papilla rising above skin surface. C—Feather papilla in V.S. D—Feather germ elongates. E—Stereogram of later stage in V.S. F—Feather germ in T.S. G—Down feather in its follicle in V.S. H—Mature down feather of a newly hatched bird. I—Young contour feather.

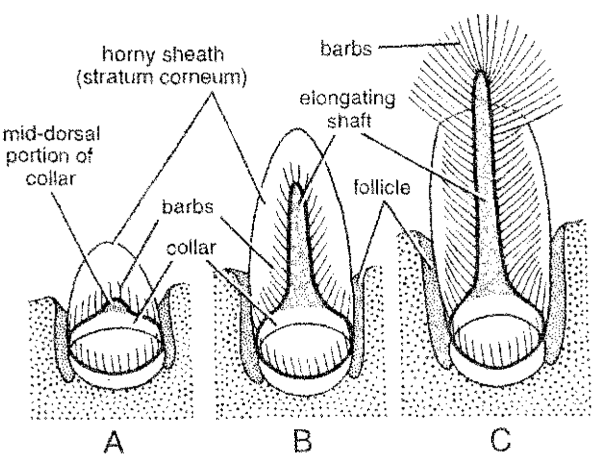

Fig. 12. Schematic development of a contour feather from the down feather stage.

is produced, having a number of barbs springing at the same level from the distal end of the quill.

2. Development of a contour feather. In case of a *contour feather*, a fresh papilla formed at a deeper level, so that the earlier structure (down feather) drops of from the apex o the latter. Development is similar up to the down feather stage. But the ridges of Malpighian layer do not remain all of one size. Instead, two of them in the centre of the dorsal surface fuse to form the *rachis*, and outgrow the rest due to differential growth. As the rachis elongates, it carries up with it the neighbouring barbs which become the lateral barbs. A similar fusion of two ventral barbs with differential growth results in the formation of the *after-shaft* or *hyporachis*. The line of fusion of two sides of the collar of Malpighian layer is represented in the completed feather by the umbilical groove.

The old feathers are shed periodically and the birds are said to moult. New feathers grow out from the follicles and the bird acquires new plumage. Pigments deposited during growth impart different colours to the feathers. The colours may change, fade out or decolour during life.

[V] Uses of feathers

Feathers serve a variety of important and decorative functions, some of which are as follows :

1. Protection. Feathers provide a light-weight, impervious, flexible but resistant and durable body covering. They protect the underlying tender skin from wear or any mechanical and physiological injury.

2. Heat retention. The most important physiological function of feathers is heat retention. Consequently, the birds maintain extremely high body temperatures, commonly 104° to 112°F, even in subzero weather. The plumage forms an efficient non-conducting covering with its innumerable dead air spaces, useful as insulation. In cold weather, the heat-loss is reduced to minimum by fluffing out the feathers, a practice which increases the depth of insulating material by adding to the air spaces within the feathery layers. Conversely, in warm weather, the feathers are often depressed or held close to the body to allow some escape of body heat.

3. Organs of flight. Feathers are light, elastic and horny structures. They furnish the bird with an admirably light-weight. The thin, flat and overlapping wing and tail feathers, with the close almost airtight linkage effected by the barbules and the hooklets, from surfaces to support the bird in flight.

4. Protective colouration or camouflage. Feathers may help to render the bird inconspicuous by their close resemblance to habitual surroundings. This camouflage or protective colouration guards them against their enemies.

5. Ornamentation, sex determination and courtship. On some parts of body, feathers become modified to serve decorative and ornamental functions or utilized in courtship displays. Usually the male birds have more showy feathers than females which helps them in attracting the females.

6. Natal covering. Down feathers are of special importance as natal covering in birds that are born in an advanced state of development (pheasants, ducklings) and as a dense undercoat in many aquatic birds.

7. Formation of nest. In great many cases feathers are used in the formation of nests. They not only conserve the heat around the imperfectly warmblooded nestlings, but make the brooding parent more comfortable.

8. Other uses. According to some Ornithologists, the peculiar powder produced by the disintegration of the powder downs in herons, bitterns, and other birds is useful in keeping the plumage in good order and checking the multiplication of ectoparasites. Other feathers form the eyelashes and still others project near the base of the beak, both probably akin to filoplumes. The spine-tipped rectrices of chimney-swifts and woodpeckers facilitate clinging to vertical surfaces. The conspicuous markings probably help in the recognition of kin by kin.

Feathers are used by man in a variety of ways. It may be surprising to know that some countries even export millions of pounds weight of feathers from different birds every year.

Inspite of the development of fountain pens and ball-points, some birds feathers are still used for special kinds of writing and drawing. In the past, of course, all writing was done with quill pens made from certain birds feathers. In fact, the word 'pen' is derived from a Latin word meaning 'feather'.

Feathers are used for stuffing cushions and mattresses. They are also used in medicine, for holding fine doctors brushes, for making 'flights' for darts used in games, and for battledores. In worldwar II, feathers were used for camouflage. Recently, there have been experiments with feathers as a substitute for hair in reinforcing plaster for buildings. Feathers can be useful to farmers too. When they are cleaned for industrial uses, they lose as much as one-third of their weight as dirt and foreign matter which makes a valuable kind of fertilizer for crops.

Endoskeleton

The endoskeleton of fowl (*Gallus*) has been described, in the Section on 'Vertebrate Osteology', because of its larger size which is more convenient for study than that of the pigeon.

Coelom and Viscera

The coelom or body cavity is spacious and divided into anterior *thoracic* and posterior *abdominal* cavities by a membranous *oblique septum* or *diaphragm* (Fig. 13). The thoracic cavity is further divided into 3 compartments : an antero-ventral *pericardial cavity*, enclosing the heart, and two dorso-lateral *pleural cavities* each enclosing a lung. The pericardial sac rests between

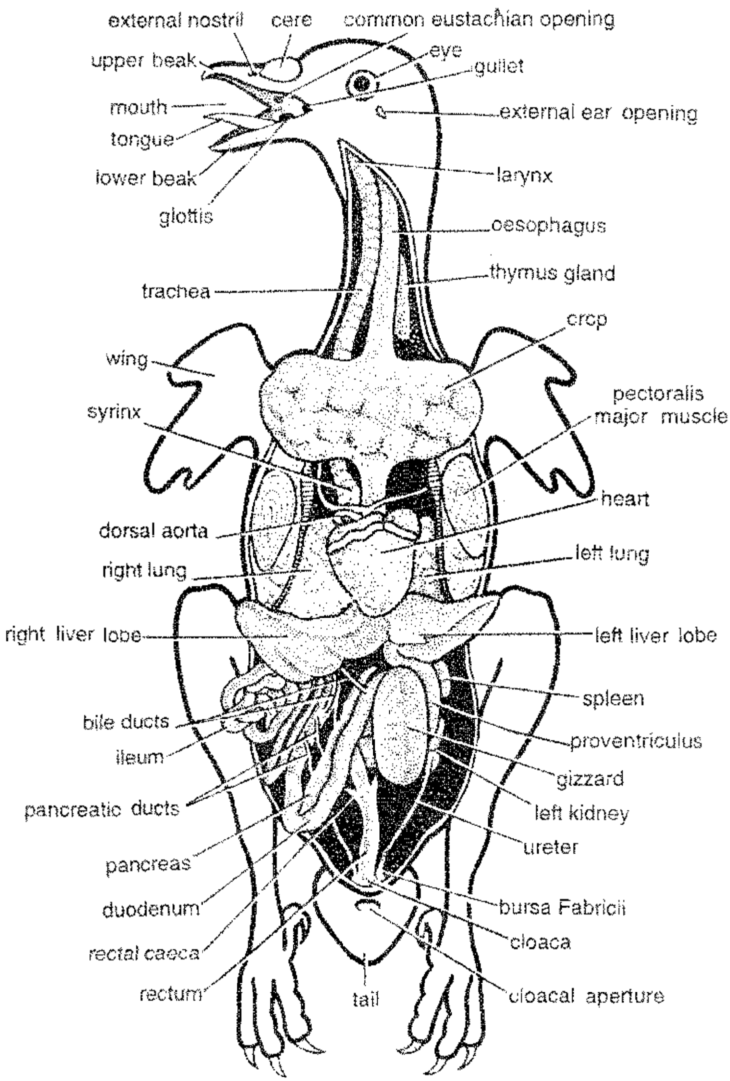

Fig. 13. Pigeon. Dissection of general anatomy.

the two lobes of liver, which are attached to the pericardial sac with the help of *coronary ligament.* The large abdominal or peritoneal cavity contains digestive excretory and reproductive organs suspended by meseneries. Coelom is filled with a coelomic fluid and lined by peritoneum.

Muscular System

The musculature of birds is generally highly developed and very efficient. The muscles are greatly specialized to serve different functions. Histologically, the muscles are of the usual three kinds : striated, unstriated and cardiac, as in other vertebrates (Fig. 14).

The diaphragm of the pigeon is rudimentary. The muscles of the back are almost atrophied due to inactivity or immobility of the trunk vertebrae. On the other hand, the muscles of the neck, tail, wings, legs and ventral side of the body are well developed. A large number of small cutaneous muscles serve to erect the feathers. But the most important muscles are those concerned with flight, bipedal locomotion and perching.

[I] Flight muscles

Birds fly by flapping their wings which are the modified forelimbs. Accordingly, the muscles moving the forelimbs are greatly modified. The flight muscles are many and belong to three main categories : pectoral, accessory and tensor.

1. Pectoral muscles. The most important flight muscles are the *pectoralis major* and *pectoralis minor.* They are mainly responsible for the up and down movements of the wings. These large flight muscles are attached to the keel of the sternum and to the wings. In some pigeons, they account for nearly one-half of the total weight of the body.

(a) ***Pectoralis major.*** The enormous triangular pectoral or *pectoralis major* is the largest and most powerful flight muscle arising ventrally from the sternal keel and the clavicle, one on each side, and forming the so-called 'breast'. These immense muscles include nearly one-fifth of the total weight of the body. They are dark red in colour due to rich blood supply. Anteriorly, the broad and flat

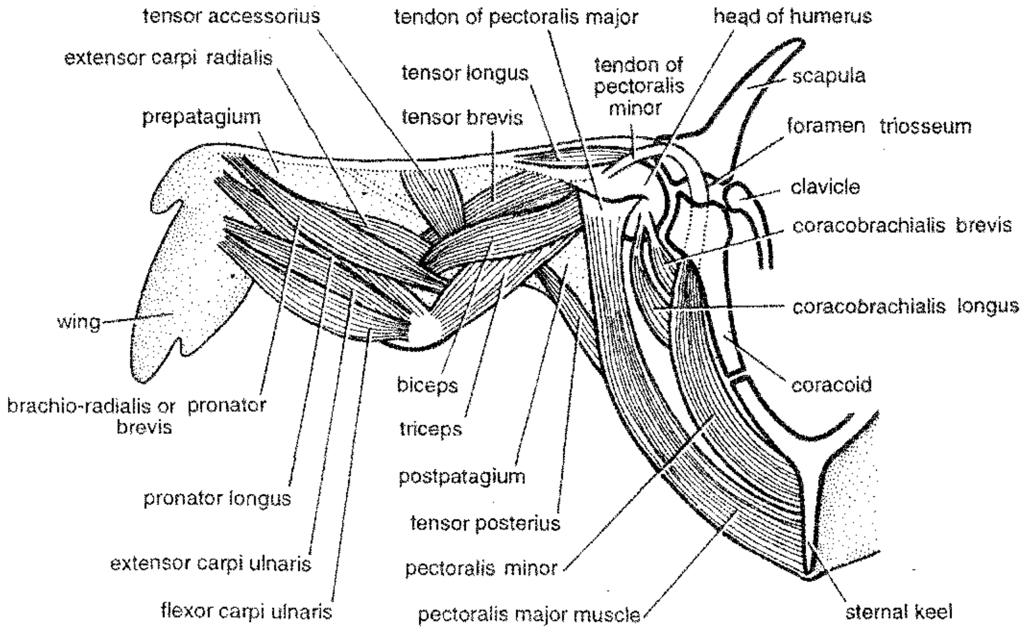

Fig. 14. Pigeon. Flight muscle of breast and right wing in ventral dissection.

tendon of each muscle is inserted on the ventro-lateral surface of the head of humerus or *great trochanter*. It is the *depressor muscle* causing the downstroke of the wing. When it contracts, the wing is pulled downwards and forwards, so that the body of the bird is lifted up and propels itself through the air.

(b) Pectoralis minor. In other vertebrates, the forelimbs are raised by muscles placed dorsally upon the back or shoulder. But in birds, the elevation of wing is performed by a ventrally placed smaller and elongated muscle, called *pectoralis minor*. It is also called the *deep pectoralis* or *supracoracoideus* or *subclavius*. It lies on the sternum, in the angle between keel and body, beneath the pectoralis major. Antero-dorsally it tapers to a long, strong and thin tendon which passes upwards through *foramen triosseum* to be inserted on the trochanter upon the dorso-posterior surface of the head of humerus. The foramen triosseum is an aperture or gap left between clavicle, coracoid and scapula. Pectoralis minor is an *elevator muscle*, causing the upstroke of the wing. When it contracts, the foramen triosseum acts like a pulley for its tendon, pulling the humerus backwards and upwards, thus raising the wing during flight. Pectoralis minor is large in birds with a quick take off, such as pigeons. It is the largest in humming birds, being nearly one-tenth of the total weight of the body.

During flight, the pectoralis major and pectoralis minor muscles contract and relax alternately in rapid succession. The pigeon can fly at the rate of 60 miles per hour.

2. Accessory muscles. Several small accessory muscles also help in elevating or depressing the wings. A small triangular depressor muscle, the *coraco-brachialis longus*, lies beneath the pectoral muscles. It arises from the corcacoid and the costal process of the sternum and its narrow tendon is inserted upon the posterior aspect of the head of humerus. A second smaller and narrower muscles, the *coraco-brachialis brevis*, lies in front of the previous muscle. They help to rotate the wing in the glenoid cavity.

Among important *intrinsic muscles*, the *biceps* and the *triceps* of the upper arm operate the elbow and perform adjustments during flight. The *extensor carpi radialis* and the *extensor carpi ulnaris* of the forearm also help them in the stretching and folding of the wing. Two *brachio-radialis muscles* help in the medial rotation of radius. The much reduced *digital muscles* also serve to move individual parts or even individual feathers during flight. The bastard wing or alula, attached to the first digit, is moved independently by *policis muscles*.

3. Tensor muscles. Three deltoid muscles keep the prepatagium fully stretched when the wing is spread out during flight. These are *tensor longus, tensor brevis* and *tensor accessorius*. A similar muscle, *tensor posterius*, keeps the postpatagium stretched during flight.

[II] Perching mechanism

The muscles of the legs are enlarged and strong. The shank and feet have few muscles and look slender and delicate. But certain muscles in the upper part of the legs have a special arrangement and long tendons for moving the toes. As a result, when a bird sits on a perch (branch of tree, wire or rod) and squats, its toes are mechanically flexed and firmly grasp the perch. The muscles involved are known as *perching muscles* and their arrangement is termed *perching mechanism*. This is quite automatic and its enables the bird even to sleep on a twig without any risk of falling down.

Perching muscles are characteristic of all birds. They comprise of two sets of muscles, *flexor* and *extensor*.

1. Flexor muscles. Gripping of the toes is chiefly accomplished by the action of 8 flexor muscles, 6 to the anterior toes and 2 to the hind toe or hallux. The muscles lie on the back of the tibiotarsus and are inserted upon the knee-joint. Their tendons form an elaborate system attached to the phalanges on their lower surfaces. Important flexor muscles are as follows :

(a) Ambiens. In many birds and reptiles, a small but characteristic muscle, the *ambiens*, arises

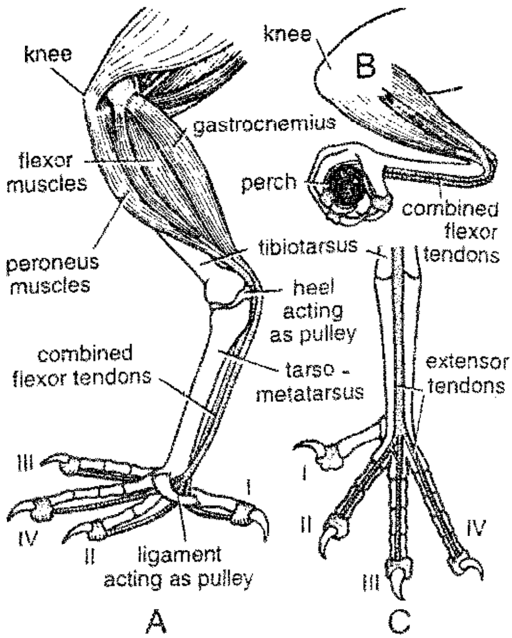

Fig. 15. Perching mechanism of a bird. A—Dissection of leg showing flexor muscles and tendons. B—Leg bent with toes flexed around a perch. C—Extensor tendons.

from the anterior part of the pubis and extends down along the inner surface of the thigh. Its tendon runs beneath the patella bone round the knee-joint and passes to the outer side of the tibiotarsus to join the upper end of the flexor muscle of the second and third toes. Since the ambiens is connected with two toes only, it plays only a minor role in perching and can be cut off without serious loss to the perching ability of the bird.

(b) Peroneus medius. This muscle is present on the anterior aspect of the shank, attached to the upper part of the tibiotarsus bone. Its tendon trifurcates to supply the three anterior toes.

(c) Gastrocnemius. It is the big calf muscle present on the back of tibiotarsus. Its tendon also joins those of the peroneus muscles to supply the anterior toes.

(d) Flexor perforans. This muscle is also attached to the upper part of the tibiotarsus. Its tendon passes to the hind toe or the hallux. It is joined by a slip with the peroneus medius, so that a pull on any tendon will flex all the toes.

All the flexor tendons pass behind the shank, over the heel or the inter-tarsal joint. Then they pass through an annular ligament beneath the foot to go to the different toes. When the bird rests on a perch, the leg is bent on the knee-joint, so that the flexor tendons, which pass over the inter-tarsal joint, become stretched. By the pull thus exerted the toes are automatically bent around the perch and grasp it firmly. All the flexor tendons are interconnected and act as a single unit, so that a pull upon any one tendon brings about the flexion of all the toes.

The toes also remain flexed on perch because of an interlocking mechanism. The under surface of the flexor tendons and the upper surface of the tendon sheath are ridged at the metatarso-phalangeal joint, which is pressed against the perch by the mere weight of the body. As soon as the bird settles on a perch, these two opposite sets of ridges interlock so that the toes remain flexed and the bird remains locked to its perch.

2. Extensor muscles. Several extensor muscles are found at the front of the tibiotarsus. The tendon of the *tibialis anterior muscle* passes down in front of the inter-tarsal joint and then trifurcates to supply one branch to each anterior toe. There they become attached to the upper surfaces of the phalanges. Their contraction serves to open the toes, when the bird raises its shank while taking off the perch. A nerve centre on the planter surface of the foot initiates the grip reflex when the foots touches the perch.

Digestive System

The digestive system of pigeon exhibits, like all other birds, a number of unique features and is adapted for rapid and efficient digestion. It includes the alimentary canal and the digestive glands. Due to loss of teeth and arial mode of life, digestive system is highly modified. The alimentary canal is short with respect to the size of bird. Moreover, its different parts are modified in such a way, that assimilation of digested food takes no time (Fig. 16).

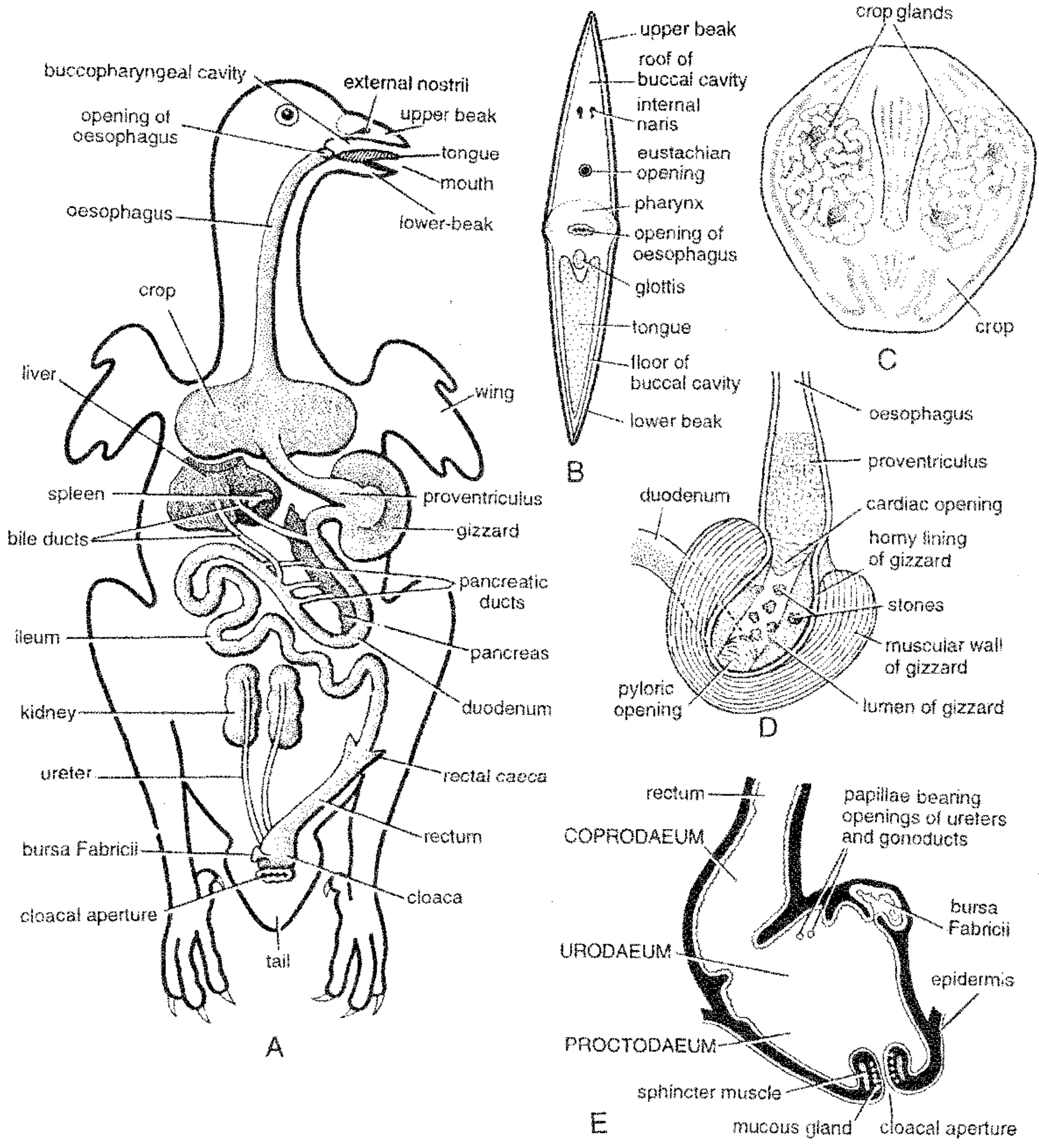

Fig. 16. Pigeon. Digestive system. A—Alimentary canal. B— Bucco-pharyngeal cavity. C—Crop cut open. D—Stomach in sagittal section. E—Cloaca in longitudinal section.

[I] Alimentary canal

The alimentary canal of pigeon is a long and coiled tube of varying diameter. It begins at the mouth, successively comprising the buccal cavity, pharynx, oesophagus, stomach, small intestine, and the large intestine, which terminates with the cloacal aperture.

1. Mouth. Mouth opening is a wide slit, bounded by upper and lower horny beaks, which are without teeth. Mouth opens into buccal cavity.

2. Buccal cavity. The interior of buccal cavity is comparatively featureless. Its floor is occupied by the *tongue* which is large, narrow, somewhat triangular and pointed at the tip. Taste buds are scanty but numerous mucous glands are present.

3. Pharynx. Posterior part of buccal cavity may be termed pharynx. A pair of elongated apertures, the *posterior nares*, open on its roof. They are largely covered by the palatal folds of the skull roof. Behind the nares opens the single median aperture of the *eustachian* or *pharyngotympanic tubes*. Each tube extends from its opening to the cavity of the middle ear. The tube and the cavity are derived partly from the evagination from the first *visceral pouch*. The floor of pharynx has an oval aperture with tumid lips, the *glottis*, which leads into the trachea.

4. Oesophagus and crop. Posteriorly, the pharynx leads into a long wide, distensible and thickwalled tube, the *gullet*, or *oesophagus*. It runs back through the neck to join the stomach. At the base of the neck and just in front of the sternum, the middle of oesophagus at once expands into a thin-walled, bilobed, elastic sac, the crop. It serves as an immense food reservoir into which the hurriedly swallowed, dry and hard food-grains are stored, moistened and softened.

Pigeons are noted for their unique ability to produce 'pigeon's milk', a soft, cheesy and nourishing secretion, from both the sexes, especially during the breeding season. It is formed by the degeneration of the epithelial cells lining the crop. It is regurgitated into the mouth of the young birds until they are old enough to manage a grain-diet like their parents. The *prolactin* hormone, secreted by the anterior lobe of the pituitary gland, stimulates and controls the formation of the pigeon's milk which includes water, fat, protein (casein) and lactose. The milk is produced by both sexes and contains water 65-81%, protein 13.3-18.8%, fat 6.9-12.7% and ash 1.5%. The 'bird milk' is also produced in some parrots.

The crop also contains mucus-secreting glands. Beyond the crop, the oesophagus again becomes thick-walled, as it enters the stomach.

5. Stomach. The stomach of pigeon is differentiated into two parts : an anterior glandular *proventriculus*, and a posterior muscular *ventriculus* or *gizzard*.

(a) Proventriculus. The proventriculus is a small but thick-walled sac, externally appearing like a slight dilation of oesophagus. Its thick mucous lining secretes the gastric juice. A small, oval and red body, the *spleen*, is attached by peritoneum to the right side of the proventriculus.

(b) Gizzard. The large, hard and laterally compressed gizzard has the shape of biconvex lens. Its walls are thick and muscular. The small and narrow lumen is lined by an epithelium which is thick, rough, horny and yellow or green in colour. It has many tubular glands. The cavity of gizzard always contains grit or small pebbles called *gastroliths* swallowed by the bird. These stones help the gizzard in grinding up the food. The opening of gizzard into small intestine is guarded by a sphincter, called the *pyloric valve* or *pylorus*.

6. Small intestine. The mid-gut or the small intestine is a narrow tube about 75 cm long. It comprises an anterior *duodenum* and a posterior *ileum*.

(a) Duodenum. The duodenum leaves gizzard dorsally, so that the *pyloric opening* of gizzard into duodenum lies close to the *cardiac opening* of proventriculus into gizzard. The duodenum forms a distinct U-shaped loop enclosing the pancreas between its two limbs. Internally duodenum contains *villi*, *crypts of Liberkuhn* and *goblet cells*. The duodenum receives three ducts from pancreas and two bile ducts from the liver.

(b) Ileum. The rest of the small intestine, or ileum, is a very long and extensively convoluted tube of uniform diameter. Its inner lining is thrown into numerous, minute, finger-like processes, or *villi*, which greatly increase its area of secretion and absorption.

7. Large intestine. The slender ileum passes without any change of diameter into the large intestine. The junction of the two is externally marked by the presence of a pair of small, conical, blind pouches, the *rectal* or *colic caeca*, which probably absorb some water from the food. The large intestine or hind-gut is an exceedingly short tube, because the faecal matter is relatively small. It is differentiated into an anterior *rectum* and a posterior *cloaca*.

(a) Rectum. The rectum is narrow, about 4 cm long and of the same diameter as the ileum. Its opening into cloaca is guarded by an anal sphincter.

(b) Cloaca. The terminal part of alimentary canal is cloaca. It is a large prominent tripartite chamber divided into three linear compartments : an anterior *coprodaeum*, which receives the rectum, a short middle *urodaeum*, into which the ureters and the genital ducts open, and a large posterior *proctodaeum*, which opens to the outside by the *cloacal aperture* or *vent*. A small, glandular, thick-walled blind pouch of lymphatic tissue, the *bursa Fabricii*, lies against the dorsal wall of proctodaeum in young birds, but atrophies in the adult, before sexual maturity. Its function remains uncertain. Its endodermal lining produces lymphocytes which probably protect against local infection in the cloaca. Thus, it is often described as *cloacal thymus*, as it resembles the thymus gland which is also lymphatic.

[II] Digestive glands

1. Buccal glands. Small *buccal glands* are present in the buccal cavity but they are probably not salivary. They secrete mainly mucus to moisten food and probably amylase. The tongue also contains mucous glands.

2. Salivary glands. Paired *angular* and unpaired *sublingual* salivary glands are found in the pharyngeal region. The secretions of these glands are called *saliva* which moistens the food. However, a few ornithologists believe that it contains enzymes too.

3. Gastric glands. The thick epithelial lining of proventriculus contains numerous *gastric glands*, so large as to be visible to the naked eye. These secrete the gastric juice containing peptic enzymes.

4. Liver. The liver is relatively large, compact, dark-red and bilobed, consisting of a larger right lobe and a smaller left lobe. The surface of the liver is hollowed to receive the heart, duodenum and gizzard. There are two *bile ducts*, one from each liver lobe. The left bile duct opens into the proximal limb and the right bile duct into the distal limb of the duodenum. There is no *gall bladder* in the common pigeon, though it is present in some birds and even in some species of pigeon. Loss of gall bladder is an adaptation to aerial mode of life. The liver secretes bile.

5. Pancreas. The *pancreas* is a compact reddish gland, lying between the two arms of the duodenum into which it discharges its secretion. There are three *pancreatic ducts*, all opening into the distal limb of the duodenum. The pancreatic juice contains several enzymes.

6. Intestinal glands. The endothelial lining of the small intestine contains innumerable microscopic glands, producing various enzymes.

7. Tubular glands. Internal lining of the gizzard contains these glands. The fluid secreted by these glands is thick, horny and yellowish green in colour.

8. Caecal glands. Produce digestive juices for the digestion of vegetable fibers. These glands are also helpful in absorption of water from food.

[III] Food, feeding and digestion

Birds are highly selective in their diet and eat food that can be largely utilized. The pigeons feed chiefly on cereals, pulses, seeds and sometimes small insects, which are picked up with the beak. The tongue manipulates and lubricates the food-grains in mouth cavity, with the secretion of buccal glands. As there are no teeth, the food, swallowed, as such passes through the oesophagus into the crop where it is stored. Here it is thoroughly mixed with water, mucus and secretion of buccal glands, and considerably softened, aided by the warmth of the body, by buccal amylase and by bacterial and autolytic action. The crop walls do not produce any enzyme. From crop the food enters the proventriculus, where it is chemically acted upon by the secretions of the gastric glands containing a peptic enzyme. Gastric secretion is intermittent and under the control of the nervous system. The food grains are crushed and ground up in the gizzard by its muscular contractions id d b its ifi d ith liu and small stones swallowed by the bird. The gizzard is more acidic than the crop, implying that its walls secrete hydrogen ions, but there is little digestion here. The ground up and partly digested food, known as *chyme*, passes through the pylorus into the duodenum, where it is mixed with the bile and the pancreatic and intestinal juices. Secretion of enzymes and digestion is similar to those in mammals, and all the three classes of foodstuffs are digested. The bile salts probably help in the digestion and absorption of fat, as in mammals. The digested food is absorbed through the wall of the ileum and the caeca. The peptones are absorbed through the lymphatic system into blood. The other digested portions are absorbed through villi or projections of the lining of the ileum. The undigested part is very little. It passes into the rectum and cloaca, to be finally ejected through the cloacal aperture. The faecal matter is almost dr du t rab r ti f r i h r u .

The food requirements of birds are great and digestion is rapid because of the high rate of metabolism. An average bird must eat at least half of its body weight every day. Some, like humming birds, must eat far more than this. These animated flying machines require tremendous energy to operate their powerful breast muscles. Their tremendous metabolic efficiency makes it possible for them to transform one-third of their food stuffs into energy. Mammals can convert only one-tenth of their food into energy.

Respiratory System

The intense activity of flight demands large supplies of oxygen, as the respiratory system of birds is more complicated than of any other vertebrate (Fig. 17). Respiration is *pulmonary* and the respiratory organs are fairly simple. A true muscular *diaphragm* is absent in birds and the expansion of the thoracic wall is limited. The *lungs* are relatively small and compact organs, continued into a unique system of *air sacs*. The *expiration* is more active process than *inspiration*.

The respiratory system includes the *respiratory tract*, the *respiratory organs* or the *lungs* and the *air sacs*.

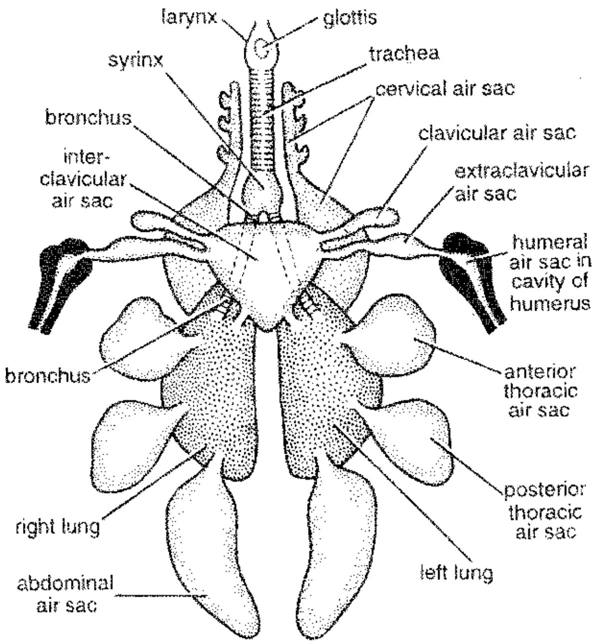

Fig. 17. Pigeon. Respiratory system in ventral view.

[I] Respiratory tract

It includes the nares, nasal sacs, glottis, larynx, trachea and syrinx.

1. Nares. The *nostrils* or *external nares* are a pair of slit-like oblique openings lying at base of the upper beak, overlapped by a swollen sensitive pad of skin, the *cere* or *operculum*. The nostrils lead into short *olfactory or nasal sacs*, which open directly into the pharynx by *internal nares*.

2. Trachea. A median slit-like opening, the *glottis*, situated just behind the root of the tongue, leads into the wind pipe or trachea. At its anterior end, the trachea has an expanded voiceless chamber, the *larynx*. It is greatly reduced in birds. It is supported by a *cricoid* cartilage composed of four pieces, and by paired *arytenoid* cartilages. But the thyroid cartilage and the *vocal cords*, characteristic of mammals, are absent, so that larynx does not produce sound in birds.

The *trachea* is a long, cylindrical and flexible tube running back through the neck, ventral to the oesophagus, but is displaced to the left in the middle region by the crop. On entering the thoracic cavity, it expands into a syrinx and then bifurcates into two short *bronchi*, one for each

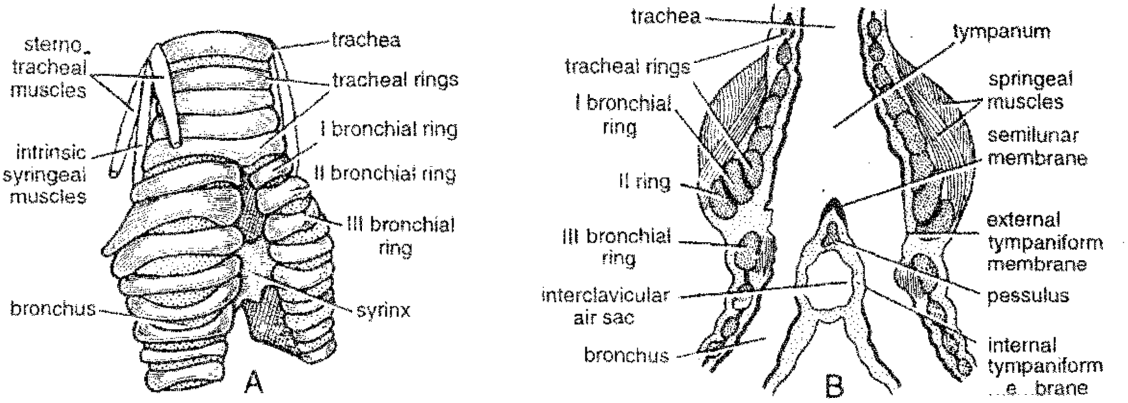

Fig. 18. Pigeon. Syrinx. A—External view. B—Diagrammatic L.S.

lung. The trachea and the bronchial tubes are supported by a series or closely-set *rings*. All the tracheal rings and the first bronchial rings are complete and bony; the rest of the bronchial rings are incomplete mesially and cartilaginous.

3. Syrinx and sound production. At the posterior end or base of the trachea, at its junction with the bronchi, is found a special structure, the *syrinx* or *voice box*, concerned with sound production (Fig. 18). It is characteristic of birds as it does not occur in other vertebrates. Syrinx consists of an expanded chamber, called *tympanum*, the walls of which are supported by the last three or four rings of trachea and the first half ring of each bronchus. At the junction of the two bronchi a bony ridge, the *pessulus*, extends dorso-ventrically. It supports a small, vibratory *crescentic* or *semilunar membrane*. The mucous membrane of each bronchus forms an *internal tympaniform membrane*, associated with the inner wall and an *external tympaniform membrane* associated with the outer wall. These membranes are controlled and regulated by a pair of *intrinsic syringeal muscles*, which arise from the sides of the trachea and are inserted into the syrinx, and a pair of *sterno-tracheal muscles*, which arise from the sternum and are inserted into the trachea. The voice is produced by the vibrations of the tympaniform membranes as the air expelled from the lungs, during expiration, passes between them. The pitch of the voice is altered by changes in the tension of these membranes controlled by the syringeal and sternotracheal muscles. The semilunar membrane may supplement the vibrations of the tympaniform membranes.

The syrinx is absent in ostriches, storks and some vultures.

[II] Respiratory organs or lungs

The two bright-red lungs are small, compact and non-elastic bodies. They are different from the lungs of other vertebrates in that they do not store air. They do not hang freely in thoracic cavity, but are closely applied by their dorsal surface to thoracic vertebrae and the ribs (Fig. 19). Dorsally, they have no peritoneal covering. The ventral surface is free and covered by a thick sheet of fibrous tissue, the *pleura* or *pulmonary aponeurosis*, a special development of the peritoneum. Small fan-like *costo-pulmonary* or *inter-costal muscles*, which arise from the junction of the sternal and vertebral ribs, are inserted in the pleural covering.

The two lungs of a bird are rather solid, spongy structures, as in a mammal, and not hollow thin-walled sacs with lobulated walls, as in frog.

The antero-ventral end of each lung is pierced by a bronchus. It is termed, *primary bronchus* in birds. Within the lung it loses its cartilaginous rings, reaches up to its distal or posterior end, and becomes the *mesobronchus*. It sends branches into air sacs and also gives off *secondary bronchi*, which may be distinguished as dorsal, ventral and lateral, according to their position. The secondary

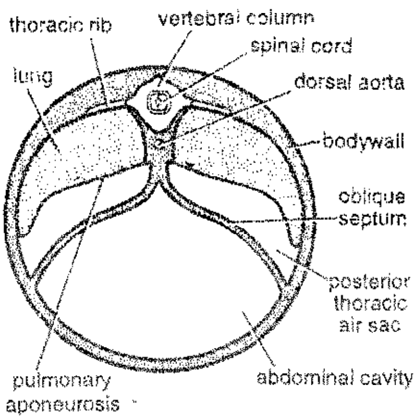

Fig. 19. Pigeon. T.S. thorax showing position of lungs.

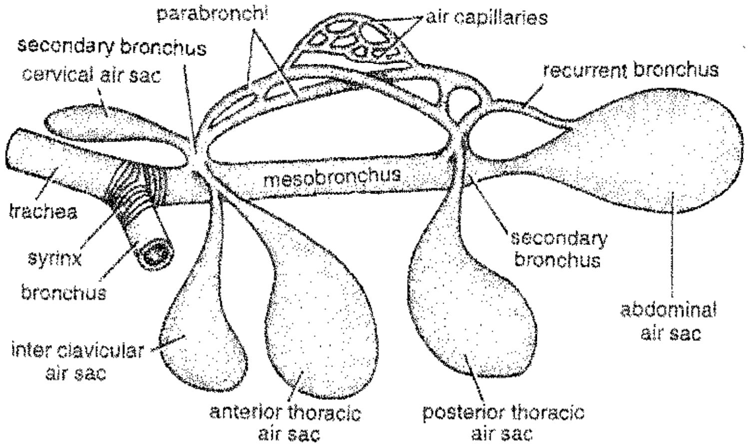

Fig. 20. Pigeon. Scheme of histological structure of a lung and origin of air sacs.

bronchi (*dorsobronchi* and *ventrobronchi*) branch again into many *tertiary bronchi* or *parabronchi*. These give rise to an intricate system of ramifying and anastomosing fine, thin-walled tubules or *air capillaries*, forming loops, and forming the main substance of the lung. The lung parenchyma shows hexagonal areas or units, each consisting of a central parabronchus, surrounded by a system of associated air capillaries with interlacing blood capillaries. Each air capillary opens at both the ends into a parabronchus. There are no blind pouches or alveoli. As the parabronchi and air capillaries join with their neighbours, none ends blindly. As a result, there is no dead space in lungs, through which air does not flow. The inner vascular surfaces of the air capillaries serve as respiratory membranes through which gaseous exchange with blood occurs. This is quite unlike the lung of a mammal in which blind pouches, or *alveoli*, provide the respiratory membranes. In spite of its small size and inelasticity, the avian lung is more efficient than that of any other vertebrate.

[III] Air sacs

Around the lungs and connected with the ends of the main bronchial branches are remarkable, large, thin-walled, membranous, non-muscular and non-vascular *air sacs* (Fig. 20). They are formed by the dilation of mucous membrane of bronchus. They lie among the viscera and even extend into some of the larger bones. Their total volume is several times than that of the lungs and they fill up much of the body cavity. Their general pattern is the same but slight differences occur between different species of birds. They arise from the secondary bronchi except the abdominal air sacs, which arise at the posterior end of the mesobronchus. Openings of bronchi into air sacs are termed *ostia*. All air sacs remain in communication with the pneumatic cavities of the bones. Except the cervical air sacs, all others rejoin the bronchi, through *recurrent bronchi* or *saccobronchi*. Air sacs are paired in origin but in pigeon, the two interclavicular air sacs fuse early in development. Thus there are 9 major air sacs in pigeon. They are named according to their location in the body such as interclavicular, cervical, anterior thoracic, posterior thoracic and abdominal. A layer of fibrous tissue, the oblique septum, encloses the ventral walls of both thoracic air-sacs. It extends up to the pericardium and joins the similar septum of the other side along the middle line and divides the body cavity into the chambers. In one chamber lungs, thoracic and interclavicular sacs and in the other heart, liver, stomach, intestine and abdominal air sacs are enclosed.

The 9 major air sacs of pigeon are as follows :

1. Interclavicular. It is a single median and somewhat triangular air sac, connected with both lungs. It is situated in the angle between the two limbs of the furcula. On either side, it gives off an *axillary* or *extra-clavicular sac* in the arm-pit, communicating with an air-cavity of the *humerus*, and a *clavicular sac*.

2. Cervical. A pair of small cervical sacs arises anteriorly, one from each lung. They lie at the base of the neck, dorsal to the interclavicular and alongside the vertebral column. They give off minor saccules in the neck.

3. Anterior thoracic. A pair of anterior thoracic air sacs lies ventral to the lungs in the anterior part of the chest, in close contact with the ribs and the pericardium. They extend back so as to overlap the posterior thoracic air sacs.

4. Posterior thoracic. The pair of small posterior thoracic air sacs is found in the posterior part of the thoracic cavity, just in front of the abdominal air sacs. Each sac overlaps the posterior end of its lung and communicates with its outer posterior angle.

5. Abdominal. A large *posterior* or *abdominal air sac* arises from the outer posterior angle of each lung. They lie along the dorsal wall of the abdomen, ventral to the kidneys, amongst the coils of the small intestine.

Functions of air sacs. The air sacs communicate with bronchi on the one hand, and with the pneumatic cavities of the bones, on the other hand. The following functions have been attributed to them.

(a) Lightness. They probably act as *balloons* to provide *lightness* and *buoyancy* to the body, probably by reducing the specific gravity of the body, although this view is no longer supported now.

(b) Flight. Their association with *flight* is also confirmed by the fact that the best fliers amongst birds possess the most highly developed air sacs.

(c) Accessory respiratory organs. The sacs function principally as the *accessory breathing organs*. Their smooth lining is devoid of capillaries and does not take part in gaseous exchange. But they serve as *reservoirs* and take part in the movements of air during respiration. They take care of the residual (dead) air, thus ensuring a complete renewal of air in the lungs at each breath. At each expiration, they act as *bellows* forcing their air out through the lungs, thus leaving no dead space or unrespired air in the lungs.

(d) Temperature regulation. They may also aid as cooling devices in the regulation of the temperature of the body, thereby compensating for lack of sweat glands. It occurs by internal perspiration i.e., water vapours diffuse from blood into the cavities of air sacs and pass out through the lungs, accompanied by loss of body heat.

(e) Cardiac movements. Another probable function of air sacs, according to Muller (1908), appears to allow for the movement of the heart in an otherwise very rigid thorax.

(f) Balancing. Air sacs are arranged nicely on the two sides of the body so that the proper center of gravity is maintained for the flight. If some how the equilibrium is altered, it is restored by shifting the contained air from one side of the body to another.

(g) Minimized mechanical friction. Air sacs and its bronchus are inserted between muscles like pads which reduces mechanical friction during flight.

(h) Resonator. Air sacs help in forceful expulsion of air and controls the pitch of sound thus, act as resonator.

[IV] Respiratory mechanism

The breathing in birds has many peculiarities. The lungs, though relatively small and non-distensible due to a rigid skeletal framework around them, have a large internal surface for gaseous exchange. Expiration is an active process, not inspiration as in other vertebrates. The breathing mechanism is like that of a suction pump, and differs at rest from that during flight. We still do not know exactly how the system works and the exact course of air within it.

1. Ventilation at rest. When the bird is resting, its sternum rises and falls alternately by the activity of abdominal and intercostal muscles. During *inspiration*, the sternum is lowered, the air sacs expand and the lungs are compressed. As a result, fresh, air moves through nostrils, trachea and mesobronchus into the posterior air sacs. At the same time, air already present in the lungs moves to the anterior air sacs. During *expiration*, the sternum is raised, the air sacs compressed and the lungs expand. Air high in O_2 content moves from posterior air sacs into the lungs, and the stale air of anterior air sacs moves into the mesobronchus, the trachea, then out through the nostrils.

2. Ventilation during flight. During flight, the sternum is rendered immovable and the air goes in and out of the lungs by the elevation and depression of the back, synchronized with the strokes of the wings. The faster a bird flies, the more rapid is the air circulation and gaseous exchange in the lungs.

[V] Efficiency of avian lungs

The presence of anastomosing and intercommunicating air capillaries in avian lungs, accompanied by the presence of air sacs, brings about several advantages :

(1) There is a one-way flow of air through the air capillaries. The direction of air in lung is counter to that of the blood flow, as also found in the gills of many fishes.

(2) The inspired air rushes through the lungs into the air sacs and thence into the pneumatic cavities of the bones. Unlike other vertebrates, the avian lung, therefore, is completely emptied at each breath. There is no dead space in the lungs, the residual air being confined to the air sacs.

(3) Moreover, the air of lungs is renewed twice at every breath, once during inspiration and again during expiration.

(4) The air does not travel back during expiration through the same route by which it entered during inspiration. Most air reaches the air sacs directly through the secondary bronchi. But from air sacs it goes back into the lungs through separate ducts, called the *recurrent bronchi*.

(5) The respiratory rate of birds is also very high. In pigeon, it is 29 times per minute at rest, as contrasted with 14 to 20 times per minute in man. As the air passes over the respiratory epithelium rapidly and several times, the aeration of blood is very complete in birds and their body temperature is relatively higher than that of other vertebrates. Their body temperature varies from 40.5°C (105°F) to as high as 46°C (115°F).

This explains how the small and non-elastic avian lungs function more efficiently than those of other vertebrates, in spite of the fact that birds have the highest oxygen requirements of all animals because of their active mode of life and high metabolic rate.

Circulatory System

The circulatory system is quite comparable, in structure, to that of other higher vertebrates. It consists of (i) heart, (ii) arteries, (iii) veins, (iv) lymphatic vessels and (v) blood.

[I] Heart

The birds show some advance over the ancestral reptiles in having a completely 4-chambered heart, with 2 *atria* or *auricles* and 2 *ventricles*, as in mammals. A *sinus venosus* or a *conus arteriosus* is absent. The sinus venosus is said to be incorporated into the right auricle (Fig. 21).

External features. The heart in birds is comparatively larger than in other vertebrates. It lies in the thoracic cavity, mid-ventrally, ventral to oesophagus, partly surrounded by the lobes of the liver. The heart is reddish in colour. It is conical in shape with the apex directed backwards and the broad base, forwards. It is enclosed in a thin, transparent and membranous sac, the *pericardium*, which is made of an outer parietal layer and an inner visceral layer. The two layers enclose a narrow *pericardial cavity*, filled with a watery *serous* or *pericardial fluid*, which protects the heart from shocks and injuries and permits movements during beating. An external hollow transverse groove, the *coronary sulcus* or the *auriculo-ventricular goove*, separates the two anterior, darker, smaller and thin-walled auricles from the posterior, lighter, bigger and thick-walled

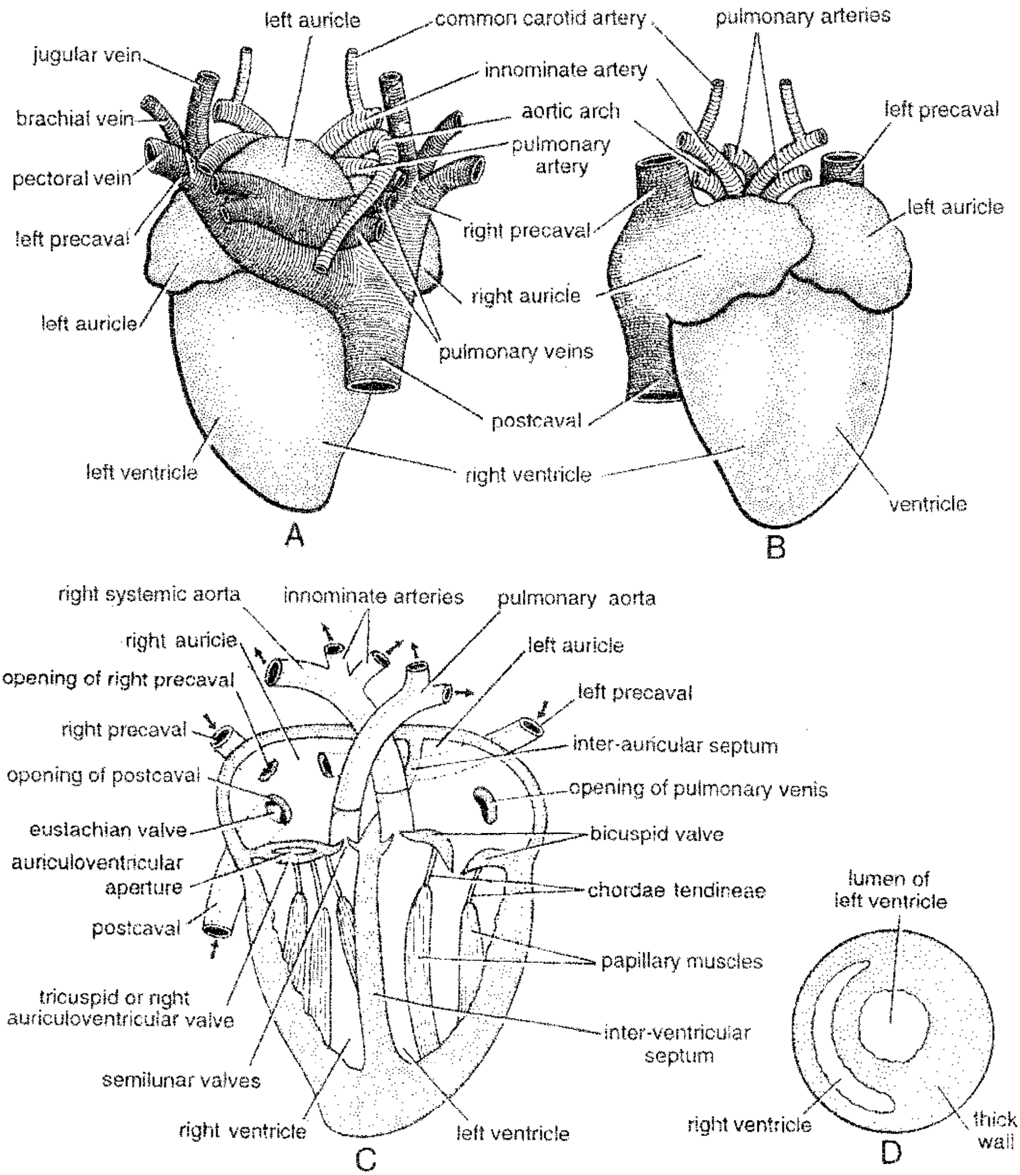

Fig. 21. Pigeon. Structure of heart. A—Dorsal view. B—Ventral view. C—Internal structure in ventral dissection. D—Ventricle in T.S.

ventricles. Similarly, a faint *inter-auricular groove* demarcates the two auricles.

Internal structure. Internally, the two thin walled auricles are separated by a complete, thin membranous partition, the *inter-auricular septum.* It bears in its middle a small oval area, the *fossa ovalis,* representing the position of the foramen ovale in the embryo. The two ventricles are also completely separated from each other by a thick, muscular *inter-ventricular septum.* The *right auricle* is larger and receives the three large caval veins, the right and left precavals and the postcaval in its dorsal wall. The opening of the postcaval is guarded by a muscular *eustachian valve.* The right auricle opens into the *right ventricle* by a crescenitc aperture, the *right* *auriculo-ventricular aperture*. It is furnished with a pair of strong muscular flaps, without chordae tendineae, forming the *right auriculo-ventricular valve*. In function, it represents the *tricuspid valve* of the mammals. The right ventricle, having thinner walls, partly encircles the left ventricle, having thicker walls. In a transverse section the right ventricle appears crecentic, while the left ventricle appears circular. The right ventricle gives off a single trunk, the *pulmonary aorta*, which soon divides into two pulmonary arteries, each going to a lung. The opening of the pulmonary trunk is guarded by three *semilunar valves*.

The *left auricle* is smaller and receives four pulmonary veins from the lungs. It opens into the left ventricle by a circular *left auriculo-ventricular aperture*. It is guarded by two membranous flaps forming the *left auriculo-ventricular valve*, which corresponds to the *bicuspid* or *mitral valve* of mammals. The flaps are connected to thick *papillary muscles*, arising from the wall of the left ventricle by two *chordae tendineae*. The left ventricle gives rise to the single *right systemic* or *aortic, arch*, which is continued into the *dorsal aorta*. The left arch, which is present in the frog and lizard, is absent in birds. The opening into the aortic arch is guarded by three semilunar valves. Bars of muscles, called *trabeculae* or *columnae carneae*, traverse the cavities of the ventricles.

Working. The heart is a force-pump, which drives the blood to all parts of the body. As in mammals, the avian heart is completely four-chambered, so that there is complete separation of arterial and venous bloods. The right half receives and discharges only venous, the left only arterial blood. Thus, birds, like mammals, possess a complete *double circulation* of the blood, as follows :

(a) Pulmonary circulation. The right ventricle pumps venous blood into the pulmonary aorta which divides into the right and left pulmonary arteries leading to the right and left lungs, respectively. From the lungs, oxygenated blood is returned to the left auricle by the 4 pulmonary veins.

(b) Systemic circulation. From left auricle the blood passes through the left auriculoventricular valve into the left ventricle. Thence, it is driven through the aorta into smaller arteries, which break up into capillaries and the blood nourishes all the tissues of the body. The capillaries unite to form veins, which finally form the three great venae cavae, which return the impure blood to the right auricle. From the right auricle it passes through the right auriculo-ventricular valve into the right ventricle, where the pulmonary circulation begins.

[II] Arterial system

The blood leaves the heart through two main blood vessels, or the *arteries*, (Fig. 22) as follows :

1. Aortic arch. There is no left systemic arch. The single aortic arch represents the right systemic arch of lower verterbrates. The retention of only the right aortic arch is characteristic of all birds. It arises anteriorly from the left ventricle and immediately sends off two small *coronary arteries* to the heart itself. It then gives off the two short but stout and thick *right* and *left innominate arteries*. Each of these divides into an anterior *common carotid* and a lateral *subclavian artery*. The common carotid, in turn, divides into the *internal carotid artery* to the brain, and the *external carotid artery* to the head and neck. A branch from the common carotid, called *comes nervi vagi*, joins the external carotid artery. The subclavian further divides into two unusually large branches, brachial and pectoral. The *brachial artery* conveys blood to the wing. The *pectoral artery* supplies blood to the large pectoral muscles of the breast and also sends an *internal mammary artery* to the ventral thoracic wall.

Dorsal aorta. The aortic arch now curves over dorsally towards the right side and runs behind mid-dorsally as the *dorsal aorta*. It furnishes the following main branches :

(1) A single, median, strong *coeliac artery* supplies blood to the proventriculus, gizzard, duodenum, liver and spleen.

(2) The unpaired *anterior mesenteric artery* supplies the greater part of the small intestine.

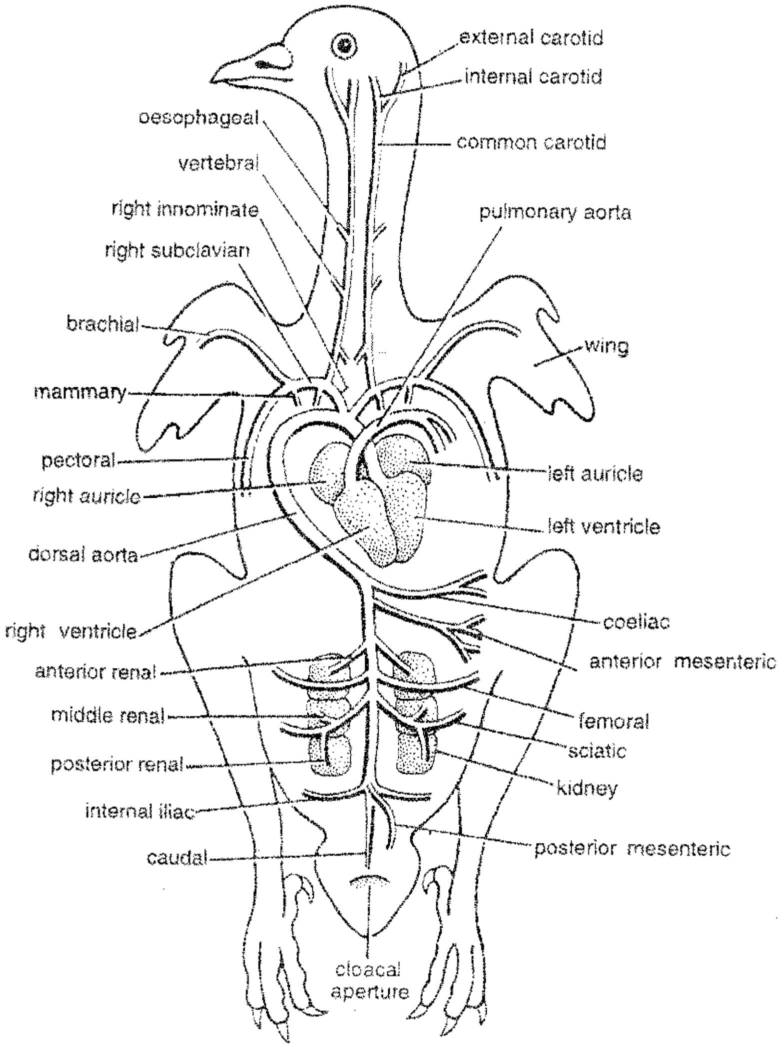

Fig. 22. Pigeon. Arterial system.

(3) A pair of *anterior renal arteries* enters the first lobes of the kidneys. In the male, each renal artery gives off a branch to the testis; but in the female, only the left renal artery gives off a branch to the ovary.

(4) A pair of *femoral arteries* passes outwards dorsal to the anterior lobes of the kidneys and supplies the pelvic muscles and outer muscles of the thighs.

(5) A pair of *sciatic* or *ischiatic arteries* passes outwards between the median and posterior lobes of the kidneys and supplies the inner muscles of the thighs and the legs. Each sciatic artery gives off a *middle renal artery* to the middle lobe of kidney and a *posterior renal artery* to the posterior lobe of kidney.

(6) A single *posterior mesenteric artery* supplies the rectum and cloaca.

(7) The paired *internal iliac arteries* go to the hinder part of the pelvis.

(8) A single *caudal artery*, which is the terminal part of dorsal aorta, passes into the tail.

2. Pulmonary aorta. The right ventricle gives of a single *pulmonary aorta*, which passes ventral to the systemic arch and divides into two pulmonary arteries, each entering a lung.

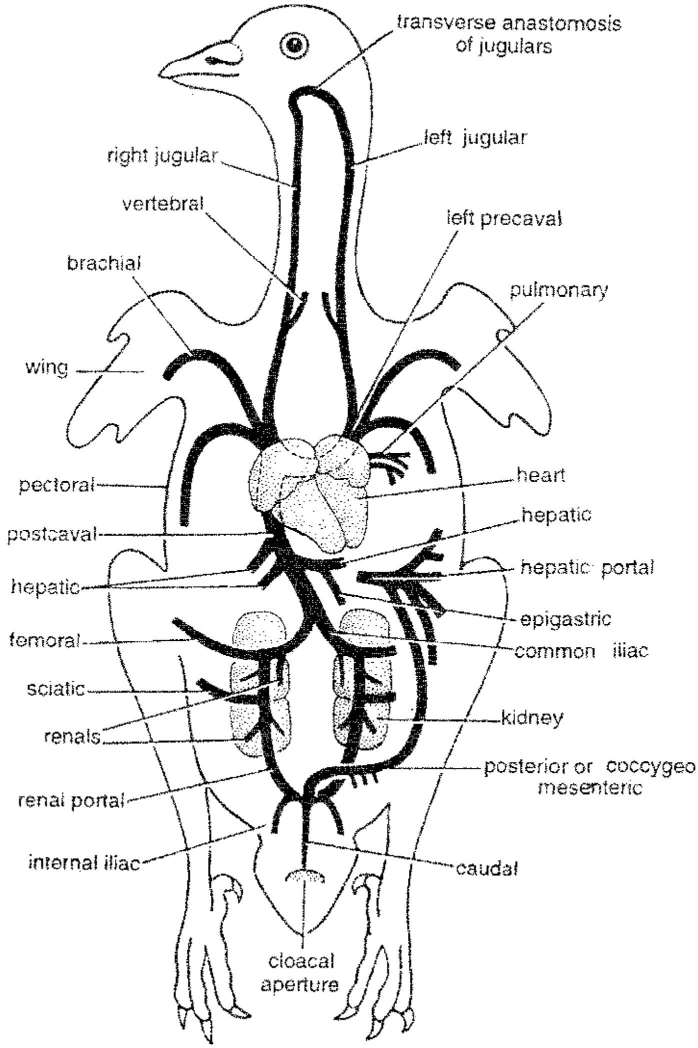

Fig. 23. Pigeon. Venous system.

[III] Venous system

The venous system consists of (1) the *caval veins,* (2) the *pulmonary veins,* (3) the *hepatic portal system* and (4) the *renal portal system* (Fig. 23).

1. Caval veins. The venous blood returns to the right auricle of the heart through three large caval veins. Two *precavals*, or the right and left *anterior venae cavae*, collect blood from the anterior part of body; while a single *postcaval*, or *posterior vena cava,* collects blood from the posterior part.

(a) ***Precavals.*** The precaval vein or the anterior vena cava of each side of formed by the union of a large *common jugular* vein and a *subclavian vein.* The left precaval is larger than the right precaval. The common jugular receives two small veins, the *internal* and *external jugulars,* from the head and also drains the neck through a small *vertebral vein* from the spinal cord and neck muscles. The common jugular veins of the two sides are connected together beneath the base of skull by a transverse loop, the *jugular anastomosis*. This prevents blocking of the flow of blood from the head, when one vein is momentarily shut off by twisting the neck. A slender *brachial vein* from the wing and a stout

pectoral vein from the pectoral muscles unite to form the subclavian vein which joins the precaval. A small *internal mammary vein* from the ventral thoracic wall also joins the pectoral vein.

(b) ***Postcaval.*** The postcaval collects blood from the posterior region of the body. To understand its formation it is convenient to begin at the tail. A short unpaired *caudal vein* from the tail divides anteriorly into the right and left *renal portal* or the *hypogastric veins*. From the bifurcation of the caudal vein arises a median *coccygeo-mesenteric vein* which is characteristic of birds. It runs forwards parallel to cloaca and rectum, receiving their blood, and is continued along the mesentery to join the hepatic portal vein. Each renal portal vein is joined by an *internal iliac vein* from the pelvis. As the renal portal vein passes onwards over the kidney, it sends of a few small branches, the *afferent renal veins*, into it. It also receives a delicate *sciatic vein* between the posterior and middle lobes of the kidney, and joins a prominent *femoral vein* between the middle and anterior lobes. The sciatic and the femoral veins bring blood from the leg. The femoral vein further receives small *efferent renal veins* from the kidney and leaves it as the *common iliac vein*. The right and left common iliac veins unite, just anterior to the kidneys, to form the comparatively short *postcaval vein*, which runs fowards through the liver substance (right lobe) to open into the right auricle. Three *hepatic veins* convey blood from the liver into the postcaval close to the point where it leaves the liver. An *epigastric vein*, corresponding in part to the abdominal vein of amphibians and reptiles, takes blood from the fat-laden fold of peritoneum, or *great omentum*, and discharges into one of the hepatic veins.

An anterior abdominal vein is absent in birds. Probably the epigastric vein represents its anterior part and the coccygeomesenteric, its posterior part, in birds.

2. Pulmonary veins. Two pulmonary veins carry oxygenated blood from each lung and join with their fellows of the other side to open by a common opening into left auricle.

3. Hepatic portal system. As in other vertebrates, blood from various organs of digestive system reaches the liver by a *hepatic portal vein*, which is formed by the union of *gastro-duodenal, anterior mesenteric, posterior mesenteric* and the *coccygeo-mesenteric* veins. As already stated, the coccygeo-mesenteric or inferior mesenteric is characteristic of birds and now considered to be the hepatic portal vein. After collecting blood from rectum, ileum, duodenum and gizzard, it divides into two branches, one entering each liver lobe, into which they form capillary networks. The blood filters through liver whence it is conveyed to postcaval vein through hepatic veins.

4. Renal portal system. It is greatly reduced in birds. The renal portal veins do not break into capillaries in the kidneys, but send off only a few small branches (*afferent renal veins*). Thus, blood from posterior region of body reaches directly to the heart, and not through renal capillaries, as in frogs and lizards.

[IV] Blood

The blood of birds may be called the richest blood in the animal kingdom, for it has more red blood corpuscles per ounce than in any other animal. The red blood corpuscles and minute, oval and nucleated and a space of one square inch will contain 10,000,000 of them. Every part of body in nourished by the blood. Only through the agency of blood food and air can make good what is lost by wear and tear. White blood corpuscles are much less in number and are of different types–*lymphocytes, hetrophils, polymorphoinuclear pseudo-eosinophilic granulocytes, basophils, eosinophils* and *monocytes*. *Blood platelets* are absent in pigeon but blood coagulation is fast.

[V] Heart rate

Owing to their excessive activity, birds need a fast circulation for speedy distribution of building material to quickly exhausted cells. Naturally, their heart beat is quicker than in any other animal. It is slower in larger birds than it is in smaller ones. When resting the pigeon's heart beats several hundred times per minute. It reaches a far higher figure during excitement and flight, and the count is around 1,000 after a long flight. In a bird which has just alighted the pulsations are beyond the count of the ear.

[VI] Temperature regulation

The body-temperature of birds fluctuates from about 100°F in the New Zealand kiwis, to about 112°F in most passerines.

Birds adjust to changing environmental conditions in an interesting variety of ways. Arctic species in general are more densely feathered than are tropical species. The feathers are fluffed to preserve heat in cold weather, and depressed to dissipate heat in warm weather. Shivering, reduced metabolism and breathing, and tucking the bill in feathers during sleep to reduce heat-loss during breathing, are other means adopted in winter.

Birds have no sweat glands in their skin. In warm weather the chief means of heat and water loss is accomplished by 'perspiring' into the air sacs with consequent removal of excess heat through the lungs and mouth.

[VII] Associated organs

A *lymphatic system* with a few *lymphatic glands* is associated with the blood-vascular system. The *spleen* is also intimately connected with it. It is a small, oval and reddish gland, attached to the right side of the proventriculus by a peritoneal fold. Several *lacteal vessels* come out from small intestine and unite to form paired *thoracic ducts* which leads into precaval veins.

Nervous System

The nervous system consists of (i) *central nervous system*, including the brain and the spinal cord, (ii) *peripheral nervous system*, including cranial and spinal nerves, and (iii) *autonomic system*, including sympathetic and parasympathetic systems.

[I] Brain

Birds possess good sense organs and a high sense of intelligence, which demand a good central nervous system. Accordingly the avian brain is roughly ten times the size of that of reptiles of the same size and is comparable with that of mammals. However, it is devoid of superficial convolutions, such as met with in the brains of higher mammals (Fig. 24).

1. External structure. The brain of pigeon is comparatively short and broad, rounded in form and whitish in colour. It completely fills the cranial cavity of the skull. It is covered by two protective *meninges* (singular, *meninx*) or membranes, an outer *duramater* of connective tissue and an inner *pia-arachnoid* rich in blood supply. The narrow space between the two membranes contains *cerebrospinal fluid*, besides connective and fatty tissues and some veins.

Brain has the usual 3 principal divisions : fore-brain, mid-brain and hind-brain.

(a) Fore-brain. The *olfactory lobes* are conical and very small, in correlation with the poorly developed sense of smell. Flying high above the ground, the birds cannot depend much upon their sense of smell. The two pyriform *cerebral hemispheres* are very large and convex and separated by a deep sagittal fissure. They are relatively smooth and devoid of fissures characteristic of the mammalian brain. The cerebral hemisphere consists largely of *corpora striata* which is composed of solid mass of tissue. Each corpora striata is differentiated into three regions– upper *hyperstriatum*, lower *palaeostriatum* and intermediate *mesostriatum*. Roof of cerebral hemispheres is called *neopallium* which is unconvoluted. The hemispheres overhang posteriorly concealing the dorsal surface of the *diencephalon* completely. At the posterior end of the deep sagittal fissure, separating the two hemispheres, lies the single, delicate, small, median, *pineal body*. On the ventral surface of the diencephalon, which is mostly visible, the two optic nerves cross each other forming the *optic chiasma*. Behind the chiasma projects a median process, the *infundibulum*, bearing a large *hypophysis* or *pituitary body*, which is devoid of the intermediate lobe.

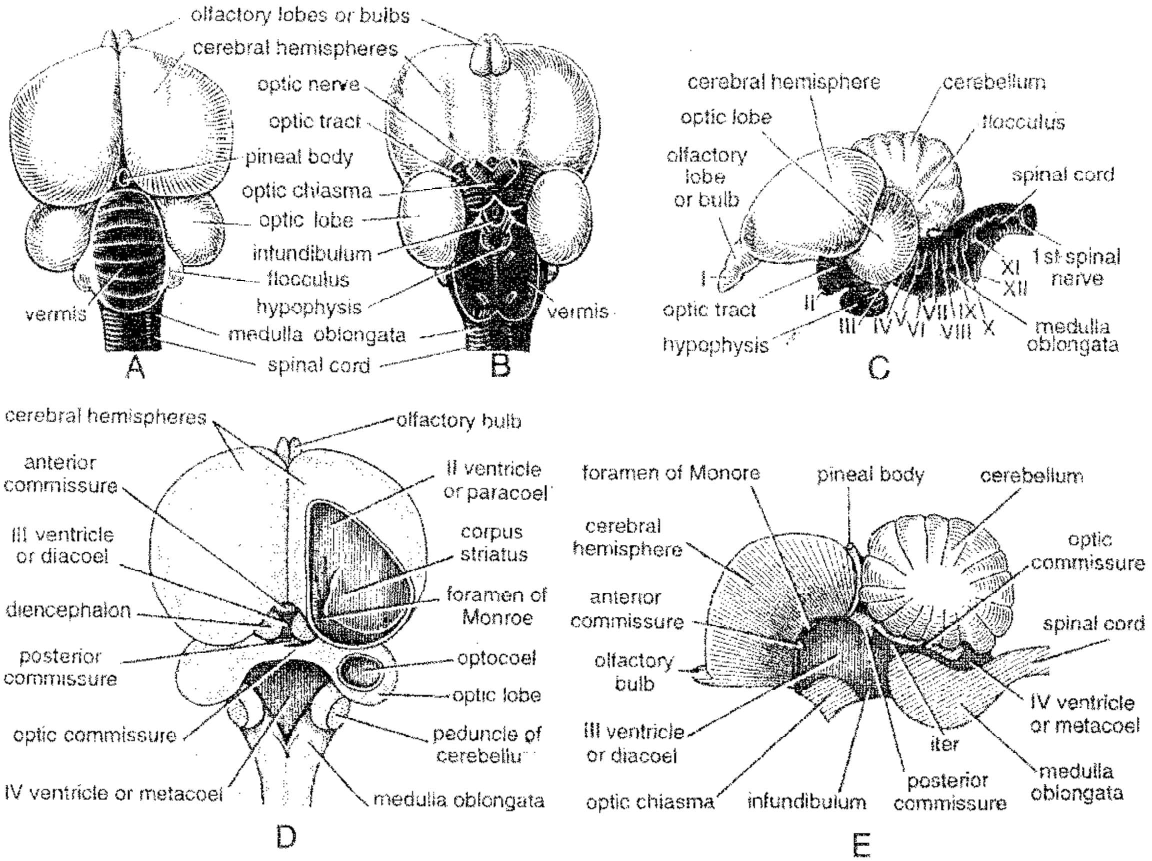

Fig. 24. Pigeon. Structure of brain. A—Dorsal view. B—Ventral view. C—Left lateral view. D—Cavities in dorsal dissection. E—In sagittal section.

(b) Mid-brain. The two rounded *optic lobes* on the mid-brain are conspicuously developed in keeping with the keen sight of birds. The optic lobes become lateral due to the backward extension of the cerebral hemispheres to meet the cerebellum. The two optic lobes are connected together by a transverse *optic commissure*.

(c) Hind-brain. The *cerebellum* is well developed and ridged transversely. It is relatively larger than even in mammals. It is divided into a large median lobe or *vermis*, and two small, conical lateral lobes or *flocculi*. The large and much convoluted cerebellum indicates the delicate sense of equilibrium and the great power of muscular coordination belonging to birds. The *medulla oblongata*, concealed beneath the cerebellum, descends almost vertically from it, to join the spinal cord. It is broader in front and tapers behind to merge into the spinal cord. At the point where the medulla oblongata and the spinal cord meet is a well-marked ventral flexure, as in lizards.

2. Internal structure and cavities. The brain is hollow from within and its cavities are called the *ventricles* which are greatly reduced. The cavities of the two cerebral hemispheres are termed the *lateral ventricles* or the *paracoels*. Their roof or *pallium* is thin and there is very little development of cerebral cortex. However, their ventro-lateral walls are very thick and made of *corpus striatum* (sing). The instinctive behaviour and ability to manoeuvre in flight are largely due to the enormous development of corpora striata (pl.) in cerebrum and an equally great

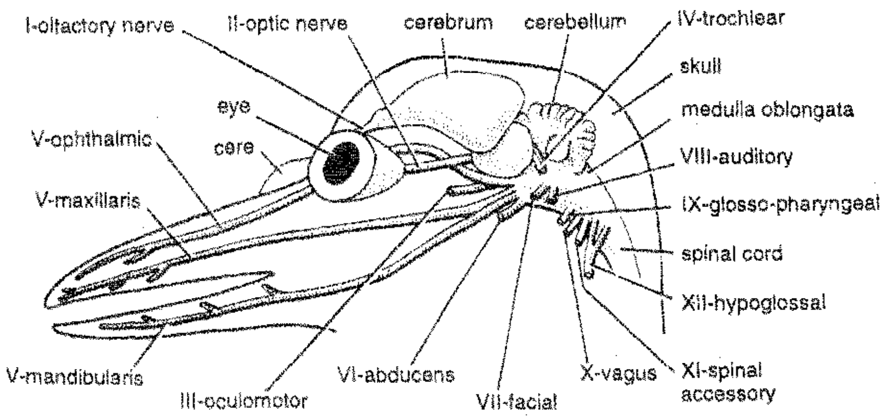

Fig. 25. Pigeon. Cranial nerves in left lateral dissection.

development of the cerebellum. An *anterior commissure* interconnects the corpora striata of the two hemispheres.

Posteriorly, each paracoel communicates by a small common aperture, the *foramen of Monro,* with the narrow, vertical cavity of the diencephalon termed the *third ventricle* or *diacoel.* Its thin roof, called *epithalamus,* contains a richly vascular tissue, the *anterior choroid plexus,* just in front of the pineal body. The diacoel is bounded laterally by thick *optic thalami,* while its thick floor is termed *hypothalamus.*

A *posterior commissure* separates the diacoel from the narrow cavity of the mid-brain, called the *iter.* It communicates dorsally with the cavities of the optic lobes, called the *optocoels.* Each optic lobe contains an extension from the *aqueduct of Sylvius,* a narrow passage contained in the mid brain connecting the *third ventricle* with *fourth ventricle.* Thick longitudinal bands of nerve fibres, called *crura cerebri* (singular *crus cerebrum*), run beneath the optic lobes to connect the diencephalon with the medulla oblongata.

The cavity of the medulla oblongata is named the *fourth ventricle* or the *metacoel* (or *myelocoel*). Its sides and floor are thick-walled, whereas the roof is thin, richly vascular and termed the *posterior choroid plexus.*

The ventricles of the brain contain the cerebrospinal fluid, secreted by choroid plexes. Histologically, the brain consists of *grey matter* containing nerve cells, and *white matter* containing nerve fibres. The grey matter is external in the olfactory lobes, cerebral hemispheres, diencephalon and cerebellum while it is internal in the optic lobes and the medulla oblongata.

3. Functions. The functions of different parts of brain are as follows :

Olfactory lobes. Smell.

Cerebral hemispheres. Voluntary movements or conditioned reflexes, instinctive behaviour, intelligence, will, memory, emotions, etc.

Diencephalon. Relay impulses to cerebral hemispheres, integrating centre of autonomic system, and perception of extreme cold, heat, pain, etc.

Optic lobes. Sight.

Crura cerebri. Conduction of sensory impulses.

Cerebellum. Voluntary movements and balance.

Medulla oblongata. Involuntary movements.

[II] Cranial nerves

12 pairs of cranial nerves arise from the brain and leave the cranium through special holes. Cranial nerve 'o' or terminal nerve is absent in *Columba.* Their numbers, names and nature are as follows :

No.	Name of the cranial nerve	Nature of the cranial nerve	No.	Name of the cranial nerve	Nature of the cranial nerve
I.	Olfactory	– sensory	VII.	Facial	– Mixed
II.	Optic	– sensory	VIII.	Auditory	– Sensory
III.	Oculomotor	– Motor	IX.	Glossop-haryngeal	– Mixed
IV.	Trochlear	– Mixed	X.	Vagus	– Mixed
V.	Trigeminal	– Mixed	XI.	Spinal accessory	– Motor
VI.	Abducens	– Motor	XII.	Hypogl-ossal	– Motor

[III] Spinal cord

The spinal cord is the continuation of the medulla oblongata. It is reduced in length in birds, correlated with their short vertebral column. It has the same structure as in other vertebrates and is covered by the same protective membranes as the brain. It presents two enlargements, branchial and lumbar, from which *branchial* and *sacral plexes* of nerves are given off to the fore and hind limbs respectively. On the dorsal surface of the lumbar enlargement, the two halves of the cord diverge for a short distance, enclosing an elliptical space, the *rhomboidal sinus*, containing a gelatinous substance, and bounded above by the membranes of the spinal cord. The *central canal* of spinal cord is continuous with the fourth ventricle of medulla and filled with the cerebro-spinal fluid. Histologically, it consists of inner grey matter and outer white matter, the former in the shape of H. The spinal cord controls reflex activity and serves to conduct impulses to and from the brain.

[IV] Autonomic nervous system

The sympathetic and parasympathetic system include nerves and ganglia. Fibres link up the spinal nerves with the ganglia and the spinal cord. The sympathetic nerves supply chiefly the urinogenital, alimentary, respiratory and circulatory systems.

Sense Organs

The faster an animal moves, the more necessary becomes its need to have good sensory organs to obtain accurate and rapid information about its surrounding. Pigeons possess all the senses, namely touch, taste, smell, hearing and sight.

[I] Tactile organs

Tactile organs are poorly developed in birds due to feathery covering of their body. The sense of *touch* is confined chiefly to the beak in birds. The *operculum* or *cere*, which is a sensitive soft fold of skin at the base of the upper beak in pigeons, is said to have a stimulating effect during love making. *Grandy's corpuscles* present in the beak skin are important touch receptors. Besides this, numerous *Herbst's corpuscles* present in dermis are supposed to be vibration and heat receptors.

[II] Gustatory organs

Birds do possess a sense of *taste*, but not very strongly developed due to scarcity of taste buds, which are present chiefly on the dorsal surface of the tongue in pigeons. It seems that birds, like pigeons, which feed largely on grains and seeds and swallow them whole, make little use of taste.

[III] Olfactory organs

The sense of *smell* is poorly developed in birds, as flying animals cannot depend on smell. Accordingly, the olfactory sense organs and the olfactory lobes of the brain are reduced in birds. The nostrils, overhung by cere, lead into the small, paired *olfactory sacs* or *nasal chambers* in the base of the upper beak. The two chambers are separated medially by mesethmoid and bounded externally by ectoethmoid, which is produced inwards into 3 scroll-like *turbinal processes* to increase the olfactory surface. The anterior portion of each chamber serves as a non-sensory respiratory part or *vestibule*, containing the anterior turbinal covered by laminated epithelium. The posterior sensory or olfactory part contains the middle and posterior turbinals invested by the one-layered epithelium of *Schneidernian membrane* innervated by the fibres of olfactory nerve. The two olfactory chambers open into the pharynx by the internal nares.

[IV] Auditory organs or ears

Night birds feel largely by ears. The sense of *hearing* is acute in most birds, and the ear is more complex than that of reptiles. It almost approaches the mammalian organization but there is no *external ear* such as is met with in mammals. A circular *external ear opening* lies on each side of the head, behind the eye, concealed beneath a special group of feathers, called the *auriculars* (Fig. 26). They are locally constricted and do not interfere with sound reception. It leads into a short canal, the *external auditory meatus*, at the base of

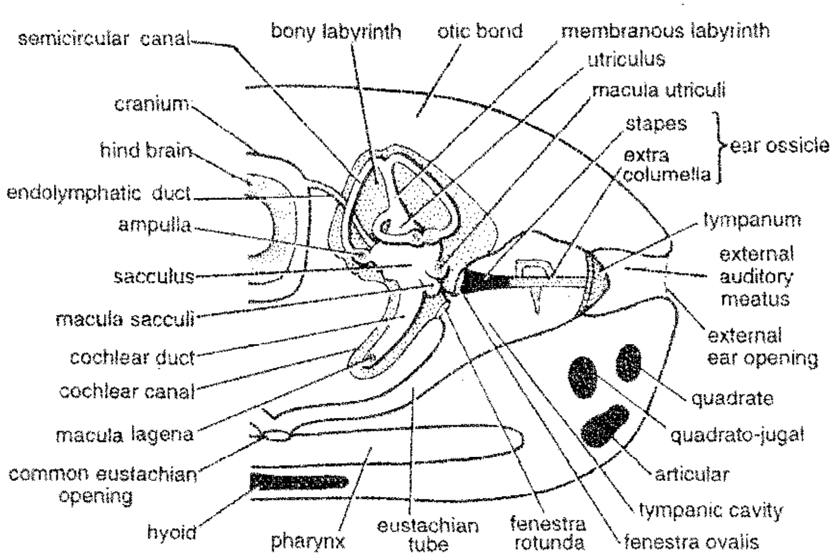

Fig. 26. Pigeon. T.S. head through internal ear.

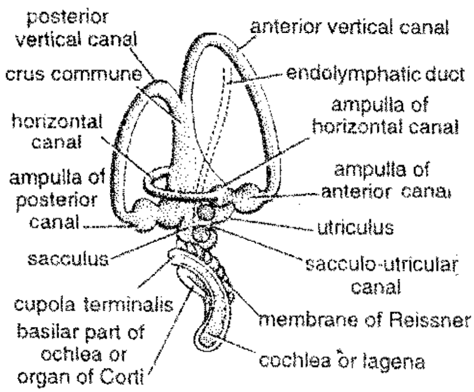

Fig. 27. Pigeon. Internal ear (membranous labyrinth).

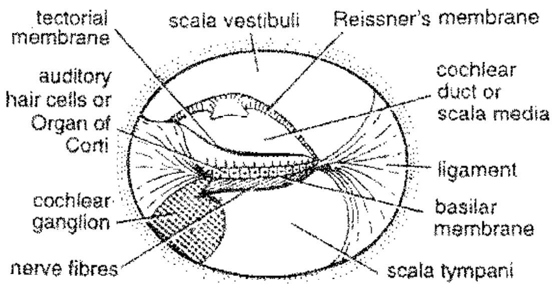

Fig. 28. Pigeon. Cochlea in T.S.

which lies a thin, transparent, vibrating septum, called *tympanum* or *ear-drum*. A single rod-like bone, the *columella auris*, transmits sound waves from tympanum, across the middle-ear cavity, to the fenestra ovalis of the inner ear. Its inner disc-like bony portion, the *stapes*, plugs the fenestra ovalis, while the outer 3-rayed cartilaginous portion, the *extra-columella*, is attached to the inner surface of the tympanum. From the air-filled middle-ear cavity, or the *tympanic cavity*, on each side, a *eustachian tube* leads to the pharynx and unites with that of the opposite side to open by a common aperture at the back of the palate. It serves to equalize the air-pressure on both sides of the *tympanum*. The inner ear, (Fig. 27) or the *membranous labyrinth*, lies embedded in dense ivory-like bone in the side wall of the skull surrounded with a fluid, the *perilymph*, and itself filled with a dense fluid, the *endolymph*. It consists of the usual three *semicircular canals* (one horizontal and two vertical), relatively smaller *sacculus* and *utriculus* and a short blind tube, the *cochlear duct* or *lagena*, which is larger than in reptiles but less developed than in mammals. The cochlear duct, with its surrounding bony labyrinth, or cochlear canal, is termed *cochlea* (Fig. 28). Its short length in birds suggests that the ultrasonic hearing would be difficult. In a transverse section, the cochlea shows three chambers : an upper *scala vestibuli*, a middle *scala media* and a lower *scala tympani*. The scala media is the actual cochlear duct and contains endolymph. The other two chambers contain perilymph and their junction at the apex of cochlea is termed the *helicotrema,* where the scala media terminates blindly. At the inner end of cochlea, scala vestibuli is continuous with the fenestra ovalis, while the scala tympani with the fenestra rotunda. The floor of scala media is formed by the *basilar membrane* and the roof by the *Reissner's membrane.* The basilar membrane consists of tall auditory cells, together forming an *organ of Corti* which is sensitive to sounds of higher frequencies. The free ends of the auditory cells bear hairs, which are embedded in a *tectorial membrane,* lying above the organ of Corti. From the basal ends of the cells arise the nerve fibres which unite to form the cochlear branch of the auditory nerve. Groups of auditory cells are called *cristae* and *maculae.* Those present in the ampullae are called *cristae ampullares* which possess the sense of direction and equilibrium. One macula is present in utriculus and one in sacculus. A macula lagena, present at the tip of the cochlear duct, perceives sounds of low frequencies. Expressed in cycles per second, the range of hearing in domestic pigeon is 200-7,500 cycles per second.

[V] Visual organs or eyes

The sense of sight or vision is highly developed in birds in adaptation to the aerial mode of life. Good vision is necessary to cover considerable distances, to find food, to recognize mates, to avoid obstacles, to know when and where to land and so on. Accordingly, the eyes are exceptionally well developed and proportionately larger than in other vertebrates. In structure, the avian eye does not differ much from that of man.

Shape. The eye-ball is not spherical as in man. It has the form of a biconvex lens, being flattened anterio-posteriorly. It is somewhat concave in front and convex behind.

Eyelids. *Eyebrows* or *eyelashes* are absent. The *eyelids* are not conspicuous. The *upper eyelid* is slightly movable, but the *lower eyelid* is better developed and more movable arising upwards to close the eye. The eyelids do not blink, though they are closed while sleep. A semi-transparent, *third eyelid* or *nicititating membrane* is also present forming a fold at the anterior angle of the eye. It can be drawn posteriorly over the surface of eye with great rapidity. The nicutating membrane serves mainly for cleansing the eye-ball, also as a protective covering when birds are facing or flying against the wind, to reduce the glare of the sunlight during day in nocturnal birds, and to shield the eyes of aquatic birds under water (Fig. 29).

Glands. The nictitating membrane is lubricated by the oily secretion of a *Harderian gland* present in the inner angle of the eye. Tear glands or *lacrymal glands* are also well developed and present below the outer angle of the lower eyelid. Their watery secretion, nourishes the non-vascular cornea, keeps wet its surface and washes away dust particles.

The eye-ball is hollow and its wall is made of the usual three layers; the outer *sclerotic coat,* the middle *choroid* and the inner *retina.*

Sclerotic. The outer exposed part of the eye beneath the eyelids is formed by a bulging or convex, transparent and horny layer, the *cornea.* It is the anterior exposed continuation of the sclerotic coat (Fig. 30). The outer surface of cornea is covered by a likewise quite transparent, delicate and sensitive epithelial membrane, the *conjunctiva,* which is a continuation of the mucous lining of the eyelids. The posterior hidden part of the sclerotic, covering the inner surface of the eye, is opaque, white, dense and cartilaginous. Anteriorly, at the junction with cornea, the sclerotic coat is strengthened by a ring of 10-12 small, overlapping bony *sclerotic plates* or *ossicles.*

Choroid. Beneath the sclerotic wall lies a thin, dark, pigmented and richly vascular membrane, the *choroid.* Anteriorly, the choroid forms a circular, pigmented diaphragm, the *iris,* pierced by a rounded aperture, the *pupil.* The iris regulates the amount of the entering light. It contains striated circular and radial muscles, which reduce and enlarge the pupil, according to need. At the base of the iris, the choroid becomes thickened and radially folded to form the *ciliary body,* from which *ciliary processes* or *suspensory*

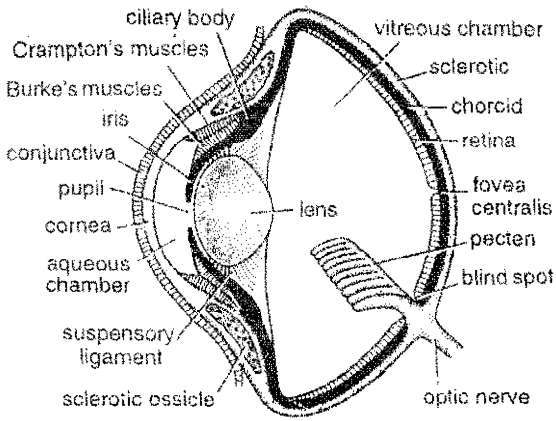

Fig. 29. Pigeon. Eye in sagittal section (V.S.).

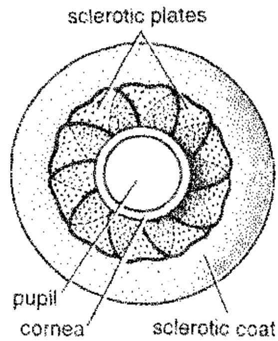

Fig. 30. Pigeon. Sclerotic plates in frontal view of eye.

ligaments extend to the lens. The ciliary body contains well-developed striated *ciliary muscles*.

Retina. The light-sensitive *retina* lies within the choroid in the posterior region of the eye. It is transparent, devoid of blood vessels and nearly twice as thick as in the human eye. The retina consists of nerve fibres and cells and contains numerous minute *rods* and *cones*. Pigeon, being a diurnal bird, has more cones than rods, but rods outnumber cones in nocturnal birds.

Sensitive spots. Two sensitive spots, or *foveae*, are found on the retina. The *central fovea* (the *yellow spot* of mammals), lying near the centre of retina as a slight depression, is more sensitive and used for lateral or *monocular vision*. The *temporal fovea*, lying more towards the outer side of the eye, is used for forward or *binocular vision*. The sensory spots have relatively more cones and provide most distinct vision. However, cones are well present all over the retina, so that every part of it forms a good and detailed image. Besides, the lower part of retina contains yellow droplets and upper part contains red droplets. These serve as filters, increasing the contrast of blue sky and green fields respectively. Thus, colour vision is highly developed.

Lens. The lens is suspended behind the iris by suspensory ligaments. It is soft, pliable, crystalline, colourless, transparent and biconvex. Its posterior side is more convex than its anterior side. A thin fibrous capsule surrounds the lens. The lens divides the eye cavity into a small anterior *aqueous chamber* and a large posterior *vitreous chamber*. The anterior chamber is filled with a colourless watery fluid, the *aqueous humour*. The posterior chamber contains a thick colourless, gelatinous substance, the *vitreous humour*. The two humours keep the eye-ball taut and also serve to focus the light rays on the retina.

Pecten. A remarkable comb-like structure, the *pecten*, projects into the cavity of eye from the region of and ventral to the *blind spot* where optic nerve enters the eye-ball (Fig. 31). It is soft, somewhat rectangular, highly vascular, pigmented, and folded like a fan. The pecten occurs in all birds, except kiwi (*Apteryx*). It is also found in some reptiles, but is absent in mammals. The actual function of pecten is unknown, but possibly, it aids in the *nutrition* of the eye-ball, or in *accommodation* which is remarkably well developed in birds, by pressing the lens forwards. It probably regulates the *fluid pressure* within the eye. It may cast a shadow on retina and thus help in the *perception of movements*.

Vision. The large eyes in birds indicate a keen sight that is probably unsurpassable in the animal kingdom. Due to large size of the eye-ball muscles remain small, so that birds move their eyes little or not at all. Instead, they easily turn their heads because of their long and flexible necks. The lateral position of the eyes indicates

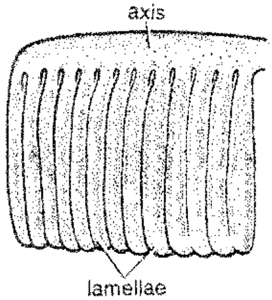

Fig. 31. Pigeon. Pecten.

monocular vision, that is, each eye has its own field of vision. The large lateral areas of monocular vision enable the bird to see far to the sides to avoid predators. However, some degree of overlapping occurs between each eye's field of vision in front, forming a field of *binocular vision*. This small forward area of binocular vision allows depth of the field necessary to feed on seeds, etc.

Accommodation. Birds have great power of accommodation (Fig. 32). Their eyes also accommodate rapidly, since birds must change quickly from distant to near vision, as they manoeuvre among the branches of a tree or sweep down to the ground from a considerable height. The ability to accommodate is two-fold, effected by the change in the position of cornea and the shape of the lens. The ciliary muscles include two sets. The contraction of the anterior *Crampton's muscle* pulls the cornea reducing its curvature, while that of the posterior *Brucke's muscle* draws the lens forward increasing the curvature of its anterior surface, thus bringing about accommodation for near objects. This is the same mechanism as is used by most reptiles. Maximum accommodation in a young man is about 10 *diopters**. In birds, it is about 20 diopters, and in cormorants which need more accommodation to see clearly under water, it is 40 to 50 diopters*. Since many birds have colourful outfit, it suggests that the birds can identify colours. This may be more important in sex recognition. Abundance of cones in birds helps in colour vision. Besides the cones in some birds, the retina has oil drops of yellow, orange or red colours. These oil drops are suggested to act as

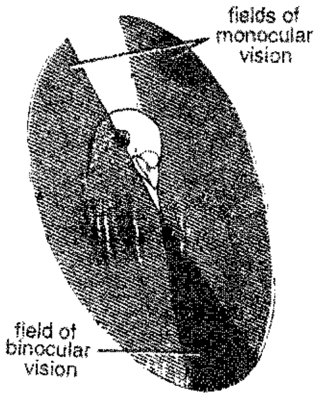

Fig. 32. Pigeon. Fields of vision.

filters increasing birds perception of these colours. The amount and distribution of these droplets varies in different birds species. In pigeon the yellow droplets are concentrated in the lower part of the retina and this may be ment for sky vision or to tone down the blue colour. In king fisher there is abundance of red droplets which may reduce the glow of water.

Urinogenital System

The excretory and the reproductive organs lie in very close contact, structurally, so that they are studied together under the urinogenital system. Functionally, they are quite unrelated.

[I] Urinary or excretory system

The excretory organs of pigeon include one pair of *kidneys* and one pair of ureters, in both the sexes. A *urinary bladder* is lacking in adaptation to flight, possibly to reduce body weight.

1. Kidneys. The main urinary organs are one pair of dark-brown metanephric kidneys, lying posteriorly in the body cavity, attached dorsally and embedded in the hollows of the pelvis. Their ventral surface is covered by peritoneum. They are flattened and three-lobed, each lobe divided into smaller lobules. A small, yellowish, elongated and streak-like *adrenal body* lies attached ventrally to the anterior lobe of each kidney. It is a ductless gland. Each kidney consists of a large number of

* Diopter — A unit adopted for calibration of lenses, being the reciprocal of the focal length when expressed in metres.

convoluted and tightly packed *uriniferous tubules*. Birds have relatively more tubules than do mammals. One cubic millimeter of tissue from the cortex of a bird's kidney contains 100 to 500 renal corpuscles in contrast to 15 or less in a mammal. Each tubule begins as a small glomerulus and includes a specialized portion, called the *loop of Henle*. When the glomerular filtrate passes through the loop, much of its water is reabsorbed. As a result, much concentrated urine passes down the ureter. The kidneys receive a little venous blood from the branches of the femoral veins and arterial blood from the dorsal aorta by renal arteries. The blood leaves the kidney by renal veins, which unite with femoral and renal portal veins, to form the common iliac veins.

2. Ureters. Uriniferous tubules of each kidney unite to form a ureter or metanephric duct. It is a straight, narrow tube, arising ventrally from anterior lobe of kidney, and running backwards to o_en into the *urodaeum* or middle com_artment of cloaca, piercing through its dorsal wall or roof.

3. Physiology of excretion. The cloacal wall reabsorbs much of the water from the excretory fluid, which is thus reduced to a semi-solid state. Like reptiles, birds are *urecotelic* animals because the excretory waste consists mainly of urates and uric acid (not urea) and is voided from the cloaca, with the faeces, as a whitish substance or *guano*. Excretion of uric acid instead of urea involves little need of water because it is mainly insoluble in water and precipitates out easily.

[II] Male reproductive system

In pigeon, the two sexes are separate and sexual dimorphism is absent.

The chief reproductive organs in the male are the paired testes and the vasa deferentia. There is no *intromittent* or *copulatory organ* homologous to the mammalian penis (Fig. 33).

1. Testes. The two oval and whitish *testes* are attached ventrally by peritoneum (*mesorchium*) to the anterior ends of the kidneys. The right testis is often slightly smaller than the left one. During the breeding season, they are greatly enlarged, shrinking to tiny bodies afterward. The essential part of each testis consists of coiled, narrow *seminiferous tubules*, lined by epithelial cells which give rise to *spermatozoa*, by spermatogenesis. Groups of hormone-producing *Leydig* or *interstitial cells* are present between the tubules. The high body temperature tends to inhibit spermatogenesis in the testes. According to one suggestion, the abdominal air sacs help in keeping the two testes cool, which is necessary for the development of the spermatozoa, but there is no definite proof.

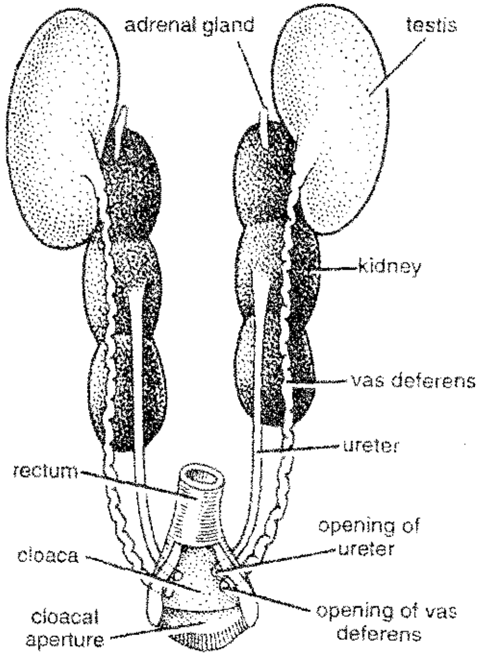

Fig. 33. Pigeon. Male urinogenital system.

Structure of sperm. A mature sperm is an elongated filamentous structure made of head, middle piece and tail. *Head* containing nucleus is drawn at the tip into an *acrosome* into which Golgi bodies are accumulated. It helps in piercing through the vitelline membrane of ovum during fertilization. *Middle piece* contains mitochondria which provide energy for the beating of tail. Tail is extremely long, flagellum-like and an axial filament runs throughout its length.

2. Vasa deferentia. From the inner border of each testis arises a convoluted, narrow and opaque *sperm duct* or the *vas deferens*. It runs backwards along t e outer si e an parallel to t e *ureter* o that side, to open dorsally upon a small papilla into the urodaeum of cloaca. The anterior end of each vas deferens is much convoluted to form an *epididymis*. It is connected with the seminiferous tubules of the testis by extremely find tubules, the *vasa efferentia*. Near the cloaca each vas deferens is slightly swollen to form a *seminal vesicle*, for temporary storage of spermatozoa, during the breeding season. During copulation, the seminal fluid containing spermatozoa is discharged into the cloaca of the female.

[III] Female reproductive system

The female organs develop only on the left side. In the embryo there are two ovaries and two oviducts. But those of the right side become atrophied in the adult, probably as a means of reducing body weight, while those of the left side persist and become functional (Fig. 34).

1. Ovary. The *left ovary* is a large irregular organ lying ventral to the anterior lobe of the left kidney. It remains attached to the kidney by a double fold of peritoneum, called *mesovarium*. The size of the ovary increases considerably during the breeding season. The surface of the ovary is studied with numerous *follicles* or *ovisacs* of different sizes and each containing a single *ovum* or *oocyte*. The ova, rich in yolk contents, are at various stages of development. At times, a vestigial right ovary is also present. When the ova are fully mature, *ovulation* takes place by the rupture of follicles. First maturation division almost coincides with ovulation. The ova or *primary oocytes* released in the coelom are caught by the expanded funnel-like opening of the oviduct.

2. Oviduct. The *left oviduct* (Mullerian duct) is a long, broad and convoluted tube passing backwards to the cloaca. It is attached to the dorsal body wall by a double peritoneal fold, called *mesotubarium*. The oviduct is differentiated into many regions. The upper end of the oviduct forms a wide, membranous coelomic funnel, the *ostium* or *infundibulum*, its margin beset with long

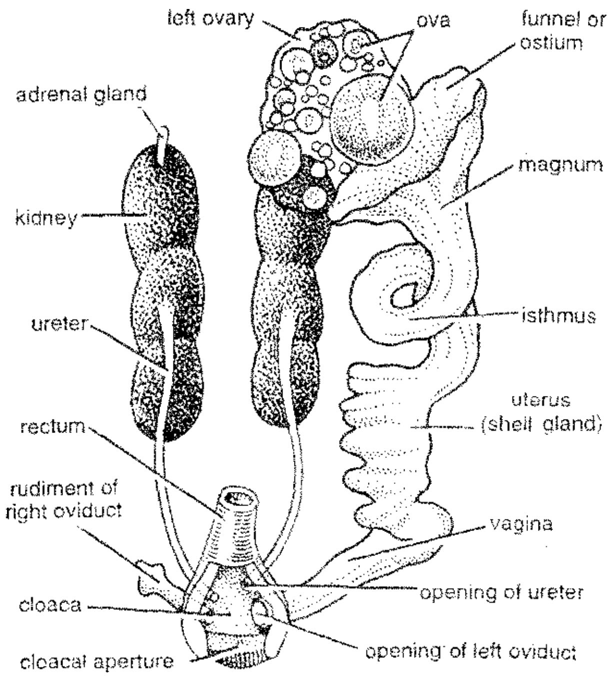

Fig. 34. Pigeon. Female urinogenital system.

ciliary processes or *fimbrae*. It opens by a wide, slit-like aperture into the body cavity, near the ovary. As the ova become mature they are liberated into the body cavity and thence enter the oviduct through the ostium. If spermatozoa are present, the ova become fertilized. The wall of the ostium probably secretes the thin chalaziferous layer of dense albumen around the fertilized eggs. The succeeding part of oviduct, or *magnum*, secretes the *albumen* or *egg-white*. It is followed by a narrow portion, the *isthmus*, which secretes the parchment-like *shell membranes* and some albumen. The fourth part, or *uterus*, is thin-walled and secretes the hard *calcareous shell* and albumen. The fifth part, or *vagina*, is thick-walled and muscular. It probably contains unicellular glands, which secrete the pigment and the external cuticular layer of the shell and also produce mucus for smooth laying of the eggs. It opens into the urodaeum or middle chamber of cloaca.

A vestigial *right oviduct* is attached to the right side of the cloaca.

[IV] Significance of a single ovary

In most birds, both ovaries are present during embryonic development. Later, the right ovary degenerates and the left becomes functional in the adult bird.

(1) In non-laying birds, the ovary remains small with minute eggs. But in the breeding season, the ovary and eggs become enormously developed. The ova not only become numerous but each accumulates the large amount of yolk before being laid. Considering the large size of eggs, the bird cannot possibly afford to keep two functional ovaries in its body.

(2) A single ovary results in loss of weight as well as in decreasing the number of eggs produced. This is in keeping with the elimination of unnecessary weight or ballast, as also observed in other body structures, in adaptation to the flying habit of the birds.

(3) The retention of a single ovary also helps in the safe manipulation of large eggs with breakable shells. Had there been two ovaries and two oviducts, it might well prove disastrous, if two eggs with fragile breakable shells should approach the narrow exit side by side at the same time. The right rudimentary ovary can be made to enlarge and function if the left one is removed.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give the natural history of the common pigeon. What features in its anatomy are adapted to its habits ?
2. Give an account of structure and development of a typical feather.
3. Describe the various types of feathers found in *Columba.*
4. Describe the food, feeding habits and digestive system in the common rock pigeon.
5. Give an illustrated account of flight muscles of pigeon.
6. Give an account of perching mechanism in birds.
7. Describe the respiratory mechanism and organs of respiration in *Columba.*
8. Give the structure of an avian heart and trace the course of blood through it.
9. Describe the arterial or venous system of a pigeon.
10. Describe fully the brain of *Columba.* and discuss its peculiarities.
11. Describe the urinogenital system of a bird. Discuss the significance of presence of single ovary in birds.

» *Short Answer Type Questions*

1. Give an account of exoskeleton in pigeon.
2. Give an account of functions of feathers in birds.
3. Compare the respiratory mechanism of birds, reptiles and mammals.
4. Draw full page neatly labelled diagrams of pigeon. (i) Arterial system, (ii) Air sacs and lungs, (iii) Digestive system, (iv) Typical quill feather and (v) Internal structure of heart, (vi) V.S. of eye.
5. Write short notes on — (i) Air sacs in birds, (ii) Feathers, (iii) Flight muscles, (iv) Perching mechanism, (v) Syrinx.

» *Multiple Choice Questions*

1. The study of birds is termed as :
   (a) Ornithology (b) Oology
   (c) Herpetology (d) Icthyology
2. Study of birds eggs :
   (a) Ornithology (b) Oology
   (c) Herpetology (d) Icthyology
3. Which of the following is not true for birds?
   (a) Feathered (b) Flying
   (c) Quadraped (d) Possess wings
4. The common rock pigeon does not nest on :
   (a) Fissures of rocks (b) Forts
   (c) Houses (d) Trees
5. Pigeon's milk is manufactured in :
   (a) Crop (b) Oesophagus
   (c) Buccal cavity (d) Stomach
6. Jaws in *Columba livia* are covered by :
   (a) Operculum (b) Rhamphotheca
   (c) Cere (d) Nictitating membrane

7. Nostrils in pigeons are overhung by :
   (a) Feathers (b) Rhamphotheca
   (c) Operculum or cere (d) Nictitating membrane
8. The only cutaneous glands in pigeon :
   (a) Sweat glands (b) Sebaceous glands
   Mammary glands
   (d) Preen glands or uropygial gland
9. The foot of birds is covered by :
   (a) Epidermal scales (b) Dermal scales
   (c) Dermal plates (d) Feathers
10. The arrangement and distribution of feathers on birds :
    (a) Plumage (b) Pterolysis (c) Pterylae (d) Apteria
11. The remiges attached to second digit of hand of birds are called :
    (a) Manuals (b) Metacarpals
    (c) Digitals (d) Cubitals
12. Bastard wing is attached to :
    (a) Hand (b) Second digit
    (c) Fore arm
    (d) Pollex or thumb
13. Down feathers are present in :
    (a) Newly hatched pigeons (b) Male pigeons
    (c) Female pigeon (d) Adult pigeons
14. The coelom in birds is divided into thoracic and abdominal cavity by :
    (a) Transverse septum (b) Oblique septum
    (c) Longitudinal septum
    (d) Diagonal septum
15. Which of the following is not a flight muscle :
    (a) Pectoral muscle
    (b) Coraco-brachialis longus
    (c) Gastrocnemius
    (d) Coraco-brachialis
16. The foramen triosseum is an aperture between :
    (a) Clavicle and coracoid
    (b) Coracoid and scapula
    (c) Clavicle and scapula
    (d) Clavicle, coracoid and scapula
17. Pectoralis minor is a :
    (a) Elevator muscle (b) Perching muscle
    (c) Visceral muscle (d) Depressor muscle
18. In birds gizzard is used for :
    (a) Chewing food (b) Grinding food
    (c) Mixing food (d) Digesting food
19. What fraction of food stuff is converted into energy by birds :
    (a) Half (b) Two third
    (c) One third (d) One fourth
20. Coccygeo-mesentric vein collects blood from :
    (a) Kidney (b) Tail
    (c) Pelvis (d) Cloaca and rectum
21. Which of the following animal groups has richest blood
    (a) Birds (b) Mammals
    (c) Reptiles (d) Amphibians
22. The meninges covering the brain of a bird are :
    (a) Duramater and piamater
    (b) Duramater and pia-arachnoid layer
    (c) Piamater and arachnoid layer
    (d) Duramater and arachnoid layer
23. The cavity of mid brain is called :
    (a) Diacoel (b) IV ventricle
    (c) Iter (d) Optocoel
24. In pigeons gray matter is internal in :
    (a) Olfactory lobes (b) Cerebral hemisphere
    (c) Cerebellum
    (d) Optic lobe and medulla oblongata
25. In birds voluntary movements are controlled by :
    (a) Cerebellum (b) Optic lobes
    (c) Crura cerbri (d) Medulla oblongata
26. In pigeons retina possesses :
    (a) Rods and cones equally
    (b) More cones than rods
    (c) More rods than cones
    (d) Only cones
27. Pecten is absent in which bird :
    (a) Pigeon (b) Peacock (c) Kiwi (d) Crow

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d) 13. (a) 14. (b) 15. (c) 16. (d) 17. (a) 18. (b) 19. (c) 20. (d) 21. (a) 22. (b) 23. (c) 24. (d) 25. (a) 26. (b) 27. (c).

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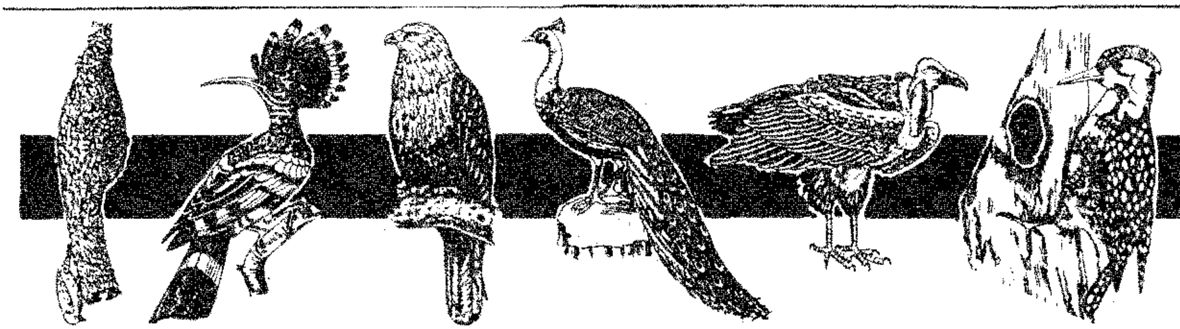

Class 8. Aves : The Birds

Distinctive Characters

Birds constitute a well-defined group of vertebrate animals. As a class they form a more homogeneous group than any other class of vertebrates. They possess a series of strongly marked characters such as distinguish hardly any other class. The diagnostic features of birds are :

1. Feather-clad, air-breathing, warm-blooded, oviparous, bipedal flying vertebrates.
2. *Body* is more or less spindle-shaped and divisible into four distinct regions : head, neck, trunk and tail. Jaw bones prolonged into a toothless *beak* or *bill*. *Neck* is long and flexible. *Tail* is short and stumpy.
3. *Limbs* are two pairs. Forelimbs are modified as *wings* for flying. Hind limbs or legs are large, and variously adapted for walking, running, scratching, perching, food capturing, swimming or wading, etc. Each foot usually bears four clawed toes, of which the first or *hallux* is directed backwards.
4. *Exoskeleton* is epidermal and horny, represented by (i) *feathers* forming a non-conducting body covering for warmth, (ii) *scales* on the legs, similar to those of reptiles, (iii) claws on the toes, and (iv) *sheaths* on the beaks.
5. *Skin* is dry and devoid of glands except the *oil* or *preen gland* at the root of tail.
6. *Pectoral muscles* of flight are well developed.
7. *Endoskeleton* fully ossified, light but strong and without epiphyes. Long bones pneumatic or hollow and have no marrow. Usually, there is a fusion of bones.
8. *Skull* smooth and *monocondylic*, bearing a single occipital condyle. Cranium large and dome-like. *Sutures* indistinct.
9. *Lower jaw* or *mandible* consist of 5 or 6 bones and articulates with quadrate.

10. *Vertebral column* short. Centra of vertebrae *heterocoelous* (saddle-shaped). Cervical vertebrae numerous, bear small cervical ribs. Some thoracic vertebrae fused together. A *synsacrum* results by fusion of posterior thoracic, lumbar, sacral and anterior caudal vertebrae. *Tail vertebrae* few, compressed laterally and the last 3 or 4 fused into a ploughshare bone, *pygostyle*.
11. *Sternum* large, usually with a vertical, mid-ventral *keel* for attachment of large flight muscles.
12. *Ribs* double-headed (*bicephalous*) and bear posteriorly directed *uncinate processes*.
13. Both clavicles and single interclavicle fused to form a V-shaped bone, called *furcula* or *wishbone*.
14. *Pelvic girdle* large, strong and fused with synsacrum throughout its length. Pubic and ischiatic symphyses lacking. Acetabulum perforated.
15. Proximal carpals free. Distal carpals fuse with three metacarpals to form *carpometacarpus*.
16. Proximal tarsals and tibia fused to form *tibiotarsus*. Distal tarsals fused with II, III and IV metatarsals to form *tarso-metatarsus*. I metatarsal remains free.
17. *Ankle joint* is inter-tarsal.
18. Oesophagus is frequently dilated into a crop for quick feeding and storage. Stomach divided into a glandular *proventriculus* and muscular *gizzard*. Junction of small intestine and rectum marked by a pair of *rectal caeca*. A three-chambered *cloaca* present.
19. *Heart* completely 4-chambered. There is neither sinus venosus nor truncus arteriosus. Only *right aortic (systemic) arch* persists in adult. *Renal portal system* vestigial. Red blood corpuscles nucleated.
20. Birds are the first vertebrates to have *warm blood*. Body temperature is regulated *(homoiothermous)*.
21. Respiration by compact, spongy, non-distensible *lungs* continuous with thin-walled *air-sacs*.
22. *Larynx* without vocal cords. A sound box or *syrinx*, producing voice, lies at or near the junction of trachea and bronchi.
23. *Kidneys* metanephric and 3-lobed. *Ureters* open into cloaca. *Urinary bladder* absent. Birds are *urecotelic*. Excretory substance of urates eliminated with faeces.
24. *Brain* large but smooth. Cerebrum, cerebellum and optic lobes greatly developed. *Cranial nerves* 12 pairs.
25. *Olfactory organs* poor. Middle ear contains a single ossicle. *Eyes* large and possess nictitating membranes, sclerotic plates and a vascular pecten.
26. *Sexes* separate. *Sexual dimorphism* often well marked. Male has a pair of abdominal *testes* and a pair of sperm ducts. A copulatory organ absent except in ratites, ducks, geese, etc. Female has a single functional left *ovary* and *oviduct*.
27. Fertilization internal, preceded by copulation and courtship. Females *oviparous*. Eggs large with much yolk and hard calcareous *shell*.
28. Eggs develop by external *incubation*. Cleavage discoidal, *meroblastic*. Development direct. *Extra-embryonic membranes* (amnion, chorion, allantois and yolk-sac) present.
29. Newly-hatched young fully formed *(precocial)* or immature *(altricial)*.
30. *Parental care* is well marked.

Classification of Aves

Birds show less diversification than any other group of vertebrate animals. This singular uniformity of structure is imposed upon them by the demands of flight. The great homogeneity of birds, therefore, fails to present convenient external features, such as the teeth of mammals, for their classification.

About 9,000 living species of birds are known at present 25 to 30 avian orders are recognized depending on the taxonomist. According to Wetmore* (1960), there are 34 orders, 27 orders of living birds of which two have recently become extinct, and 7 orders of fossil birds. To define

* Wetmore, A. 1960. A classification for the birds of the world. Smithsonian Misc. Collns, Vol. 139. (II), 1-37.

each order adequately is beyond the scope of this book, so that, we shall list only the more economic groups. The names of orders end in *'formes'*, which means 'form'.

Class *Aves* is first divided into two subclasses as follows :

Sub-class I. Archaeornithes
(Gr., *archios*, ancient+*ornithos*, bird).

1. Extinct, archaic, Jurassic birds of Mesozoic Age, about 155 million years ago.
2. Wings primitive, with little power of flight.
3. Tail long, tapering, with more than 30 vertebrae, lizard-like, bearing two lateral rows of rectrices.
4. Each hand bearing three unfused and clawed fingers.
5. Skull with teeth in both jaws, embedded in sockets (alveoli).
6. Vertebrae amphicoelous.
7. Tail with 18-20 free caudal vertebrae, without pygostyle.
8. Sternum without a keel.
9. Carpals and metacarpals free.
10. Thoracic ribs slender, without unicinate processes.
11. Abdominal ribs present.
12. Cerebellum small.

This sub-class includes a single order.

Order Archaeopterygiformes

Example : *Archaeopteryx lithographica*, from Jurasic of Bavaria, Germany; one specimen lying in the British museum, London, the other lying in the Berlin Museum, Berlin.

Sub-class II. Neornithes
(Gr., *neos*, modern+*ornithos*, birds)

1. Modern as well as extinct post-Jurassic birds.
2. Wings usually well-developed and adapted for flight, with few exceptions.
3. Tail short and reduced, caudal vertebrae 13 or even less, with rectrices arranged in a fanlike manner.
4. Wing composed of 3 partly fused fingers without claws.
5. Teeth absent except in some fossil birds.
6. Vertebrae heterocoelous in living forms.
7. Few caudal vertebrae free. Rest fused into a pygostyle.
8. Sternum usually with a keel.
9. Distal carpals fused with metacarpals to form carpometacarpus.
10. Thoracic ribs usually with uncinate processes.
11. Abdominal ribs absent.
12. Cerebellum large.

The sub-class is divisible into 4 super-orders :

Super-order 1. Odontognathae
(Gr., *odontos*,teeth)

1. Extinct, Upper Cretaceous birds.
2. Jaws bear teeth, "so advantageous for catching fish."
3. Brain of the avian type.

Order 1. Hesperornithiformes

1. Large flightless marine birds.
2. Sharply pointed pleurodont teeth, present in grooves rather than in sockets.
3. Vertebrae amphicoelous.
4. Shoulder girdle reduced.
5. Sternum without a keel.
Examples : *Hesperornis*, *Enaliornis*, *Baptornis*, etc.

Order 2. Ichthyornithiformes

1. Whether teeth were present is not definite.
2. Neck vertebrae amphicoelous.
3. Shoulder girdle well-developed.
4. Sternum with a well-developed keel.

Examples : *Ichthyornis*, *Apatornis*.

Super-order 2. Palaeognathae or Ratitae
(Gr., *palaios* old+*gnathos* jaw; L., *ratis*, raft)

1. Modern big-sized, flightless, running birds, without teeth.
2. Wings vestigial or rudimentary; feathers devoid of interlocking mechanism.
3. Rectrices absent or irregularly arranged.
4. Pterylae are irregular.
5. Oil gland is absent, except in Tinamus and Kiwi.
6. Skull is dromaeognathous or palaeognathous that is, vomer is large and broad and interpolated between palatines.

7. Skull sutures remain distinct for long time.
8. Quadrate articulates by a single head with skull.
9. Sternal keel vestigial, absent or flat, raft-like.
10. Uncinate processes are vestigial or absent.
11. Tail vertebrae free. Pygostyle small or absent.
12. Scapula and coracoid are comparatively small and fused at an obtuse angle (more than a right angle).
13. Clavicles are small or absent.
14. Ilium and ischium not united posteriorly except in Rhea and Emu.
15 Pectoral muscles poorly developed.
16. Syrinx is absent.
17. Male has a large and erectile penis; female has a clitoris.
18. Young are precocious.
19. Distribution is restricted.

The flightless birds or ratites are not represented in India. They are grouped in 7 orders as follows;

Order 1. Struthioniformes
(Gr., *struthio*, ostrich+form)

1. Legs strongly developed, each with two toes (3rd and 4th) with stunted nails. Flightless, terrestrial birds.
2. Pubis form a ventral symphysis.
3. Sternum lacks keel.
4. Pygostyle absent.
5. Head, neck and legs sparsely feathered. Feathers without aftershaft.
Examples : True ostriches (*Struthio camelus*) of Africa and western Asia (Arabia).

Order 2. Rheiformes
(Gr., *Rhea,* mother of Zeus+form)

1. Each leg bears three clawed toes.
2. Ischia form a ventral symphysis.
3. Sternum lacks keel
4. Head and neck partly feathered. Feathers lack aftershaft

Examples : American ostriches or common rhea (*Rhea americana*) represented by two species in South American pampas; Darwin's rhea (*Pteroncemia pennata*).

Order 3. Casuariformes
(NL., *Casuarius*, genus of cassowary+form)

1. Forelimbs greatly reduced.
2. Head bears a comb-like structure.
3. Neck and body densely feathered. Feathers with aftershaft nearly equal to shaft.

Examples : Cassowaries (*Casuarius*) of Australia, and New Guinea and Emus (*Dromaius novaehollandiae*) of New Zealand.

Order 4. Apterygiformes
(Gr., a, *not+pteryx*, wing+form)

1. Feathers simple, hair-like or bristle-like.
2. Wings vestigial.
3. Long bill with nostrils near the tip.
Examples : Kiwis (*Apteryx)* of New Zealand.

Order 5. Dinornithiformes

1. Giant birds, became extinct nearly 700 years ago.
2. Wings almost absent, beaks short and massive legs bearing four toes each.

Examples : Moas (*Dinornis maximus*) of New Zealand.

Order 6. Aepyornithiformes

1. Recently exterminated, rather later than moas.
2. Wings tiny, but legs powerful and 4-toed.
3. Coracoid, scapula and wing bnes reduced or absent.
4. Hind limbs massive.
5. Feathers with large aftershaft.
Examples : Giant Elephant-birds of Africa and Madagascar. *Aepyornis titan, Mulleornis.*

Order 7. Tinamiformes
(NL., *tinamus*, genus of tinamou+form)

1. Small terrestrial birds, not flightless but essentially great runners (cursorial).
2. Sternum is keeled.
3. Pygostyle reduced.
4. Eggshells with high gloss.
Examples : Tinamous (*Tinamus*), *Eudromia.*

Super-order 3. Impennae

Order 1. Sphenisciformes

(Gr., *spheniscus,* wedge + form)

1. Modern, aquatic, flightless, with paddle-like wings or flippers.
2. Feet are webbed.
3. Feathers small, scale like, covering entire body.
4. Thick layer of fat beneath skin.
5. Nest in colonies or rocky islands or ice.

Examples : Penguins (*Aptenodytes*) of Southern Hemisphere.

Super-order 4. Neognathae or Carinatae

(New jaw or L., *carina*, a keel)

1. Most modern, usually small-sized, flying birds.
2. Wings well-developed, feathers with interlocking mechanism.
3. Rectrices present and arranged regularly.
4. Pterylae are regular.
5. Oil gland is present.
6. Skull is neognathous, that is, vomer is short allowing palatines to meet.
7. Skull sutures disappear very early.
8. Quadrate is double-headed.
9. Sternum with a well-developed keel.
10. Uncinate processes are present.
11. Pygostyle is present.
12. Scapula and coracoid meet at a right angle or acute angle.
13. Clavicles are always well developed.
14. Ilium and ischium are united posteriorly.
15. Pectoral muscles large.
16. Male has no copulatory organ.
17. Young are altricious.
18. Distributed all over the world.

The super-order Neognathae includes several orders. For the sake of study they may be grouped into at least 6 homogeneous ecological groups, as follows :

***Group A.* Arboreal Birds**

Under this group may be placed the majority of birds spending most of their lives in and around shrubs and trees.

Order 1. Passeriformes

(L., *passer*, sparrow + form)

This is the largest of all the bird orders including half the known species. Feet are adapted for perching, while beaks are adapted for cutting.

Examples : Common house sparrow (*Passer domesticus*), common house crow (*Corvus splendens*), indian jungle crow (*Corvus macrorhynchos*), common myna (*Acridotheres tristis*), bank myna (*Acridotheres ginginianus*). Indian robin (*Saxicoloides fulicata*), black drongo or kingcrow (*Dicrurus macrocercus*), golden oriole (*Oriolus oriolus*), tailor bird (*Orthotomus sutorius*), weaver bird or baya (*Ploceus philippinus*), flycatchers (*Muscicapa*), swallows, bulbuls (*Molpestes*) magpie (*Pica*), crossbill (*Loxia*), starling (*Sturnus*), larks (*Alauda*).

Order 2. Piciformes

(L., *picus*, wood pecker + form)

It includes woodpeckers, toucans, sap-suckers and their allies.

Examples : Yellow fronted pied woodpecker (*Dendrocopos mahrattensis*), golden-backed woodpecker (*Dinopium benaghalensis*)

Order 3. Columbiformes

(L., *columba*, dove + form)

It includes doves and pigeons.

Examples : Blue rock pigeon (*Columba livia*), green pigeon (*Crocopus*), crowned pigeon (*Goura cristata*), passenger pigeon (*Ectopistes migratorius*), ringed turtle dove (*Streptopelia risoria*), spotted dove (*Streptopelia chinensis*), extinct dodo (*Raphus*) and solitaire (*Pezophaps*).

Order 4. Psittaciformes

(L., *psitacus*, parrot + form)

It includes parrots, parakeets, cockatoos, macaws, love-birds, etc., denizens of the equatorial jungles.

Examples : Large Indian parakeet (*Psittacula eupatria*), green parrot (*Psittacula krameri*), budgeriger (*Melopsittacus*).

Group B. Terrestrial Birds

These birds are perfectly able to fly but spend most of their time walking or running on ground.

Order 5. Galliformes
(L., *gallus*, a cock + form)

It includes gamebirds notable for their palatability, massive scratching feet, short and powerful flight and largely graminivorous diet.

Examples : Red jungle fowl (*Gallus*), peafowl (*Pavo cristatus*), quail (*Cotrunix coturnix*), grey partridge (*Francolinus pondicerianus*), chukor (*Alectoris grecca*), pheasants (*Phasianus*).

Order 6. Cuculiformes
(L., *cuculus*, cuckoo + form)

It includes cuckoos and their allies.

Examples : Cuckoo (*Cuculus canorus*), Koel (*Eudynamis scolopaceous*), crow-pheasant (*Centropus sinensis*).

Group C. Swimming and Diving Birds

Order 7. Anseriformes
(L., *anser*, goose + form)

Aquatic birds such as geese, swans and ducks belong to this order.

Examples : Wild duck or mallard (*Anas*), common teal (*Nettion crecca*), bar-headed goose (*Anser indica*), swan (*Cygnus*), mergansers (*Mergus*).

Order 8. Coraciiformes
(Gr., *korax*, crow or raven + form)

It includes kingfishers and their allies.

Examples : White breasted kingfisher (*Halcyon smyrnensis*), pied kingfisher (*Ceryle rudis*), great hornbill (*Dichoceros bicornis*), grey hornbill (*Tochus birostris*), hoopoe (*Upupa epops*).

Order 9. Gaviiformes
(L., *gavia*, sea mew + form)

It includes marine birds, called loons (*Gavia*) represented by only four species.

Order 10. Podicipediformes or Colymbiformes
(Gr., *kolymbos*, diving bird)

It includes grebes (*Podicipes*), often called divers because of their habits.

Order 11. Procellariformes
(L., *procella*, a tempest + form)

It includes tube-nosed, long and oily winged sea-birds such as albatrosses (*Diomedea*), Petrels (*Procellaria*), shearwaters.

Order 12. Pelecaniformes
(L., *pelicanus*, pelican + form)

It includes pelicans, darters, gannets and cormorants.

Examples : Pelicans (*Pelecanus*), little cormorant (*Phalacrocorax niger*), Indian darter (*Anhinga melanogaster*).

Group D. Shore Birds and Wading Birds

These aquatic birds seldom swim or dive beneath the water to any great extent.

Order 13. Charadriiformes
(NL., *charadrius*, genus of plovers + form)

This order includes a rather diverse group of water frequenting shore birds characterized by long wading legs, webbed toes and mudprobing beaks.

Examples : Red wattled lapwing (*Lobivanellus indicus*), pheasant-tailed jacana (*Hydrophasianus chirugus*), sand piper (*Tringa glariola*), snipe (*Capella*), gull (*Larus*), curlew (*Numenius*).

Order 14. Ciconiiformes
(L., *ciconia*, a stork + form)

It includes long-legged, marshy wading birds with long snake-like neck and javelin or pincer-like beak for piercing their aquatic prey.

Examples : Cattle egret (*Bubulcus ibis*), heron (*Ardea herodias*), night heron (*Nycticorax*), spoonbill (*Platalea leucorodia*), stork (*Ciconia*), flamingo (*Phonicopterus*).

Order 15. Gruiformes
(L., *grus*, crane + form)

It includes crane-like wading birds with long legs and partially webbed feet.

Examples : Common coot (*Fulica atra*), sarus crane (*Antegone antegone*), bustard (*Choriotis*) rail.

Group E. Birds of Prey

Order 16. Falconiformes
(L., *falco*, falcon + form)

The diurnal birds of prey with sharp hooked beaks and strong curved claws are as follows :

Examples : Common pariah kite (*Milvus migrans*), brahminy kite (*Haliaster indus*), sparrow hawk (*Astur badius*), white backed vulture (*Pseudogyps bengalensis*), king vulture (*Sarcogyps calvus*), peregrine falcon (*Falco peregrinus*), eagle (*Aquila*).

Order 17. Strigiformes
(Gr., *strix*, owl + form)

It includes owls which are nocturnal birds of prey characterized by large heads, huge yellow frontal eyes and powerful grasping feet feathered upto toes.

Examples : Brown fish owl (*Ketupa zeylonensis*), great horned owl (*Bubo*), *Tylopus*.

Group F. Aerial Birds

These birds are mostly on wing, and have weak or vestigial perching feet.

Order 18. Micropodiformes or Apodiformes (Gr., *apous*, footless + form)

It includes swifts and humming birds.

Examples : Indian swift (*Micropodus*), palm swift (*Cypsiurus*).

Order 19. Caprimulgiformes
(L., *caprimulgus*, goat sucker + form)

It includes shy, nocturnal, insectivorous birds such as night hawks (*Chordeiles*), whippoorwills (*Phaelaenoptilus*), goat suckers (*Caprimulgus*).

Common Birds of India

The Indian continent, including India, Pakistan, Bangla Desh, Nepal, Sri Lanka and Burma, contains one of the richest and most varied bird faunas. It includes some 2,500 species and subspecies out of which nearly 500 are winter visitors from the North.

Some of the largest Indian birds (Fig. 1) include the Sarus Crane (*Antigone antigone*) standing one and a half meters, and the Himalayan Bearded Vulture with a wingspread of nearly two and a half meters. Among the smallest Indian birds are the Tickell's Flower pecker (*Dicaeum erythrorhynchos*) and the sun birds, about half the size of the House Sparrow or even less. The pheasants and the sunbirds are noted for their glistening colours and brilliancy of plumage. The most accomplished Indian songsters are the Greywinged Blackbird (*Turdus boulboul*) of the Himalayas, the Malabar Whistling Thrush (*Myiophoneus horsfieldii*) and the Shama (*Copsychus malabaricus*). The best talker is certainly the Hill Myna (*Gracula religiosa*).

1. House sparrow. *Passer domesticus* is commonly known as the 'house sparrow' in English and 'chidiya' or 'gauriyya' in Hindi. It is cosmopolitan in distribution. It is the most commonly seen bird, freely moving and nesting in the houses where it lives as a commensal of man. It is a small bird, measuring 10 to 16 cm in length. Sexual dimorphism is distinct. The female is ash white and the male is earthy brown with blackish throat and breast and white abdomen. Beak is conical and eyes small. Feet are adapted for perching with three toes anterior and the first toe of halux posterior. Breeding occurs almost throughout the year. 3 to 5 pale white greyish eggs are laid at a time and successive broods are often raised. Sparrows are omnivorous, but chiefly granivorous, and significant avian pests of granary and storage. However, they also serve useful by destroying several agricultural insect pests.

2. Crow. *Corvus splendens* is commonly known as the 'house crow' in English and

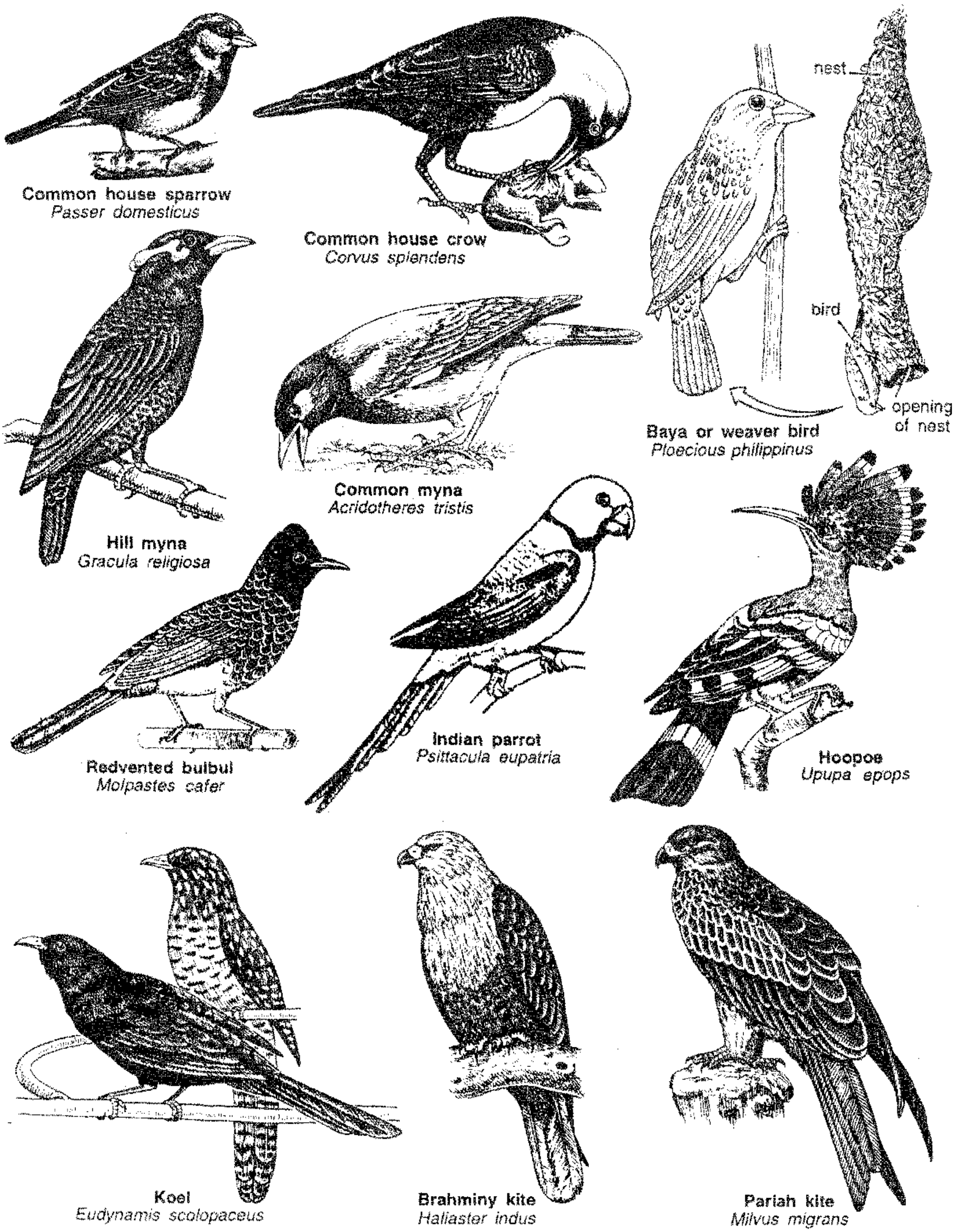

Fig. 1. Some common Indian birds.

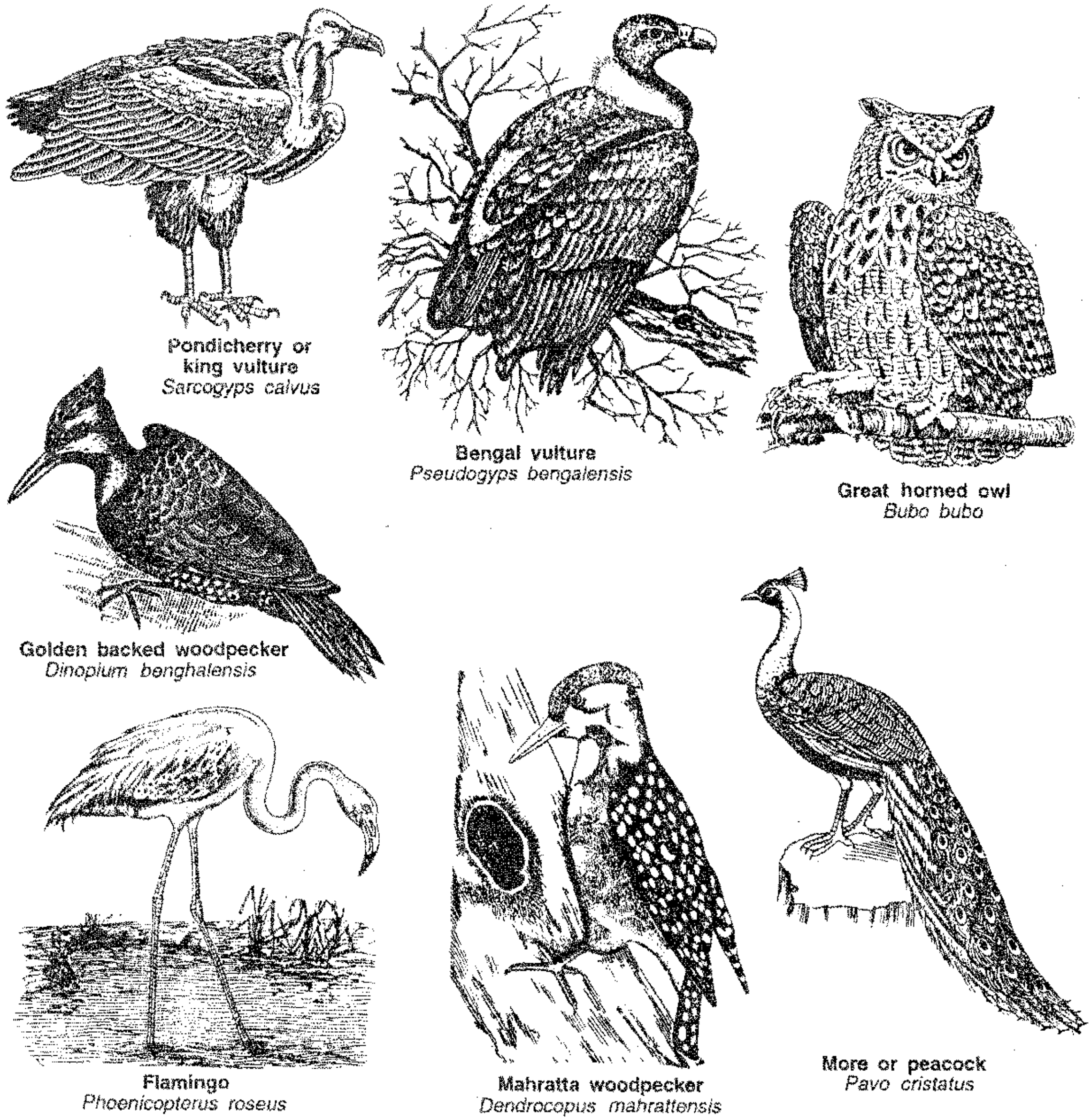

Fig. 1. (Continued). Some common Indian birds.

'kowwa' or 'kag' in Hindi. It is abundantly found throughout the peninsula of India. It is perhaps the most familiar bird of Indian towns and villages, living in close association with man. The adult grows 32 to 42 cm in length. The body is covered with a more or less black plumage while the neck and breast are grey coloured. Both sexes are similar. Eyes are large and beaks elongated. Feet are adapted for perching. Tail feathers are elongated. Crows are intelligent, cunning and audacious (bold) birds. They are omnivorous as they eat anything from dead sewer rat to kitchen refuge, insects, fruits, grains and eggs and fledgling birds pilfered from nests. The koel commonly lays its eggs in the nests of crows. The house crows act as efficient municipal scavengers.

3. Weaver bird or baya. *Ploceus philippinus*, the common weaver bird or baya looks like sparrow and lives in flocks. It is among the world's best nest builders. Elaborately woven bottle-shaped nests are commonly seen hanging from tree branches in the countryside. Weaver birds damage cereal crops.

4. Common myna. The name of common myna is *Acriodotheres tristis* which means the sad grasshopper hunter. It is common throughout the Indian Region. It is a confirmed associate of man and follows him wherever he opens up new settlements. It measures about 22.5 cm in length. The colour is perky dark brown getting paler on the underparts. Head, throat and breast are glossy black. Beak and legs are yellow. There is a small patch of bare yellow skin behind each eye. When it flies, a white patch or bar becomes conspicuous on each wing. Sexes are alike. The bank myna (*Acridotheres ginginianus*), or the 'ganga myna' in Hindi, is similar to common myna or 'deshi myna' (*A. tristis*), but its colour is pale bluish grey instead of brown and the naked skin around eyes is brick-red instead of yellow. Mynas are omnivorous eating fruits, insects and kitchen scraps.

5. Hill myna. The best talker and mimic amongst the Indian birds is the hill myna *Gracula religiosa* known as 'bolti myna' or 'pahari myna' in Hindi. The bird is about 30 cm in length and jet black in colour. Beak and legs are yellow, and bright orange coloured patches of naked skin and wattles are present on head. Wings are marked with a conspicuous white patch. Both the sexes are similar. Hill myna is arboreal and seen in pairs or noisy flocks in well-wooded country. It feeds on various wild figs in the company of green pigeons, hornbills and others. Being an accomplished talker and mimic it is much prized as a cage bird. Its articulation of human speech is clearer and truer than that of the parakeets.

6. Hoopoe. Hoopoe or *Upupa epops* is known as 'hudhud' in Hindi. It is found practically all over India. It is fond of lawns, gardens and grooves in and around villages and towns. It is about the size of a myna. It is a reddish fawn coloured bird with black and white zebra markings on back, wings and tail. The white bars flash out with beautiful effect when the bird starts flying. Its beak is about 5 cm long, very slender and gently curved. On its head it bears a conspicuous fan-shaped crest. The two sexes are similar. It probes dry land to draw out subterranean insects, grubs and pupae and is beneficial to agriculture. It emits a soft, musical 'hoo-po' or 'hoo-po-po' which is repeated in runs.

7. Koel. The Hindi name of *Eudynamis scolopaceus* is 'koel' or 'kokila'. It occurs throughout India, Pakistan, Sri Lanka and Burma. The bird is about the size of the house crow, but slim and with a longer tail. Sexual dimorphism is conspicuous. Male bird is characterized by having glistening metallic black all over with yellowish green beak and small blood red eyes with rounded pupil. Whereas the female is brown with white spots. The bird is better known by its melodious voice. It is the male bird whose voice is often heard in summer during mango season. The female does not sing but utters a sharp and quick repeated 'kik-kik-kik'. Koel is a nest parasite and does not build a nest of its own. It simply lays its eggs in a crow's nest so that the eggs and young ones, are looked after by the foster parents. Koel songs have often been associated with romantic Hindi poetry.

8. Large Indian parrot. The Alexandrine or the large Indian parakeet, *Psittacula eupatria*, is known as 'hiraman tota' in Hindi. It is common in India, Bangla Desh, Sri Lanka and Burma, but not so common in Pakistan. It is about the size of a pigeon, with a slender body and a long pointed tail. The body is covered by a brilliant grass green plumage. The beak is short but stout, sharp edged, deeply hooked and coral red. There is a conspicuous maroon patch on each shoulder. The female is green all over, but the male has a rose pink collar and a black throat. Upper mandible is movable on the frontal bone of skull. Feet are adapted for grasping, holding and climbing. There are 2 front toes and 2 hind toes, the outer hind toe is not reversible. Food consists chiefly of fruits. Parrots are gregarious with loud voicés. Parrots can copy and speak some words like man but not as distinctly as the hill myna. Even then they are popular domestic cage birds as they are easily procured.

9. Kites. *Milvus migrans* or the common 'pariah kite' is the ordinary 'cheel' in Hindi. It is found throughout India, Pakistan, Bangla Desh, Sri Lanka and Burma. It is a large bird about 60 cm in length. The plumage is reddish brown streaked with dark brown. Both the sexes are similar. It is distinguished from all similar birds by its forked tail. It is often seen singly or gregariously. The beak is sharp, pointed and hooked. The toes are elongated and bear sharp pointed claws for grasping. Largely a scavenger, it feeds on small rodents, reptiles, birds, earthworms, winged termites, garbage, etc.

We have two kinds of kites in India, the common pariah kite (*Milvus migrans*) and the brahminy kite (*Haliaster indus*). The brahminy kite is smaller than the other and much handsomer. Its head, neck and breast are pure white, while the rest of the plumage is rich chestnut brown. Its tail is rounded and not forked or wedged. Largely a scavenger in sea ports, it lives on offal, fish, frogs, small snakes, etc.

10. Vultures. The Hindi name of the black, Pondichery or king vulture (*Sacrogyps calvus*) is 'raj gidh'. It occurs throughout the Indian region but not in Sri Lanka. It is a huge bird measuring 7 feet across the wings. Its deep black colour is relieved by two white patches on upper thighs, a white band on underside of wings, and a white collar at the base of neck. The naked head, neck and legs are blood red in colour. The stout bill is hooked at the tip and bears a soft naked cere at the base. The feet are adapted for grasping with sharp claws. Both the sexes are alike. A carrion feeder, it is timid, cowardly and repulsive-looking.

The commonest Indian vulture is the whitebacked or Bengal vulture (*Pseudogyps bengalensis*) called 'gidh' in Hindi. It is a smoky black bird with a white band extending nearly the whole length of each wing on the underside. Its white back is also diagnostic. It collects in large gatherings to demolish animal carcases with astonishing promptness and incredible speed.

11. Owls. *Bubo bubo* is commonly known as the 'great horned owl' and its Hindi name is 'ghughu'. It has a worldwide distribution. It is a large and heavy bird growing up to 60 cm. The plumage above is mottled reddish-yellow, brown and grey. The underparts are lighter in tone with dark vertical streaks. Two prominent feather tufts above head look likes ears, hence the name great horned owl. The beak is short, parrot-like. Eyes are large, rounded, forwardly directed and each in disc of radial feathers. Fully feathered legs are diagnostic of horned owl. The two sexes are alike. It is a nocturnal bird. It feeds on small birds, mammals, reptiles and occasionally on larger insects, fish and crabs. *Bubo* is of great economic value to agriculture as it feeds on harmful rodents and deserves careful protection.

The brown fish owl (*Ketupa zeylonensi*) or 'ulloo' in Hindi, is also common throughout India. It is similar to the horned owl in all respects, but its legs are unfeathered. A smaller variety is the barn owl or screech owl (*Tyto alba*) about the size of a jungle crow. It has a large round head with a monkey-like face, but has no ear pojections. The barn owl also enjoys a worldwide distribution.

12. Peacock. *Pavo cristatus*, the common peafowl or peacock is called 'mor' or 'mayur' in Hindi. It is the national bird of India and to kill it is a penal crime. It inhabits dense scrub, jungles and forests. It displays a well-marked sexual dimorphism. The male bird is about the size of a vulture, very gracious and beautifully pigmented. Its ornamented gorgeous ocellated tail, about 1 or 1.5 metres long, is formed by the abnormally elongated upper tail coverts. The head is crested and the neck reflects a bright green metallic seen. The female is smaller, mottled brown and lacks the ornamental tail. Bill is short and the feet are adapted for running and scratching. Peafowls are shy and polygamous birds usually living in a party or drove of one cock and 4 to 5 hens. They feed on grains, vegetable shoots, insects, lizard and snakes and sometimes cause severe damage to newly sown seeds. The call is a loud, harsh, screaming 'may-awe'. The male bird is famous for its dance in front of hens in which the gorgeous tail coverts are erected and spread out like a fan.

13. Woodpeckers. The Hindi name for all woodpeckers is 'kathphorwa.' They are distributed practically throughout India, Pakistan, Bangla Desh, Sri Lanka and Burma. They are small birds found in light wooded country, orchards and groves around villages, clinging to tree trunks. The stiff pointed wedge-shaped tail is pressed against the stem. The long stout bill is awl or chisel-like, square at the tip and with an edge always kept sharp. The long protrusible tongue is tipped with strong and sharp hooks or barbs. The foot bears 4 toes, 2 in front and 2 behind, not reversible. Woodpeckers dig into rotten wood for beetles, grubs, ants and other insects. The golden backed woodpecker (*Brachypternus* or *Dinopium*) is about the size of a myna. The yellow fronted pied or Mahratta woodpecker (*Dryobates* or *Dendrocopos mahrattensis*) is much smaller, about the size of a bulbul.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Describe the distinctive features of class Aves.
2. Classify birds giving important features and examples of each group.

» ***Short Answer Type Questions***

3. Write short notes on—(i) Crow, (ii) Koel, (iii) Peacock.

» ***Multiple Choice Questions***

1. Exoskeleton in birds is epidermal and horny, represented by :
   (a) Feathers, forming a body covering
   (b) Scales, similar to those of fishes
   (c) Claws, on wings
   (d) Sheaths on toes
2. Centra of vertebrae in birds is :
   (a) Procoelous (b) Heterocoelous
   (c) Acoelous (d) Amphicoelous
3. In birds the last 3 or 4 tail vertebrae are fused to form :
   (a) Synsacrum (b) Furcula
   (c) Pygostyle (d) Wish bone
4. In birds, sound is produced by :
   (a) Air sacs (b) Trachea (c) Larynx (d) Syrinx
5. Middle ear in birds contains :
   (a) 1 ossicle (b) 2 ossicles
   (c) 3 ossicles (d) 4 ossicles
6. Order Archaeopteryx formes includes :
   (a) *Hesperornis* (b) *Archaeopteryx*
   (c) *Icthyornis* (d) *Enaliornis*
7. Flightless birds are included in :
   (a) Odontognathae (b) Impennae
   (c) Ratitae (d) Carinatae

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c).

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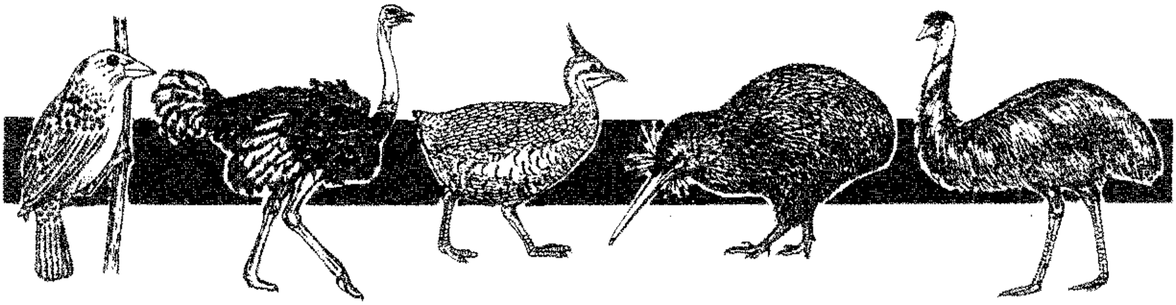

Aves : General Account

Flightless Birds (Ratitae)

The living wingless or flightless birds belong to the superorder Palaeognathae (or Ratitae) of the subclass Neornithes. They are characterized by having a palaeognathous palate, a keeless raftlike sternum and curly feathers. Table 1 tabulates the differences between Ratitae and Carinatae. Ratites are represented by several species on earth today and have persisted over a long period of geological time. These birds are much alike and all are ground-dwelling. They are usually very large, some reaching as much as 4 metres in height. They have well-developed powerful legs, small heads and rudimentary wings with fluffy feathers which are useless for flight. In fact, they depend on their fleetness for security. An interesting fact is that all modern flightless birds live in parts of the world where there are no carnivores, that is no members of the cat or wolf tribes.

[I] Orders of flightless birds

The living flightless birds belong to the following 4 orders of the superorder Palaeognathae :

Order 1. Struthioniformes. Ostriches of Southwest Asia and Africa.

Order 2. Rheiformes. Rheas of South America.

Order 3. Casuriiformes. Cassowaries and emus of Australia and adjacent islands.

Order 4. Apterygiformes. Kiwis of New Zealand.

[II] Discontinuous distribution

A remarkable example of discontinuous distribution is furnished by the flightless birds. Taking into consideration the living forms only, each of the great Southern land masses contains one order of Ratitiae (or Palaeognathae) not found elsewhere. They are distributed in far flung areas such as South America (rheas), Africa and Asia (ostriches),

Table 1. **Differences between Ratitae and Carinatae.**

	Structure	Palaeognathae or Ratitae	Neognathae or Carinatae
1.	Distribution	Restricted, discontinuous. Not found in India	Cosmopolitan, found all over the world
2.	Habitat	Terrestrial	Arboreal, terrestrial or aquatic
3.	Locomotion	Flightless running birds	Flying birds
4.	Size	Usually large-sized	Usually small-sized
5.	Wings	Vestigial or absent	Well developed
6.	Legs	Large cursorial	Variously adapted
7.	Feathers	Without interlocking mechanism Barbs free	Barbs interlocked due to barbules and barbicels
8.	Pterylae	Irregular, continuous	Regular, separated by apteria
9.	Rectrices	Absent or irregularly arranged	Regularly arranged in a fan-like manner
10.	Aftarshaft	Well developed	Poorly developed
11.	Downfeathers	Absent	Present
12.	Horny sheath of beak or rhamphotheca	Divided in several pieces	Undivided
13.	Oil gland	Usually absent	Present
14.	Skull sutures	Remain distinct for a long time	Disappear very early
15.	Type of skull	Dromaeognathous or palaeognathous	Neognathous, never dromaeognathous
16.	Vomer	Large, broad, interpolated between palatines	Small, narrow, allows palatines to meet
17.	Palatines	Short, do not articulate with rostrum	Long, articulate with parasphenoidal rostrum
18.	Pterygoids	Immovable	Movable
19.	Basipterygoid processes	Well-developed	Small or absent
20.	Pygostyle	Small or absent	Well developed
21.	Sternum	Flat, raft-like due to vestigial or no keel	Well-developed mid-ventral keel
22.	Uncinate processes	Vestigial or absent	Present
23.	Coracoid and scapula	Comparatively small, and fused at an obtuse angle	Comparatively large, not fused but meeting at an acute angle
24.	Clavicles	Small or absent, no furcula	Both clavicles and interclavicle fused to form a V-shaped furcula
25.	Ilium and ischium	Usually remain free posteriorly	Become fused posteriorly
26.	Pelvic symphyses	Pubic in ostrich, ischiatic in rhea	Public and ischiatic symphyses absent
27.	Limb bones	Not pneumatic	Pneumatic
28.	Pectoral muscles	Poorly developed	Well developed
29.	Caecum	Large	Small
30.	Syrinx	Usually absent	Present
31.	Air sacs	Poorly developed	Well developed
32.	Penis in male	Present	Absent
33.	Clitoris in female	Present	Absent
34.	Eggs	Shell thick, hard. Pore canal branched	Shell thin, fragile, Pore canal unbranched
35.	Newly hatched young	Precocial, not dependent on parents	Altricial, helpless, dependent on parents

Australia (cassowaries and emus) and New Zealand (kiwi). It is indeed very remarkable that two genera so closely allied as are *Rhea* and *Struthio*, should occupy areas so distantly removed from each other as South America and Africa. The living members are entirely wanting in Europe and North America. But the existence of their fossils in North America and Europe only proves that the flightless birds were once not confined to their present limits alone and possibly pervaded the greater part of the earth.

[III] Origin

Origin and ancestry of flightless birds have been a very puzzling problem and different views have been put forward. According to the most accepted view these birds evolved from flying ancestors and only secondarily re-adapted for a flightless terrestrial mode of life. This is supported by the fact that the ratites possess many morphological characters showing adaptation to flight. It seems hardly conceivable that their ancestors had acquired these characters and were not able to fly. One reason for the acquisition of flight by the ancestral birds probably was to be better able to flee from their enemies on the ground. If the enemies are removed, then the need for flight is no longer present, hence why fly ? Therefore, in the areas where there were abundant food supply up on the ground and practically no terrestrial predators and competitors, the ancestral ratites simply ceased flying and remained on the ground all of the time thus conserving their energies for procurement of food. The above view propounded by Romer is also supported by the present day geographical distribution of the ratites. All of them live in the regions that are now, or were in the past, free from formidable bird enemies on the ground.

The ancestry of certain ratites can be traced back to the early Coenozoic Era. A number of large ground-dwelling neognathous birds also lived then. There might have been a keen competition at that time between birds and early mammals for the conquest of the land surface which had been vacated by then by the large reptiles. While the mammals won in general, only a few ground-dwelling birds survived and these gave rise to the modern flightless birds.

[IV] Examples of Ratitae

1. Ostrich. African Ostrich (*Struthio*) (Fig. 1) is represented by atleast 4 species occurring naturally in arid regions of Africa and Arabia. It is the largest living bird attaining a height of more than 2.5 metres and a weight of 150 kg. Head, neck and legs are sparsely feathered. Feathers are without aftershaft. Wings are small and usually kept folded while running but some times expanded and used as brake or steering. Wing fingers (two) are clawed which are used for defense. Male and female birds differ in the colour of their plumage. The tail and wing feathers are white while the rest are black in the male. Female is clad in a sombre brownish livery. The thick skin can be made into leather. The long sturdy legs are admirably suited to match the speed of zebras and antelopes in whose company it feeds. It can run at a speed of 80 kilometers per hour, covering more than 8 metres in a single stride. Each foot has 2 toes only, with stunted nails. Inner toe is quite large and clawed. Both beak and feet serve as weapons of defence. Two beaks are more or less round and enclose a broad space. Prominent eyes have lashes on upper eyelid. The food consists chiefly of herbage including seeds and fruits. Contrary to popular belief, an ostrich does not hide its head in sand when in danger. Ostriches travel about in groups. They are polygamous as one male attends several females. The male has a single solid retractile penis while female has a clitoris. The egg of the ostrich is very large and next in size to that of mackerel shark. Each egg weighs nearly 1.5 kg and requires 50 minutes to boil it. Ostrich meat is coarse and of little use for food. The feathers of adult bird are used by women as decorative plumes. Ostriches are easily domesticated and there are a number of Ostrich farms in Africa and United States.

2. Rhea. Rhea (Fig. 1) is represented by 3 species inhabiting the plains or pampas of South America. They use to live in groups. They are smaller (1.5 metres) than the true or Old World ostriches (*Struthio*), but their habits are quite similar. In the rheas, there are 3 clawed toes on each foot. The rudimentary wings are better developed than in true ostrich. It has no distinct tail feathers nor the showy wing plumes like that of the African ostrich. Its head and neck are feathered, not naked as in ostrich. Rheas are very fond of bathing and are even able to swim. The male is polygamous. Nest is dug by male and all females use to lay eggs in same nest. Nearly 50 eggs are laid in a season and male incubates them. Freshly laid eggs are lemon yellow and require 40 days incubation. Though the plumes are of an inferior quality to those of ostrich, they are used in the manufacture of feather dusters. There are two species of *Rhea* viz., *Rhea americana* (American Rhea) and *Pteronemia pennata* (Darnicus Rhea).

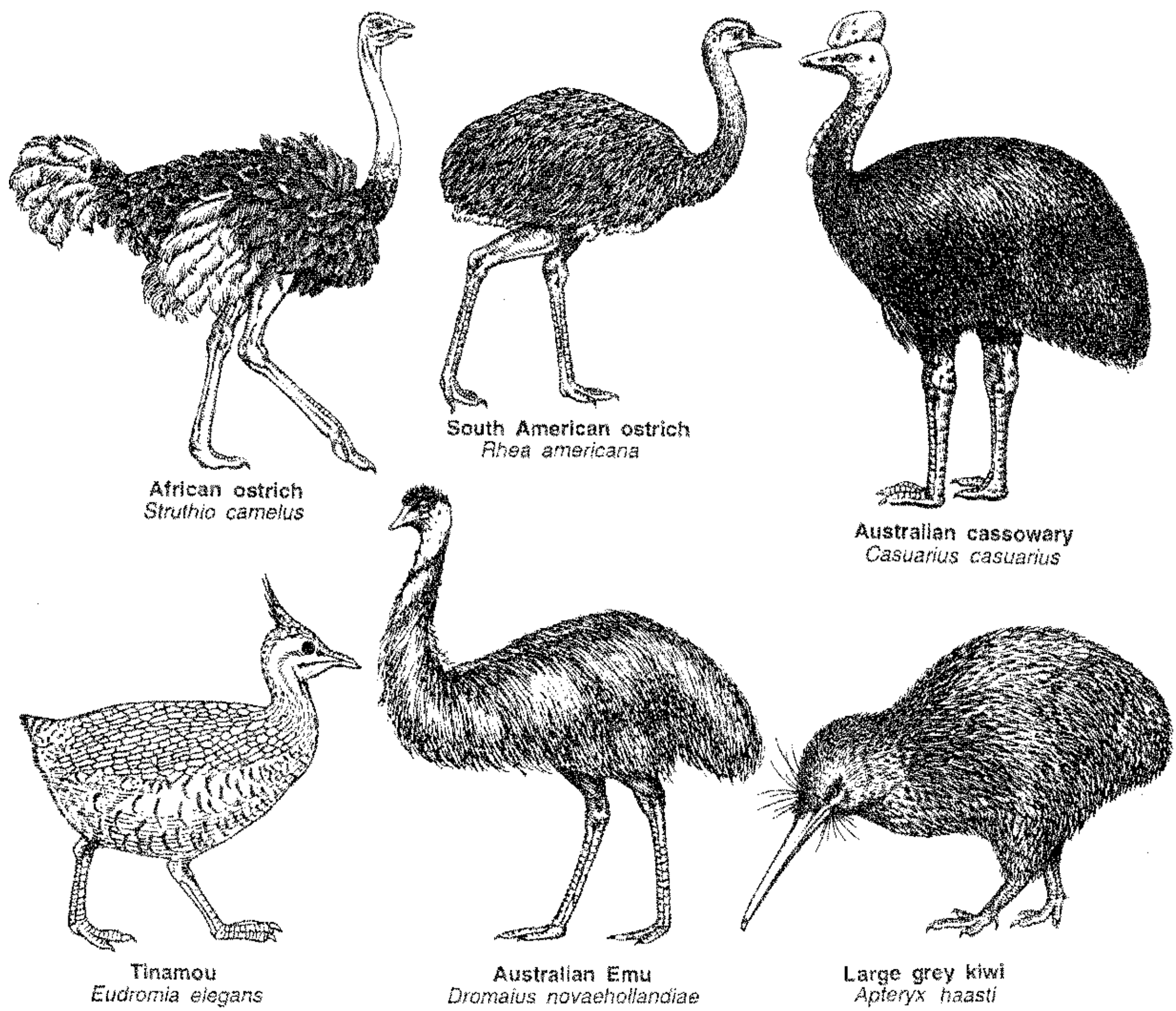

Fig. 1. Common flightless birds (Ratitae).

3. Emu. Next to ostrich, emu (*Dromiceius*) (Fig. 1) is the largest living bird, standing more than 1.5 mt. high. There are 2 species confined to Australia, inhabiting sandy plains or open forests. Emu has a more slender built than an ostrich. But it has a shorter neck covered with feathers. Body is covered with a drab-coloured plumage and both the sexes are similarly coloured. There are no large decorative plumes in the male's tail. The feathers have long aftershafts, nearly equal to shafts, so that each feather looks as if it were double. There is a remarkable tracheal pouch connected by a slit with the windpipe, and only fully developed in the adults. The bird feeds on fruits, roots and herbage. It loves bathing and swimming. Emu is invariably monogamous though seen in small parties after breeding. Male digs the nest and sits over first brood of egg. The females sit over the second brood. The eggs are green in colour and their number is usually 15 or more. The period of incubation is 60 days. The newly hatched young are strikingly stripped longitudinally, a characteristic which disappears on maturity. Emu's skin with feathers attached is often manufactured into rugs and mats. The bird's fat is used as a lubricant. The beautiful, granulated, dark-green eggs are frequently converted into artistic ornaments. Flesh is moderately good for eating.

4. Cassowary. The cassowaries (*Casuarius*), the world's third largest flightless birds (Fig. 1), live in the densely wooded parts of Australia, New Guinea and the adjacent islands, represented by about 20 species and subspecies. They are shy, nocturnal and rarely seen. Adults are black in colouration which is brown in the young. Forelimbs or wings are very small and bent at the elbow. Each foot has 3 clawed toes. The barbs of the wing feathers are in the form of long black spines, suggesting the quills of a porcupine. The rectrices are unrecognisable. The aftershaft is as long as the main shaft. The bird is distinguished from its compatriot, the emu, by a horny helmet or casque on the head. It protects the bent head as the bird rushes through the scrub. The skin of the head and neck is brightly tinted. They are quarrelsome and vicious birds and old males may attack even human beings, if disturbed. The natives sometimes capture and rear the young birds. Such individuals become very tame and affectionate. Their flesh is considered very palatable.

5. Kiwi. *Apteryx* of New Zealand (Fig. 1) is more commonly known by its Maori name 'Kiwi'. It is the smallest living flightless bird about the size of a large domestic hen. They are characterized by reddish or greyish-brown coarse hair-like feathers, strong backwardly situated legs with 3 toes in front and hallux behind, and by the elongated narrow beak curving gently downwards and strong as a rapier of steel. An extraordinary peculiarity is the location of nostrils near the apex of the beak. Their wings are rudimentary and tail feathers are lacking. Head and eyes are comparatively small. They possess a keen sense of smell, which is unique in birds. Kiwis are nocturnal and burrowing in habit, passing the daytime asleep in an underground hole, but emerging at night in search of food which includes worms and insects. It runs with great speed making wide strides. Female is larger than male. In proportion to the size of the body, the kiwi lays the largest eggs of any known animal. Only one white coloured egg is laid at a time. The enormous egg weighs about one fourth as much as the parent. The Maories of New Zealand are very fond of kiwi flesh, either roasted or boiled, while their chiefs utilized the plumage for ornamentation. In order to protect them from extermination the government of New Zealand has set aside some sanctuaries where kiwis may remain unmolested.

Affinities of Birds

[I] Reptilian descent

It is now generally believed that birds have originated from some ancestral reptilian stalk. At first sight this appears a far-fetched notion. Although, there are great differences between every bird and every reptile, yet they display striking similarity in their structure and development. Not only these two classes have so many features in common, but some remarkable fossils (e.g. *Archaeopteryx*) actually link the two groups. This led T.H. Huxley to put the two classes (Reptilia and Aves) together in a division of vertebrates termed *Sauropsida*, although this arrangement has not been generally accepted. Huxley has called on account of the similarities with reptiles as "Glorified Reptiles".

The evidence of reptilian ancestry or descent or reptilian affinity of birds is furnished by their comparative anatomy, embryology and palaeontology.

[II] Anatomical evidence

1. Exoskeleton. All birds have horny, epidermal *scales*, confined to the lower parts of their legs and feet, which are exactly like the epidermal scales of the reptiles. There is also evidence that the bird-scales are also shed and replaced like the scales of reptiles. Besides, birds are covered by *feathers* which are homologous to the reptilian horny scales, as they have similar origin and develop from similar germ-buds. The horny sheath (*rhamphotheca*) of a bird's *beak* is also comparable to the reptilian scales. In Albatross and Petrel, the horny sheath is made of separate pieces like scales of the reptilian jaws. The annual shedding of this horny sheath in Puffins is comparable to the moulting of scaly covering in reptiles. Turtles and tortoises possess horny toothless beaks like those of birds. On the other hand, the beak of the young tinamou has something similar to the teeth found in archaic birds and reptiles. Horny *claws* occur regularly on the toes of birds. They have the same basic structure in birds, reptiles and mammals.

2. Endoskeleton. In the endoskeleton of birds, the reptilian character is abundantly plain and manifested in several ways. In both the groups, the skull is well-ossified, *diapsid* and *monocondylic*, that is, articulates with the vertebral column by a single occipital condyle developed from basioccipital. Autostylic suspensorium of jaws occurs with the help of an anvil-shaped quadrate bone. An interorbital septum occurs except in snakes and legless lizards. Sclerotic plates are present in both classes. The lower jaw is made of 5 or 6 bones on either side. The mandible articulates with quadrate bone of upper jaw in skull. The epiphyses in between the vertebrae (as in mammals) are absent. Young birds have free cervical ribs, which, in the adult, coalesce with the centra of cervical vertebrae. A complete thoracic basket is formed by thoracic ribs which meet a sternum in the mid-ventral line. Uncinate processes are found on vertebral ribs of crocodiles and sphenodon. The pectoral and pelvic girdles in birds only speak of a reptilian descent. There is a well developed coracoid, single in birds, but divided into a coracoid proper and precoracoid in reptiles. The ankle joint is *inter-tarsal*, i.e., lying between the proximal and distal rows of tarsals. Number of phalanges is the same (2,3,4,5) in the toes which are also clawed.

3. Alimentary canal. Crocodiles have a gizzard and habitually swallow stones to aid in digestion, like birds. Rectum terminates into a spacious tripartite cloacal chamber, divided into coprodaeum, ureodaeum and proctodaeum. Although the division of cloaca is incomplete in birds but hints of division is evident. A caecum is present.

4. Respiratory system. Birds and reptiles respire throughout life by lungs and never by gills. Air-sacs, which are so characteristic of birds, also occur in *Chamaeleon* among lizards. Tracheal rings are complete.

5. Circulatory system. The heart and arteries of crocodiles and birds are closely comparable. The crocodiles have a completely 4-chambered heart, as in birds. The two systemic arches cross over to opposite sides. However, in crocodiles, the left arch is much smaller than the right and its suppression would result in the arrangement found in the birds, in which only the right arch persists. The blood is also similar and the red blood corpuscles are nucleated. Scott pointed out that the avian and reptilian blood bears close affinities in serological examination.

6. Nervous system. Neopallium is smooth and cerebellum divided into a median vermis and lateral flocculi. Cranial nerves are 12 pairs except in snakes.

7. Sense organs. External ear or pinna is absent. But in many birds and crocodiles, a valvular flap projects into the auditory meatus from its outer margin. A single rod-like ear ossicle, or *columella*, connects the ear drum with the inner ear. The cochlea is not coiled.

Many birds and some extinct reptiles show in the front part of the eye a ring of minute bony plates, the so-called *sclerotic ossicles*, it is a part of birds' legacy from their reptilian ancestors. Ciliary and sphincter muscles of the iris have striped fibers. In birds and in some reptiles, a characteristic comb-like *pecten* projects in the vitreous chamber of the eye from the region of the blind spot.

8. Urino-genital system. The adult kidneys are metanephric and excrete uric acid (urecotelic). The mesonephric ducts function as vasa efferentia. The rectum and urinary and genital ducts open into a cloaca. Gonads lie in abdomen. A urinary bladder is absent in snakes. Males in ratites and ducks have an intromittent organ. Intromittent organ is however absent in *Sphenodon*. Oviducts are generally differentiated into different glandular areas.

[III] Embryological evidence

A second line of proof, that birds have sprung from a reptilian ancestry, is to be found in common f atur s f th ir bry l gy r develo ment. *Fertilization* is *internal*, preceeded by *copulation*. Both are *oviparous*, i.e., lay eggs. Both la the same t e of *eggs* which are deposited outside water. Eggs are large and *telolecithal*, because the ovum contains a large amount of yolk, at one pole of which floats the cytoplasmic germinal disc with its nucleus. The ovum is surroun e y albumen, an egg mem rane an a t ick, ar calcareous *shell*, which are all secrete by special glands located in the walls of the oviduct. Sperms are closely similar in shape, size and structure. Cleavage is *meroblastic* and discoidal. Gastrulation and formation of mesoderm are similar. The extra-embryonic or foetal membranes (*amnion chorion* and *allantois*) are present. Minute gill-slits, corresponding to those of fishes, are found in the sides of the neck in embryonic reptiles and birds, but disappear in the adult. Jacobson's organ is present in embryonic stage of birds. Besides this, interclavicle is present in the avian pectoral girdle at embryonic stage.

[IV] Palaeontological evidence

The third line of proof about reptilian ancestry of birds has been drawn from palaentology. Unfortunately, fossil birds are not so well represented, because the arboreal life and softness of skeleton provided them only rare opportunities to become fossilized and preserved.

1. Archaeopteryx. The earliest-known bird in the fossil record is *Archaeopteryx lithographica*, meaning ancient wing (Fig. 2). It dates back to the late Jurassic period about 140 million years ago. It was discovered in a slate quarry at Langenaltheim, Bavaria (Germany), in 1861, by Andres Wagner. A second skeleton was discovered in 1877 and a third in 1956 from the same locality. *Archaeopteryx* seems to have been a terrestrial bird, about the size of a crow and with a long

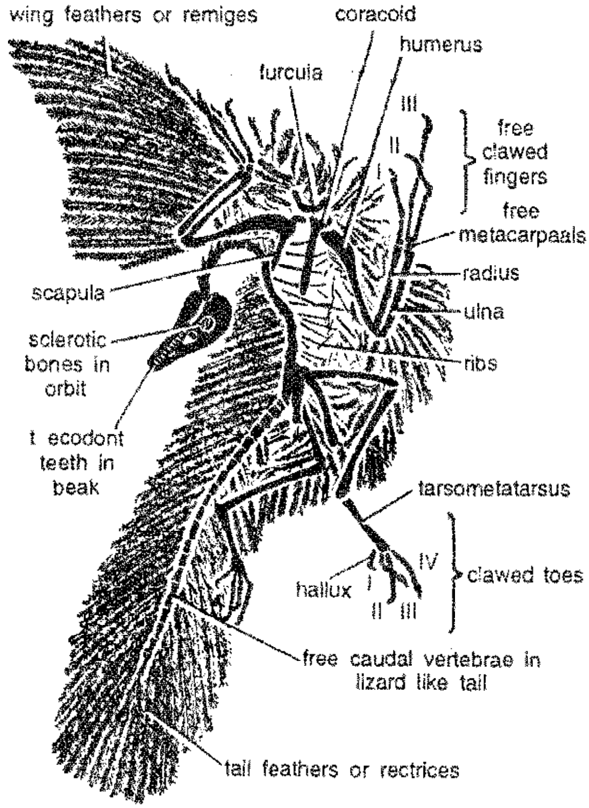

Fig. 2. *Archaeopteryx lithographica*. Fossil showing skeleton and feathers. Berlin specimen.

tapering tail like that of a typical dinosaur. This primitive bird is considered to be a *connecting link* or transitional stage between reptiles and birds, as it possesses both reptilian as well as avian characters.

(a) Reptilian characters of Archaeopteryx. *Archaeopteryx* shows striking reptilian affinities (Fig. 3B) as revealed in the structure of its parts.

(1) Scales are present on body and limbs.
(2) Bones are not pneumatic.
(3) The strong jaws are provided with homodont peg-like teeth lodged in sockets.
(4) A long, tapering, lizard-like tail composed of about 20 free caudal vertebrae. No pygostyle.
(5) Cervical vertebrae are fewer (9 or 10) than in any other bird. There is no fusion of trunk or sacral vertebrae.
(6) Centra of vertebrae are amphicoelous as in *Sphenodon*.

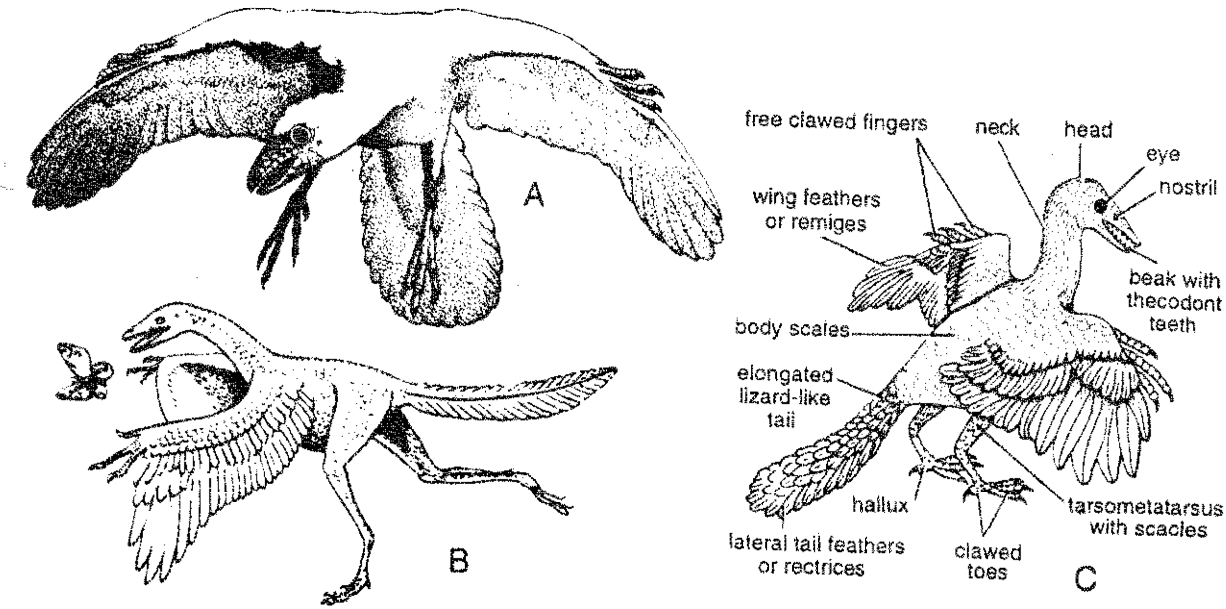

Fig. 3. *Archaeopteryx*. A—Restoration as an arboreal glider. B—Reconstruction as a cursorial predator. C—Showing detailed structure.

(7) Free cervical and abdominal ribs are also present, as in *Sphenodon* and crocodiles, in addition to single-headed thoracic ribs which are without uncinate processes.

(8) Sternum poorly developed, without keel.

(9) Each hand bears 3 free calwed fingers having typical reptilian number of phalanges, i.e., 2, 3 and 4 in the first, second and third fingers, respectively.

(10) Carpals and metacarpals are free. No fused carpometacarpus.

(11) Pelvic girdle shows an elongated ilium and a backwardly directed pubis, which are separate.

(12) Brain was simple with cylindrical cerebral hemispheres and unexpanded cerebellum.

(b) Avian characters of Archaeopteryx. *Archaeopteryx* would have been classified as a reptile, but for the unmistakable imprint of feathers. Its true avain character is reflected, beyond doubt, in the following features (Fig. 3A) :

(1) A body covering of well-developed contour and flight feathers.

(2) Forelimbs modified as wings for flight, bearing remiges and 3 digits each.

(3) Tail bears elongated rectrices, arranged in two lateral rows.

(4) Skull is proportionately large, monocondylic with a large rounded brain-case, large orbits and intimate fusion of bones.

(5) Two jaws are elongated into a beak.

(6) Bones of girdles and limbs are eminently bird-like. Scapulae are elongated and curved.

(7) Two clavicles fused into V-shaped furcula.

(8) Tibia and fibula are separate.

(9) Foot consists of a tarso-metatarsus, bearing 4 clawed toes having 2,3,4 and 5 phalanges, respectively. The halux is directed posteriorly and is opposable.

(10) Sclerotic ossicles are present in eyes.

(c) Significance of Archaeopteryx. *Archaeopteryx* exhibited both reptilian and avian characters. In fact, there has been some controversy as to whether it was a reptile or a bird. It was definitely not a bird in the modern mold, although it was not a true reptile as well. With the exception of feathers, it had a general resemblance to archosaurian reptiles. It was probably not the direct or immediate ancestor of modern birds. Similarly, nothing is known of its

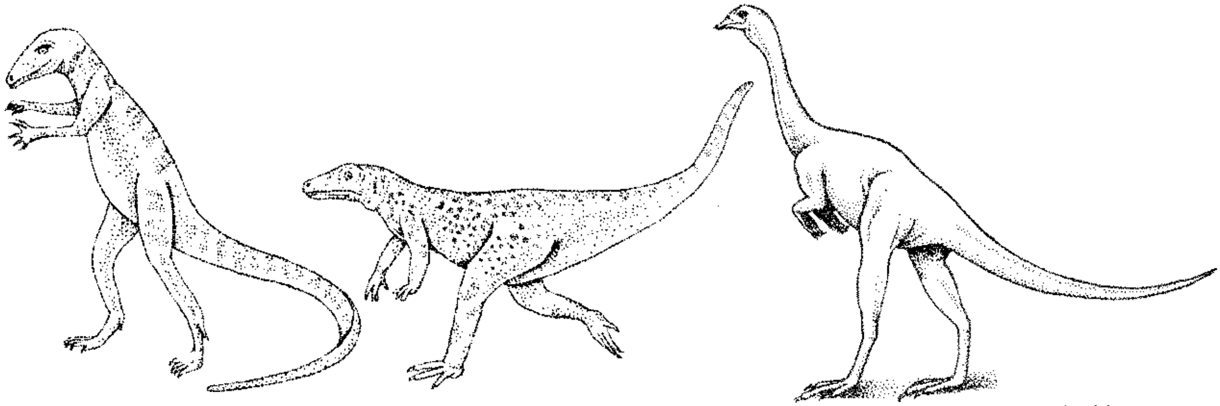

Fig. 4. Restorations of probable forerunners of birds.

immediate descendants. It was sharply marked off from later types in the absence of pneumacity, reptilian plan of forelimbs and elongated tail. The Cretaceous birds, such as *Hesperornis* and *Ichthyornis*, were distinctly birds, except that they had primitive reptile like teeth. Thus, *Archaeopteryx* is classified in a separate subclass *Archaeopteryx* because of its peculiarities distinct from all other birds, fossil as well as living, which are placed in the subclass *Neornithes*.

Origin and Ancestry of Birds

[I] Archosaur ancestors

Although *Archaeopteryx* is supposed to be a connecting link between reptiles and birds, the gap between it and the actual reptilian ancestors of birds remains yet to be filled. As we have already shown in chapter 26, the Mesozoic was the period of great adaptive radiation for various groups of reptiles, especially the diapsid archosaurians or ruling reptiles. One large ancestral group of ruling reptiles was called *Pseudosuchia* or *Thecodontia*) e.g., *Saltoposuchus*, *Euparkeria*). They were small, bipedal, (Fig. 4) carnivorous, reptiles having hind limbs much longer than forelimbs, three toes forward and one (hallux) backward, large orbits with sclerotic ring and teeth set in sockets of elongated jaws. They were sufficiently generalized to be the probably distant ancestors of birds.

Of the bewildering array of pseudosuchians, only three groups—Pterosauria, Saurischia and Ornithischia—may be singled out as potential avian ancestors. Each group had some members with bird like features. Formerly, it was considered that birds originated from the awesome, light-boned, membrane-winged flying reptiles, the *pterosaurs* or *pterodactyles*. This view is no longer supported today.

Some of the early *Ornithischians*, such as *Iguanodon* and *Camptosaurus*, were bipedal animals, but the bipedalism was marked to a greater extent in some *Saurischians*, such as *Struthiomimus* and *Ornithomimus*. These latter types were exceedingly bird-like in form walking on 3 toes and having 3 digits also in the much reduced hand, one opposable and used for grasping. Their skull was lightly built and teeth were absent in the beak-like mouth, probably due to an egg-eating habit. At present, such wingless forms are usually regarded as the ancestors of birds, that somehow developed feathers and took to flight.

The pterodactyles, supposedly evolved at a later date from a somewhat similar ancestor, never enjoyed the luxury of feathers but simply glided around on leathery bat-like wings.

[II] Proaves

But all these potential avian ancestors did not have a clavicle or wishbone. The fact that all flying birds, including *Archaeopteryx*, possess a V-shaped wishbone means that the immediate ancestors could hardly have been without it. Moreover, all these ancestral reptiles were highly specialized in several other characters which were not bird-like. This disqualifies them at once as the ancestral stock of birds. They are too specialized to be on the direct line and some of their similarities to birds appear to be convergences. Probably avian stock arose much earlier, in Permian or even earlier, from a more ancestral type. Heilmann gives the name *proavis* to this hypothetical connecting link between the rather generalized pseudosuchians and the first birds.

[III] Diphyletic origin of birds

The earliest known fossil birds include both flying (*Archaeopteryx, Ichthyornis*) as well as flightless (*Hesperornis, Diatryma*) types. The recently extinct Moas and Elephant birds were also flightless. The most primitive living birds or Ratitae (Ostrich, Rhea, Cassowary, etc.) and Penguins are also flightless. This led some authors, notably P.R. Lowe, to believe in the *diphyletic* (two-lines-of-descent) origin of birds. They maintain that the flightless and flying birds of today have descended from different flightless ancestors. According to Lowe, the present-day flightless birds were never capable of flight, and their wings are not degenerate now, but better developed than at any time in their past history.

[IV] Monophyletic origin of birds

In Ratitae, the legs are well-developed and powerful, the wings vestigial, and the feathers are fluffy. But a recently discovered fossil of *Eleuherornis*, a probable ancestor of the present-day ostrich from the Eocene of Switzerland, shows closer affinities to flying forms than does the present-day ostrich, and poses a serious blow to the concept of diphyletic origin of birds. Today most palaeonotologists believe that the Carinatae are more primitive. Presumably the Ratitae evolved from flying ancestors but readapted to a terrestrial mode of life in areas with abundant food and few competitors or enemies. The more usually accepted view today maintains that birds have a *monophyletic* (one-line-of-descent) origin, i.e., all birds have evolved from a single ancestor, perhaps close to *Axchaeopteryx*. Accordingly, the flightless birds have evolved by loss of flight from flying ancestors. The weight of the known evidence also favours this view.

Origin of Flight

Birds are sometimes referred to as reptiles with feathers, but we know nothing about the evolution of feathers from the reptilian scales, although intermediate structures between scale and feather are present on the legs of ostrich and fowl. We of course, do not know just how flight evolved in the ancestors of *Archaeopteryx*. It is possible that the ancestors were becoming more active and possibly warm blooded and feathers developed from scales primarily to conserve their body heat. Later, the feathers enlarged on the limbs and the tail probably to confer stability in fast running on ground or in rudimentary gliding from low branches.

Different views have been expressed to explain the origin of flight in birds, starting from either a terrestrial bipedal and cursorial ancestor (Nopcsa), or an arboreal ancestor (Osborn, Steiner, Beebe, etc).

1. Theory of cursorial origin of flight. According to Nopcsa, bird's flight resulted due to rapid running on the ground (Fig. 5A). According to his theory, the ancestors of birds were long-tailed, *cursorial*, bipedal animals. They were fast runners who leaped on their strong hind limbs and flapped their forelimbs in air to help them along, as do many modern birds that run fast. Gradually, the forelimbs enlarged due to fraying out or elongation of scales forming quill-feathers through the processes of mutation and selection. In the end, the forelimbs became organs of flight or wings rather than accessories to rapid running.

2. Theory of arboreal origin of flight. The other theory postulates that the ancestral birds were *arboreal* creatures (Figs. 5B–D). They climbed trees from which they glided to the ground or to

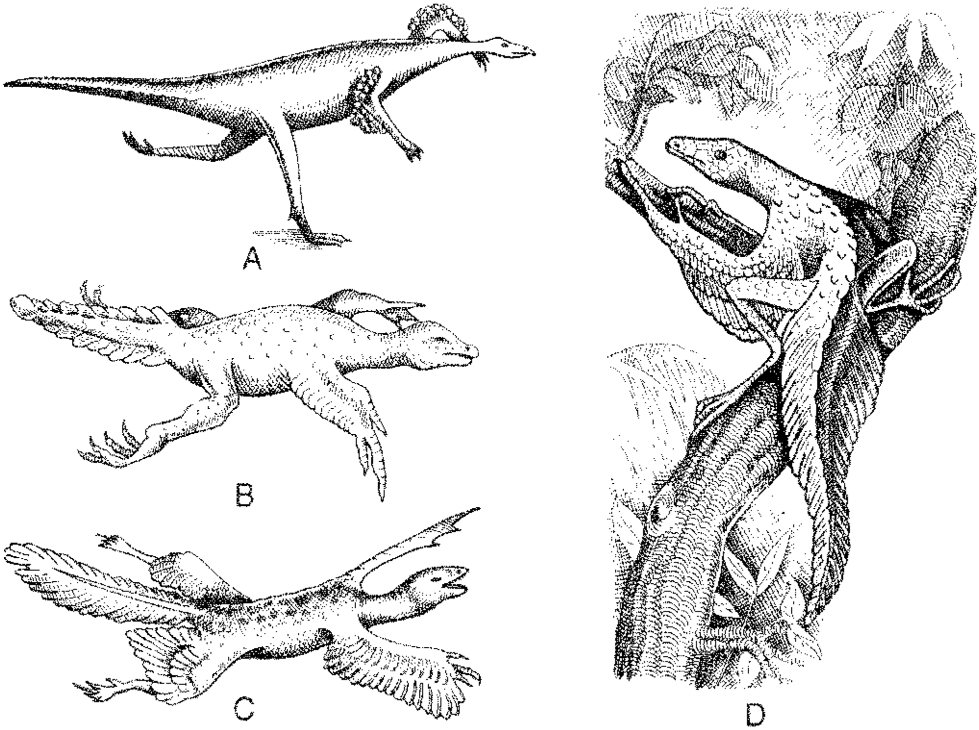

Fig. 5. Proavis. Different restorations. A—Cursorial bipedal after Nopcsa. B—Arboreal after W.P. Pycraft. C—Arboreal after C.W. Beebe. D—Arboreal after Hans Steiner.

other trees, like the modern flying squirrels. Osborn considers this arboreal, gliding ancestor to be a four-legged parachuting creature. Beebe has suggested that, in the ancestral birds, backwardly directed feathers were present in all the legs. Such a bird was capable of gliding through air from a tree or an elevated point, perhaps to a considerable distance. As time went on the forelimbs gradually enlarged and eventually converted into wings, which were able to support the animal in flight. The feathers of the hind limbs vanished and the tail shortened as seen in the modern birds. Thus, flight was an outgrowth of climbing and gliding.

Steiner maintains that the hind-limbs of the ancestor were modified for springing, while the forelimbs used for climbing and balancing the body after a leap in the air (Fig. 5D).

3. Compromise theory of origin of flight. Believers in the dual origin of birds, like Gregory, maintain that some birds evolved from arboreal and others from cursorial ancestors.

4. Theory of division of origin. Newmann was of opinion that pro-aves were aquatic reptiles. Flight might have started in connection with soaring over the water during diving for fishes.

Birds are Glorified Reptiles

Nearly a century ago, T.H. Huxley called birds 'glorified reptiles', thereby meaning that birds have evolved from some reptilian ancestor and that they are better evolved in their organisation. The three-fold evidence: from comparative anatomy, embryology and palaeontology, with fossil *Archaeopteryx* as the transitional form points unhesitatingly that the bird is a highly specialized descendant of some reptilian ancestor.

The steps and the impulse under which evolution of birds took place from a reptilian stock, are not properly understood at present. Whatever may be the mode and direction of origin of birds from ancestral reptiles, the modern birds show a marked superiority over their reptilian ancestors.

Some of the main changes leading to the superiority or glorification of birds over reptiles are as follows :

(1) While reptiles are generally sluggish, *cold-blooded* (*poikilothermous*) and earth-bound the birds are active, *warm-blooded (homoiothermous)* and alert, having more life in them than any other living creature. They have a higher rate of metabolism and a correlated carefully regulated high body temperature. Warm-bloodedness keeps them equally active throughout the year.

(2) Birds show a more *rapid locomotion* due to power of flight, perhaps also the most efficient in the animal kingdom.

(3) The derivation of avian *feathers* from reptilian scales is definitely an advance. It has made it possible for birds to fly. The insulating feathery covering preserves body heat and makes the birds warm-blooded. The elongation of feathers on forelimbs has modified them into *wings* for flight. Thus, the variety and colouration of various types of feathers show an advance over the simple uniform type of scales in reptiles.

(4) Birds, like mammals, have a completely *four-chambered heart* with *double circulation*, in which there is no mixing of pure and impure bloods. Whereas, the ventricle is imperfectly divided in reptiles, resulting in a partial mixing of bloods. Only a single systemic arch, that of the right side, persists in birds, whereas both the systemic arches are present in reptiles.

(5) The *renal portal system* is well developed in reptiles, but vestigial in birds. It is absent in mammals.

(6) Respiratory system is highly evolved. The *lungs*, with the development of *air-sacs*, bring about complete aeration and are many times more effective than those of reptiles.

(7) Birds have developed the *voice* with all the varied features of songs and calls, in contrast to the silent reptiles.

(8) Kidneys are metanephric, but show two specializations not found in reptiles. First, the uriniferous tubules are relatively longer, and second, a U-shaped piece, called the *loop of Henle*, is usally inserted in their middle. This condition is similar to that of mammals.

(9) The endoskeletal, muscular, alimentary and reproductive organs also show an advance over those of reptiles.

(10) The *brain* is proportionately bigger with better development of cerebrum and cerebellum. The senses of sight and hearing are better developed. *Eyes* are more efficient with better power of accommodation. Ears possess cochlea with an organ of Corti and, therefore, are better developed.

(11) Birds' *eggs* resemble those of reptiles but differ in that many of them are coloured.

(12) Birds possess higher grades of *intelligence* and *behaviour* practically unknown in reptiles, such as : (i) Parental care and extreme emotion in preparation of more or less elaborate nests, (ii) While most reptiles leave their eggs to hatch in ordinary environmental conditions, all birds incubate their eggs, thus ensuring hatching and better survival, (iii) Periodic migrations or wandering to and fro their winter and summer abodes, (iv) Monogamous life with selected mating, courtship behaviour and affection for the mate, (v) Singing and mating calls during breeding season.

Thus, Huxley was fully justified in commenting that 'birds are glorified reptiles'.

Birds as a Flying Machine

The flight is a highly spontaneous action. Larger birds either run or swim rapidly together enough forward momentum for a take off. Smaller birds usually take a quick jump by means of their legs followed by the beating of their wings.

A bird flies on the principle of an aeroplane, or heavier-than-air machine, rather than on that of a balloon or lighter-than-air machine. The various requirements of such a machine are met with by birds in the following ways :

1. Centralization. The internal structures are well centralized, with certain structures reduced and others eliminated. For example, heavy teeth, commonly found in the head of other vertebrates, have been replaced by a light horny beak, while a tough muscular, central gizzard, lined with grinding stones does the work which teeth once did in the ancestral birds. The heavy trailing reptilian tail has telescoped into a degenerate skeletal stub, thus centralizing weight, while in place of it a secondary tail of light, air-resisting feathers is added, to be used as a rudder in flight. The head is small and light, the neck is long and can be retracted in flight. Thus, the body-axis is shortened and the streamlined body is perfectly balanced with the centre of gravity well below the supporting wings.

2. Lightness and rigidity. These are secured by the light but strong, pneumatic skeletal framework of birds which is built on a hollow girder principle.

3. Planes for support. Another requirement of an aeroplane is the possession of planes or wings for support. In a bird, the wings and tail furnish such planes, giving a broad surface for support. In modern planes, wings can be varied to some extent, but birds are more versatile in this respect, since their wings and tails are capable of considerable adjustments to variations in the direction and strength of the wind.

4. Sustained power. Another necessity in such a machine is the development of a large amount of sustained power. This is secured by the great size of the flight muscles and heart and by the very effective aeration of blood, which results in rapid and continuous oxidation. Considerable and constant production of energy are due to effectiveness of the processes of digestion and elimination.

5. Steering and balancing. These are done by the adjustment of the wings and tail with the help of joints and muscles.

Wings are the active means of flight. To carry the weight of the bird, the wings strike vertically; to carry the bird onwards they strike obliquely. Their vigorous downward strokes serve to raise the body in the air, and various tilting and banking movements aid in altering the manner of flight.

The fan-like tail-feathers are used as a rudder for steering during flight, to suddenly check flight, and as a counter-balance in perching. The tail may be spread or folded and elevated or depressed, or tilted to direct the course of flight.

Mechanism of Flight

Principles or mechanics. Aerodynamics, or the science of motion of air, is a difficult science. A fish swims on the principle of *direct movement*. While swimming, it presses against a resistance, the water, and moves forward. A bird flies on the principle of *indirect movement*. It moves the air, which by its displacement, moves the bird. Air, displaced by the beating of wings, sets up currents that keep the animal aloft and move forward, resulting in flight. According to Newton's third law, the force of reaction of air is equal and opposite to that exerted by the moving wing on the air.

The wing is not a simple airfoil or plane. It functions both as an airfoil (lifting surface) and as a propeller for forward motion. It is thick in front, thin and tapering behind, and presenting in profile a convex streamlined upper and a flat or slightly concave lower surface. As the air flows across the somewhat tilted wing, the air stream moves faster along its upper convex surface than the concave lower surface. In accordance with *Bernoulli's law* in physics, this differential in air speed results in a decrease in air pressure above the wing surface relative to the underside. Bernoulli's law states that in a fluid stream the pressure is least where the velocity is greatest. This basic physical principle involved in flight was first worked out by the Swiss mathematician Bernoulli in 1738. The two forces, thus generated, suction above and upward thrust below the wing, tend to *lift*, keeping the bird aloft and moving forwards and upwards. The air also pushes the wing horizontally backwards and tends to *drag* or slow the bird down. Thus, the force of air on the wing can be resolved into a vertical *lift component*

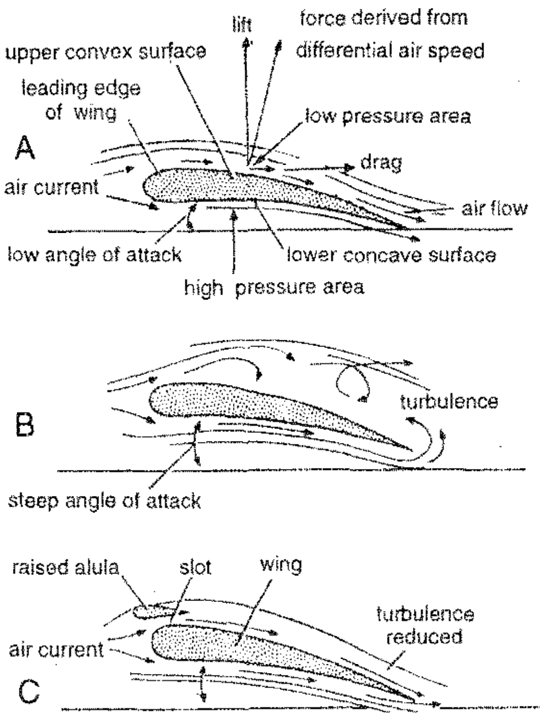

Fig. 6. Effect of a wing on air stream in flight. A—Wing tilted favourably so that air flows smoothly over its upper surface to increase lift. B—Wing tilted sharply so that air becomes turbulent above destroying lift and producing a stall. C—Raising of alula forms a slot through which air moves rapidly and smoothly, reducing turbulence.

perpendicular to the air stream, and a backward *drag component* parallel to the air stream. For the bird to fly, the lift force must equal the force of gravity on the bird, i.e., the weight of the bird. Various factors increase the lift force, such as increase in the surface area of the wing and in the speed of air flow across the wing. If the angle of the wing becomes too great, i.e., when the wing becomes tilted sharply, air swirls into the low pressure area above causing *turbulence* (induced drag). As a result lift is lost, wings stall, movement slows down and the bird plummets toward the earth. Some birds use deliberate stalling before a *dive*. But in *landing*, a bird must slow down without stalling to avoid crashing. This is achieved in many ways, by reducing turbulence. In eagles, vultures, swallows, etc, when slowing down to perch, the primary feathers are widely spread, thus causing gaps or *slots* between the leading edges of these feathers. These slots perform t e function of *Venturi tubes* showing *Bernoulli effect*. Air rus es t roug t em with greater velocity causing more lift at the slower landing speed. The vane of some primaries may be reduced or emarginated to increase the size of the slots. Another method of producing a slot with venturi effect is by raising the astard wing or *alula* which is a separate tu t o eathers on the pollex. Some birds obtain additional lift on landing by fanning out and bending down their tail feathers. The tail thus works both as a brake and a high-lift, low speed airfoil.

Modes of Flight

There are three or four chief kinds of flight in birds, and all the kinds may be used at different times by the same bird. Also, in all types of flig.t, t.e tail .elps to support and .alance t.e body, serving as a rudder.

1. Gliding or skimming. The simplest and probably the most primitive mode of flight is gliding (Fig. 7A). Birds hold their wings spread, motionless and glide for a considerable distance without flapping them. Gliding depends for its movement on the velocity acquired by previous strokes, or by descending from a higher to a lower level or by making use of air-currents. The gliding flight can only be exhibited for a short time bird soon loses velocity or height. Gliding flight can be readily observed in shore-birds coming in for a landing; in ducks, gulls and herons over water in swallows and swifts in the air in pigeons gliding from their loft to the ground or in a falcon swooping upon its quarry.

2. Soaring or sailing. It is the most remarkable (Fig. 7B) and highly specialized mode of flight, illustrated by birds with a large wing-span, such as albatross, vulture, falcon, stork, crow, etc. The bird, usually at a high level, describes great circles without any movement of the wings, whatsoever. The bird rises without loss of kinetic energy.

3. Flapping. It is the most common or ordinary mode of flight (Fig. 7C). All birds fly by flapping their wings up-and-down. Each flapping

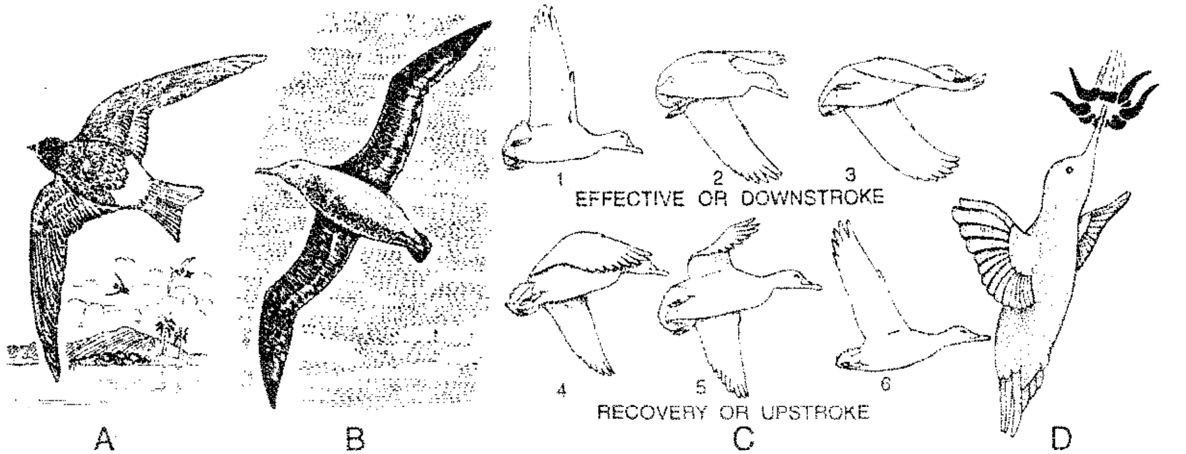

Fig. 7. Modes of flight in birds. A—Gliding (swift). B—Soaring (albatross). C—Flapping (duck). D—Hovering (humming bird).

includes an effective downstroke and a recovery upstroke of the wings. To start with, the wings are held vertically and fully spread. In the *downstroke*, they move obliquely forward, downward and backward, their distal portions tilted upwards. Thus, there is both lift and thrust. In the *upstroke*, the wings are partly folded and their primary feathers spread out for the air to slip through, thus making it easier to lift them. They move up and backwards. As a net result, the bird will be propelled forwards and sustained in the air. Pigeons can beat their wings at least eight times in one second.

4. Hovering. It is a peculiar variant of flapping flight. In hovering (Fig. (7D), found in humming birds, the body is kept vertical, while the bird remains poised in the air before a flower or above an object upon the ground, the tips of its wings apparently describing a figure of eight.

Aerial or Flight Adaptations

Young (1958) is not wrong when he calls the birds as 'masters of the air'. There is practically no system, or no organ, that has not been modified in relation to flight. The following account precisely indicates how much birds are adapted to their aerial mode of life (Fig. 8) through their anatomy, embryology, physiology and ecology.

1. Shape. The shape of the body represents the sum of all its several adaptations. The perfectly streamlined spindle-shaped body of a bird is designed to offer minimum resistance to the wind, and hence easily propelled through the air in the same manner as the fish swim through water quite easily without any waste of effort.

2. Compact body. The compact body, light but strong dorsally and heavier ventrally, helps in maintaining balance in the air. The attachment of the wings high up on the thorax, the high position of such light organs as lungs and air-sacs, the low and central position of the heavy muscles, sternum, and digestive organs beneath the midline of the attachment of two wings and consequently low centre of gravity, are also structural facts of importance.

3. Body-covering of feathers. Feathers are diagnostic of birds, since no other group of animals have developed them. The smooth, closely fitting and backwardly-directed contour feathers make the body streamlined and further help its

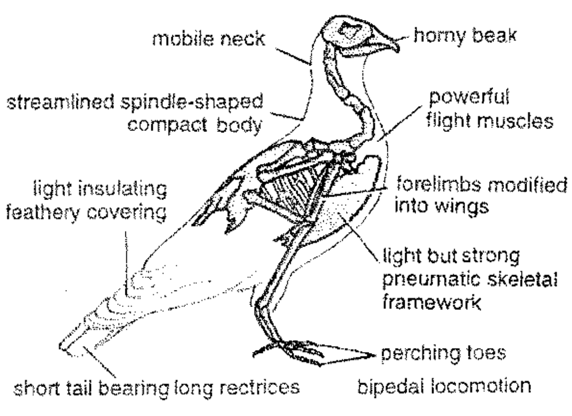

Fig. 8. Streamlining and light weight in birds for flight.

passage through the air by reducing friction to minimum. The light feathers hold a considerable blanket of enveloping air around the body and add much to its buoyancy. The nonconducting covering of feathers insulates the body perfectly and prevents loss of heat which enables the bird to endure intense cold at high altitudes and also to maintain a constant temperature.

4. Forelimbs modified into wings. The forelimbs have been converted into the unique and powerful organs, the *wings*. These marvellously designed structures equipped with special flight muscles have been developed as instruments of propulsion through air. The elongated flight-feathers of wings are called the *remiges*. The expanded membranous part or *vane* of each remex forms a flexible and continuous surface for striking the air in flight. The flight feathers of a wing form a broad surface for supporting the bird in air. The particular shape of the wing, with a thick strong leading edge, convex upper surface and concave lower surface, causes reduction in air pressure above and increase below, with minimum turbulence behind. This helps in driving the bird forwards and upwards during flight.

5. Short tail. The short muscular tail bears a series of long, strong but light caudal feathers or *rectrices* arranged in a fan-like manner and serves as a rudder for steering during flight, to suddenly check flight, and as a counterbalance in perching.

6. Beak. The conversion of forelimbs into wings is duly compensated by the presence of a bill or beak. The mouth is drawn out into the horny beak, which is used as a forcep in picking up things. Besides procurement of food, the beak is also used for nest-building, which in other animals is done by the forelimbs.

7. Mobile neck and head. The neck of birds is very long and flexible. Since the birds' bill is used for feeding, preening, nest-building, offence and defense and the like, mobility of neck and freedom of movement of the head are very important.

8. Bipedal locomotion. The forelimbs being no longer available, the hind limbs or legs spring somewhat anteriorly from the trunk to balance and to support the entire weight of the body and for locomotion on the ground or in water. Bipedality is as characteristic of birds as flight, since flightless birds have all retained the habit of walking on two legs. The legs are also relatively stronger.

9. Integument. The loose skin is a modification for flight. It is responsible for extensive movement of the skeletal musculature.

10. Large muscles of flight. While muscles of the back are greatly reduced, the flight muscles on the breast are greatly developed, weighing nearly one-sixth of the whole bird. The wing is depressed or lowered by an enormous *pectoralis major.* It is elevated or raised by *pectoralis minor* the tendon of which passes through the *foramen triosseum* to be inserted dorsally on the head of humerus. There are other muscles of minor importance.

11. Perching. The hind limbs of a bird are well suited for an aboreal life. Their muscles are well developed and help in perching. As the bird settles down on the tree, the bending of legs exerts a pull on the *flexor tendons* which make the toes automatically to flex and to grip the perch. Thus the bird, in resting or sleeping, is automatically clamped to its perch.

Throughout the internal anatomy of a bird occur modifications that fit it for flight.

12. Endoskeleton. Many adaptations for flight are apparent in the skeleton of birds. The fusion of bones built with the smallest amount of material after the 'hollow-girder principle', combines strength with lightness, one of the first essentials in successful flight. Most of the bones are *pneumatic* and filled with airsacs instead of bone marrow. Skull bones are light and most of them firmly fused together. *Uncinate processes* of thoracic ribs help in producing compactness, necessary for flight, by concentrating the mass. The rigidity of the dorsal part of vertebral column, due to fusion of vertebrae, provides a firm *fulcrum* for the action of wings. The heterocoelous vertebrae confer great flexibility and all birds can move their neck through 180° which helps in preening feathers in all parts of the body and food collection. The shortening of the caudal vertebrae and formation of *pygostyle* has assisted stability in the air. The fusion of *pelvis* with *synsacrum* provides firm attachment to the legs, supports the weight of the body when the bird is walking, and counteracts the effect of shock as the bird alights. The absence of a *mid-ventral symphysis* of pubes and ischia results in a more posterior displacement of the viscera, shifting the centre of gravity of the body nearer to the hindlegs. This also permits laying of large eggs with calcareous shells. The fusion of distal tarsals with the metatarsals to form *tarsometatarsus* and that of proximal tarsals with the lower end of tibia to form a *tibiotarsus*, help to strengthen the legs for bipedal gait. The *sternum* is greatly expanded and bears a large mid-ventral ridge or *keel* for the attachment of major flight muscles in flying birds, while it is without a keel in running birds, like ostrich. The sternum, like a T-shaped girder, also supports the abdominal viscera.

13. Digestive system. The rate of metabolism in birds is very high, food requirements are great and digestion rapid. The food that is selected has a high caloric value, largely utilized, with a minimum of indigestible waste. Consequently the digestive system is compact but effective. The rectum is short because the faecal matter is relatively small. As the flying animals cannot afford to be weighed down with any excess faecal luggage, it is got rid of at once.

14. Air-sacs and respiration. The inelastic lungs of birds are supplemented by a remarkable system of air-sacs, which grow out from lungs and occupy all the available space between internal organs, even extending to the cavities of hollow bones. The air-sacs secure more perfect aeration of lungs and help in internal perspiration, thus helping in the regulation of the body temperature. The avian lungs are completely emptied with each breath, there being no residual air remaining, so that respiration is more effectively accomplished.

While flying, the movements of the wings contribute to respiration by compressing and dilating the air-sacs, and thus the bird breathes more easily when in flight than at other times.

15. Warm-bloodedness. Birds are warm-blooded animals. The perfect aeration of blood is responsible for the high temperature of body (40°-46°C), which is a necessity for flight requiring a great output of energy over a longer period.

16. Circulatory system. Rapid metabolism and warm-bloodedness require a large oxygen supply and an efficient circulatory system. Accordingly, the avian heart is relatively large and completely divided into four chambers. It functions very efficiently with a double circulation of blood. The high proportion of haemoglobin present in the red blood corpuscles of avian blood is also responsible for its quick and perfect aeration.

17. Urecotelic excretion. Birds do not have a urinary bladder, which is present to store the urine temporarily in other animals. Moreover, the water of the excretory fluid is reabsorbed in the urinary tubules of kidneys and in the coprodaeum of cloaca. The result is the formation of a semisolid excreta, chiefly containing the insoluble uric acid and urates which are avoided at once. These features help in reducing the unnecessary weight of the body.

18. Brain and sense organs. Birds depend for their main contact with the world upon sight rather than smell, in contrast to reptiles and most mammals. Accordingly, the eyes are large and the large optic lobes correspond to the great development of sight. The eyes occupy a large portion of the head, and both eyes together are often heavier than the brain. The ability to accommodate rapidly is also well developed for birds must change quickly from a distant to a near vision in flight. The much developed and convoluted cerebellum indicates the delicate sense of equilibrium and the great power of muscular co-ordination belonging to birds. The enormous development of corpus striata in the cerebrum also adds to the extraordinary manoeuvreability to attain stability in flight.

19. Single ovary. Presence of a single functional ovary of the left side in the female bird also leads to reduction of weight which is so essential for flight.

Types of Beaks in Birds

The entire modern avian world is characterized by the absence of teeth. The upper and lower jaw bones become elongated to form a peculiar beak or bill covered by a horny sheath called *rhamphotheca*. The modification of forelimbs into wings deprived birds of some of their normal functions which had to be taken over by the beaks and teeth. Thus beaks serve both as mouth and hands.

The diversity of form of beaks is mainly related to the type of food eaten and to the manner of feeding. Birds exhibit almost indefinite variations in shape, size and structure of beaks, (Fig. 9) of which only some of the most important and common types are described here.

1. Seed-eating beak. Short, stout, peg-like and conical beaks are characteristic of small granivorous or seed-eating birds, such as *sparrows*, *finches* and *cardinals*. The weaker beaks are used for piercing up small seeds, while more powerful beaks are meant for crushing large and hard-shelled seeds and fruit stones.

2. Cutting beak. Birds such as *crows*, possess long and slender beaks with cutting edges which can be used variously.

3. Fruit-eating beak. In *parrots*, the beak is sharp, massive, deeply hooked and extremely strong. It is well adapted for gnawing or breaking open hard seeds and nuts, which form their staple diet.

The enormous beak of *hornbills*, looking so heavy and cumbersome, is really quite light as its interior is of a cellular structure. It is suggested that these cells act as resonators, thus enabling the bird to produce its exceptionally loud cry.

4. Insectivorous beak. In *swallows* and *swifts*, the beak is small, wide and delicate to scoop up their living insect prey while on wing. In *fly catchers*, the beak is short but strong, with mandibles notched at the tip and beset with numerous rictal bristles at the base. In *hoopoe*, the beak is long, slender and slightly curved and meant for turning the leaves or probing into the soil for insect grubs and pupae, etc.

5. Wood-chiselling beak. *Woodpeckers* have elongated, straight and stout chisel-like beaks for drilling into the barks or wood for insect larvae or for nest construction. They have thickened, shock-absorbent skull bones and strong neck muscles to make such pounding feasible.

6. Tearing and piercing beak. Carrion-feeding and flesh-eating birds, such as *vultures*, *hawks*, *eagles*, *owls*, *kites*, etc., have short, pointed, sharp-edged and powerful, hooked beaks for tearing flesh and operated by well-developed mandibular muscles.

7. Mud-probing beak. Familiar examples of mud-probing beaks are found in *snipe*, *stilt*, *sand-piper*, *Jacana*, *lapwing*, etc. Their beaks are extremely long and slender and are used as a probe for thrusting far down into water and mud in search of worms and larvae. Some of these birds are remarkable for the slenderness and extreme length of their beaks.

8. Water and mud-straining beak. In *ducks*, *teals* and *geese*, the beak is broad and flat. The edges of the jaws are furnished with horny serrations or transverse lamellae, which act as a sieve or strainer, letting the water and mud pass out while retaining the food in the mouth. Such a beak enables the bird to avail itself of the rich store of food in the shape of insects and other organism.

In *flamingoes*, the beak is distally curved downwards and likewise furnished with shifting lamellae. The two halves of lower jaw are considerably enlarged so that the comparatively narrow upper jaw closes upon a wide cavity.

9. Fish-catching beak. *Storks*, *herons* and *kingfishers* have long, powerful and sharply-pointed, spearing beaks to capture fish, frogs, tadpoles and similar aquatic animals. *Cormorants* have long and narrow beaks, the edges of which are armed with sharp backwardly-directed, teeth-like processes meant for capture of fish. In *snake-birds* or *darters*, these serrations take the form of fine needle-like points.

10. Spatulate beak. The *spoon-bill* possesses a very specialized form of beak. It is flattened throughout its length but terminates in a broad,

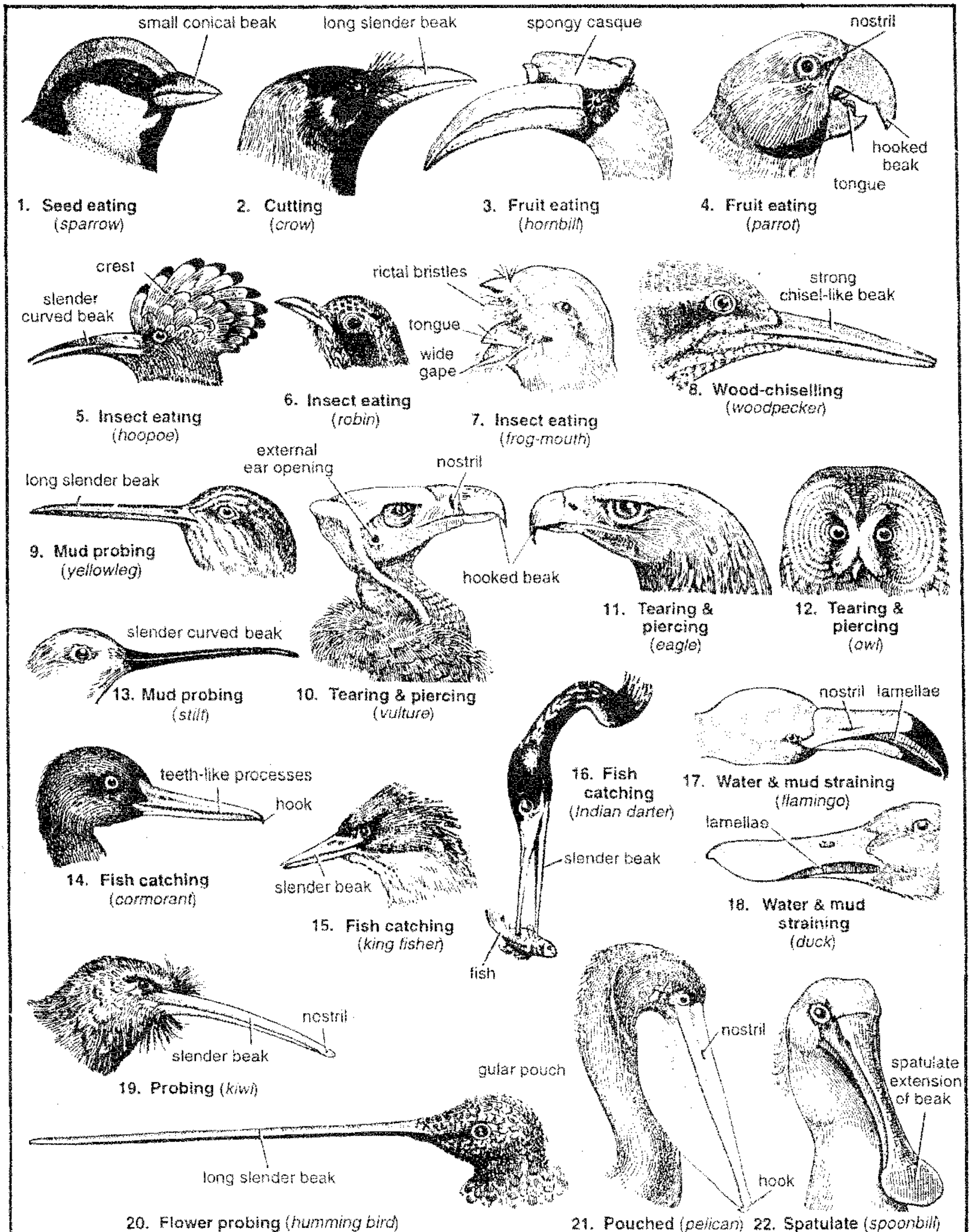

Fig. 9. Modifications of beaks in different birds.

spatulate or spoon-like expansion meant for dabbling in water and mud in search of insects, worms, fish, molluscs and other small animals upon which the bird feeds.

11. Pouched beak. *Pelicans* consume enormous quantities of fish. Their beak is large, with a capacious gular pouch of extensile skin attached to the lower mandible and serving as a fishing net.

12. Flower-probing beak. The long, pointed and rapier-like probing beak of tropical *humming birds* dive down the corollas of flowers for sucking honey and insects. They suspend themselves in mid air before the flowers, while they extract their honey and insects. Their beaks are bent or so shaped so as to suit the particular shape of the flowers.

Types of Feet or Claws in Birds

The feet of birds are also modified variously in accordance with the character of the environment and the manner of locomotion (Fig. 10).

1. Cursorial or running feet. In running birds, the legs are powerful and the number of toes is reduced. The hind toe may be elevated, reduced or absent. In *bustards*, *coursers* and ratites such as *emu, rhea* and *cassowary*, only 3 toes, directed forwards are present. *Ostrich* has only 2 toes, of which the outer one is smaller and without a nail.

2. Perching feet. The majority of birds belong to the category of perching birds or *passers*, such as *sparrows, crows, bulbuls, robins, mynahs*, etc. Three toes are anterior and slender, while one toe or hallux is posterior, strongly built and opposable, so that they can securely fasten the foot to a branch or a perch.

3. Scratching feet. The feet of *fowls, quails, pheasants,* etc. are stout, with strongly-developed claws and well adapted for running as well as scratching the earth. The foot of male bird is usually provided with a pointed bony spur for offence and defence.

4. Raptorial feet. Predatory or carnivorous birds, such as *eagles, kites, vultures, owls,* etc. have strongly taloned feet for striking and grasping their prey. The toes have strongly-developed, sharp and curved claws. Large and fleshy bulbs, called tylari, are found on the undersurface of the toes, especially developed in the *sparrow-hawk*. In *osprey* and *Ketupa*, tylari are absent but horny spines are present, which help in gripping slippery preys such as fish.

5. Wading feet. The legs and toes are exceptionally long and slender in wading or marshy birds such as *herons, snipes, jacana, lapwing,* etc. These serve to walk over aquatic vegetation or marshes. The web is absent or feebly developed.

6. Swimming feet. In swimming birds, the toes are webbed, partially or completely. In diving birds, like *coots* and *grebes*, the web is lobate and the toes are free. In swimming and paddling birds, such as *ducks* and *teals*, only the anterior three toes are united in a web. In *pelican* and *cormorant,* all the four toes are enclosed in the web.

7. Climbing feet. In *parrots* and *woodpeckers* the feet are used as grasping organs and especially adapted for climbing vertical surfaces. The second and third toes point in front, while the first and the fourth toes point backwards.

8. Clinging feet. In *swifts, martinets* and *humming-birds,* all the four toes point forwards and serve to cling to steep faces of cliffs or under caves of houses, etc.

9. Other modifications of feet. The pectinate claw (comb) on the middle toe of the *poorwill* serves to scratch the feathers of head, to straighten the disarranged rictal bristles, and probably to comb out lice. Fleshy fringes of skin develop on the sides of toes of the snowshoe-like feet of the *ruffled grouse,* during winter only, for walking on the snow. The long hind claw of *larks* and certain fringillids may also bear some functional significance.

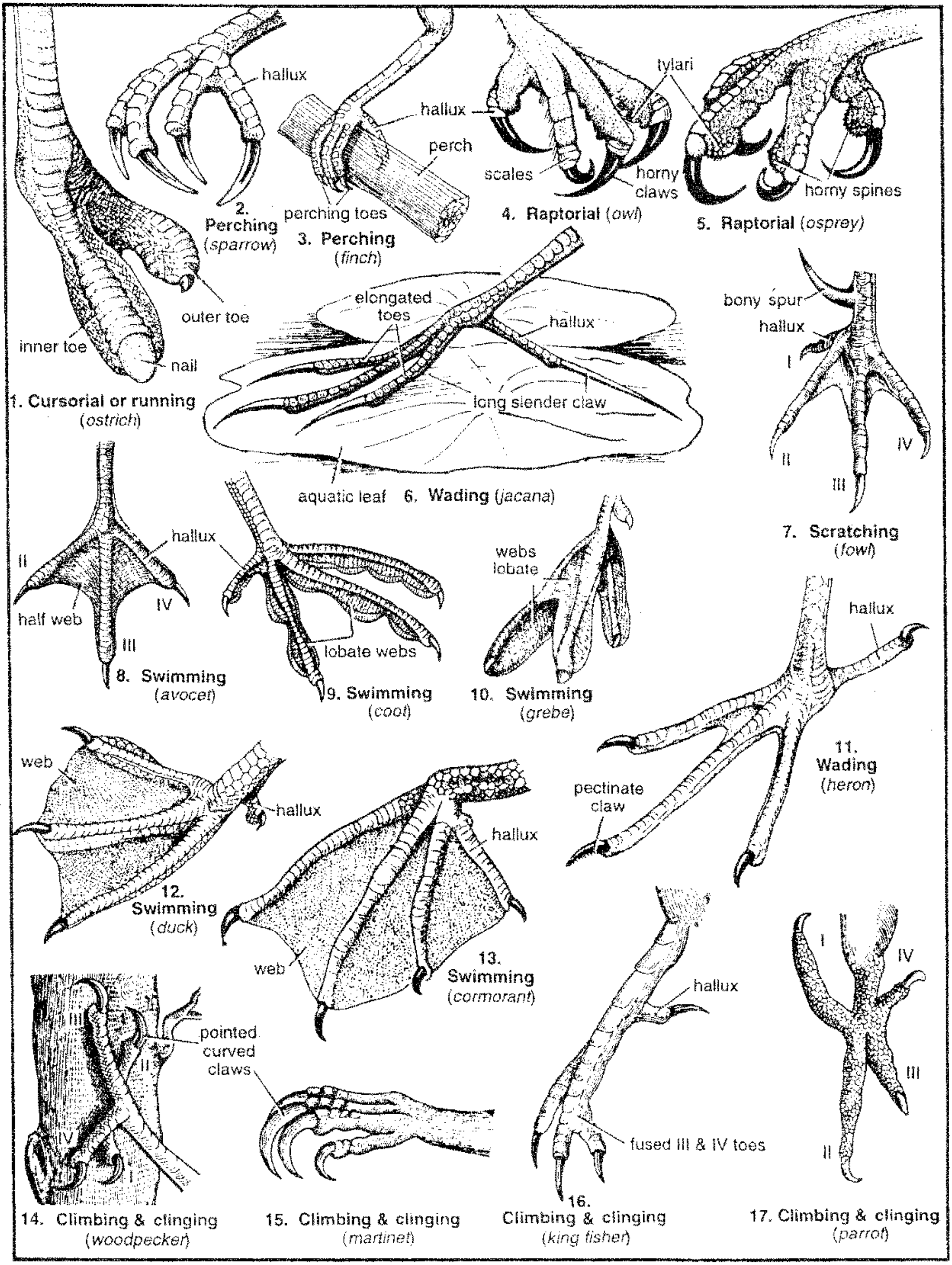

Fig. 10. Specializations of feet or claws in different birds.

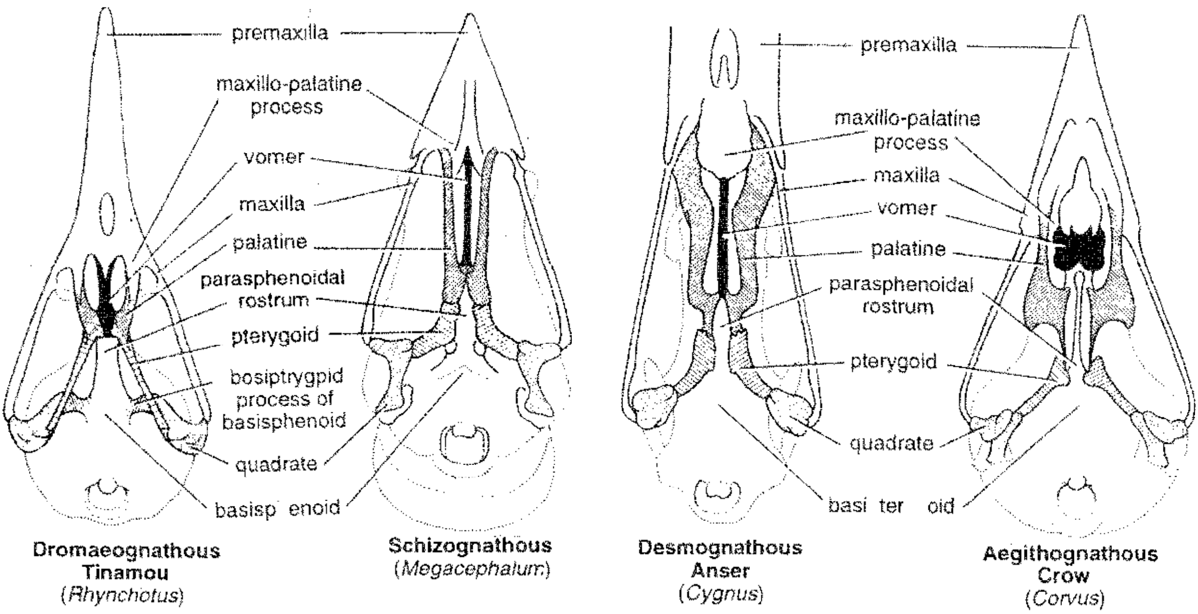

Fig. 11. Types of skull palates in birds.

Kinds of Palate in Birds

In its general features, the skull in various birds does not show much variation. Amongst some of the universal skull characters of birds are : an early ankylosis of bones except in Ratitate, rounded and spacious cranium, a single small rounded occipital condyle formed by basioccipital, the upper beak composed mainly by the two premaxillae united into a large triradiate bone, the slender maxillo-jugal arch, the large parasphenoidal rostrum, the freely articulated quadrate and the absence of the reptilian post-frontals. Orbits are large, separated by a thin interorbital septum formed by the mesethmoid which is continued anteriorly with cartilaginous internasal septum.

Importance of palate in classification. There are, however, marked differences in the structure of the palatal region of skull in birds which provides an important character for their classification. The living birds are classified in two super-orders–Palaeognathae and Neognathae. In the *Palaeognathae* or *Ratitae* are included all the flightless birds. They have a *dromaeognathous* type of palate in skull in which the large vomer is extended posteriorly, so that the two palatines do not meet with one another and with the rostrum. On the other hand, in *Neognathae* or *Carinatae* are included all the modern flying birds. They have a *neognathous* type of palate with three sub-kinds (*schizognathous, desmognathous* and *aegithognathous*), in which the vomer is small or absent, so that the palatines meet the rostrum.

Huxley, in 1887, pointed out the following four types of plate in birds (Fig. 11), based on the relations of vomer, palatines, pterygoids and maxillo-palatine processes.

1. Palaeognathous or dromaeognathous palate. This type of palate is characteristic of Ratitate, such as the ostrich, rhea, kiwi and tinamous, etc.

(1) Vomer is large and broad and usually connected posteriorly with the palatines.
(2) Palatines do not articulate with the parasphenoidal rostrum, because the vomer intervenes between the two.
(3) Maxillo-palatine processes are short and not unite with one another or with the vomer.
(4) Basipterygoid processes of basisphenoid are well developed and articulate with the hinder parts of the pterygoids.

(5) Pterygoids are immovably fixed to vomer and are reptilian in form.

2. Schizognathous palate. This type of palate is common in a variety of birds, such as pigeons, fowls, gulls, plovers, cranes, woodpeckers, trogons, etc.

(1) Vomer is small, pointed in front or absent.
(2) Palatines and pterygoids articulate with the parasphenoidal rostrum at the point where they join one another.
(3) Maxillo-palatine processes do not unite with one another or with the vomer.
(4) Basipterygoid processes may be absent or small and arising at the base of the rostrum.
(5) Pterygoids are movably articulated.

3. Desmognathous palate. This type of palate is common in most of the wading and swimming birds, such as storks, herons, ducks and geese, besides parrots, birds of prey, cuckoos, etc.

(1) Vomer is abortive or small and usually lost in the preparation of skeleton. When present, it is narrow, slender and tapering anteriorly.
(2) Palatines and pterygoids articulate with rostrum.
(3) Maxillo-palatines are large and united with one another in the middle line, often forming a flat, spongy palate ventral › the vomer.
(4) Basipterygoid processes are absent.
(5) In parrots, a specialized desmognathous type of sliding palate occurs, so that the depression of the lower jaw automatically raises the upper jaw.

4. Aegithognathous palate. This is similar to the schizognathous type of palate and occurs in passerine birds, such as crows, swifts, bulbuls, etc. Vomer is short and broad and truncated instead of being pointed in front. Posteriorly, the vomer is deeply cleft embracing the rostrum.

Migration of Birds

One of the most spectacular events concerned with bird life is the *seasonal migration* of many species, and their uncanny ability to navigate. It has intrigued mankind for many centuries. Man has looked up in wonder as clouds of migrating birds darkened the skies. Many animals migrate but none to such distances and with such regularity as the birds.

[I] Definition of migration

In a broad sense, 'migration', as defined by Cahn, "is a periodic passing of animals from one place to another, (L. *migrare*, to travel)". When applied to other animals, it means their dispersal or immigration, implying no return journey. On the other hand, bird migration is a two-way journey. It means a regular, periodic, to-and-fro movement of a population of some birds between their summer and winter homes, or from a breeding and nesting place to a feeding and resting place.

[II] Migratory and resident birds

Not all species of birds take part in the great pageant of migration. Bobwhite and the ruffled sand grouse, do not migrate at all. Birds which remain throughout the year in a country are known as *residents*. Every gradation may be found between resident birds which do not migrate and migratory birds which cover thousands of miles in their periodic journeys.

[III] Kinds of migration

Migration in birds takes place in a variety of manners, some of which are as follows :

1. Latitudinal migration. Because of the gift of wings, birds conveniently exploit two different parts of the earth. The most familiar migrations are *latitudinal* that is, north to south and vice versa. These are pronounced in the Northern Hemisphere, having larger land masses. Birds move during summer over the temperate and sub-arctic regions of Northern Hemisphere, where there are facilities for feeding and nesting. The birds return to the south for shelter during winter, when north is covered with ice and snow. Several North American and Eurasian birds cross the equator to spend winter in deeper and warmer parts of South America and Africa. The American golden plover (*Pluvialis dominica*) passes the nine months of winter 8,000 miles south in the pampas of Argentina, thus enjoying two summers each year and knows not a hint of winter. Some birds of Siberia visit the plains of Himalayas in India.

An opposite but lesser movement occurs in the Southern Hemisphere, where the seasons are reversed.

2. Longitudinal migration. Some birds make migrations that are longitudinal rather than latitudinal, that is, east to west and vice versa. Thus, the starling moves from a breeding area in east Europe or Asia towards the Atlantic coast, to avoid the continental winter.

3. Altitudinal migration. Wherever large mountains are found in temperate regions, the birds migrate regularly up and down their slopes, as the weather changes. The birds pass the summer in the mountainous regions, but return to the lowlands in winter. It is merely a dispersal or short journey from the bleaker slopes to the more protected valleys and has been called *altitudinal* or *vertical migration.* It ocurs in the grebes and coots of Andes in Argentina, violet green swallows of Great Britain, and the willow ptarmigan of Siberia.

4. Partial migration. Many species of temperate regions are only *partial migrants*. An addition is made in constant residents, which do not migrate at all, by an influx of new individuals of the same species for a short period. Thus, barn owls (*Tyto alba*), blue-birds and many blue jays of Canada and Northern United States travel southwards to mingle with the sedentary populations of the southern states. Songthrush, redbreast, titmouse, finch, etc., seen throughout the year, actually represent partial migrants, as the birds seen in winter are not the same as seen in summer.

5. Irregular or vagrant migration. In some birds, such as herons, after breeding, the adults and the young may stray from their home to disperse in all directions over many or a few hundred miles in search of food and safety from enemies. Sometimes sea birds are taken by hurricanes to as far as 2,000 miles away from home seas to drop exhausted or to die on unfamiliar shores.

6. Seasonal migration. Field observers in temperate countries have grouped migrating birds according to seasons. Thus, in Britain, swifts, swallows, nightingales and cuckoos are *summer visitors*, for they arrive in spring from the south, remain to breed and leave for the south in autumn. Some like fieldfare, snow bunting and redwing are *winter visitors*, as they arrive in autumn, chiefly from the north, stay throughout the winter and fly northwards again in spring. While some, like snipes and sandpipers are the *birds of passage*, seen for a short time twice a year on their way to colder or warmer countries in spring and autumn.

[IV] Modes of flight in migration

1. Nocturnal and diurnal flight. Ducks, gulls, shore birds and many others may migrate at night or in the day.

Many large birds fly mainly by day, such as the crows, swallows, robins, blackbirds, hawks, bluebirds, jays, cranes, loons, pelicans, geese and other shore birds. They may stop to forage in suitable places, but swallows and swifts capture their insect food in the air as they travel. These *diurnal migrants* have a greater tendency to travel in flocks, which may be well organized (ducks, geese and swans) or loose (swallows).

But a vast majority of birds are chiefly *nocturnal migrants*. These include mostly small passerine birds, such as warblers, thrushes, sparrows, etc. They prefer to fly at night, under the protective cover of darkness, to escape their enemies.

2. Segregation during migration. Certain birds, such as night hawks, swifts and kingfishers, travel in separate companies, while swallows, turkeys, blue birds, etc., travel in mixed companies of several species, due to similarity in their size, method of search of food, etc. In some species, the male and female members travel separately. Males arrive first to build the nests. The young birds generally accompany the females.

3. Range of migration. The distances travelled by migratory birds depend upon local conditions and the species concerned. The *Himalayan snow partridges* descend a few hundred feet only and cover hardly a mile or two, while the *chicades* come down nearly 8,000 feet. The champion long-distance migrant is unquestionably the *arctic tern*. It spends the summer and breeds along the northernmost icefree coasts of Labrador, far inside the Arctic circle. Then it travels a distance of 11,000 miles to reach its destination to the edges of Antarctica in winter, and returns again through the same distance in summer. European *white stork* winters in South Africa after a journey of about 8,000 miles.

4. Altitude of flight. Some birds fly quite close to the earth, while most routine migration probably takes place within 3,000 feet of the earth. Radar has shown that some small land birds, migrating at night, fly at 5,000 to 14,000 feet. Some species even cross the Andes and the Himalayas at altitudes of 20,000 feet or more.

5. Speed and duration of flight. Average flight velocity of most small birds seldom exceeds 30 miles per hour. The greatest speed, recorded in India, of two species of swifts by E.C. Stuart, is 171-200 miles per hour. Several hundreds of miles may be covered nonstop in a day or a night, with an average of about 500 miles. Birds usually travel 5 to 6 hours a day, resting in between for food or drink. The *golden plover* holds the world record with the longest nonstop bird flight, from Hudson Bay and Alaska to South America, a distance of 2,400 miles.

6. Regularity of migration. Several species of migratory birds show a striking regularity, year after year, in their timings of arrival and departure. In spite of long distances travelled or vagaries of weather, they are often punctual within a day or two in their time of arrival. Another remarkable feature, besides punctuality, is that they sometimes come back to the same breeding place year after year.

7. Routes of migration. The data furnished from lighthouse and ships reveal that migratory birds usually follow definite lines of flight. Observations by telescopes and radars show that nocturnal migration of small land birds proceeds with the general airflow on a broad front. In spring, it occurs northwards along warm air currents from the south, and, in autumn, southward on the cool winds of the north. Deviation in path occurs due to configuration of land, coastline, courses of great rivers or intervening mountain chains, etc.

[V] Problems of migration

The perplexing problems of migration have puzzled man ever since prehistoric times when he started watching the flights of birds and pondered their disappearance in the fall and their reappearance in the spring. It was the most intriguing mystery, resolving itself into separate problems, such as :

(1) How do migratory birds find their way ?
(2) What was the original cause of migration ?
(3) What is the stimulus starting migration ?
(4) What is the purpose or advantages of migration ?
(5) How are the long flights of many species sustained ?

Many of these problems have been solved by the modern scientists.

1. Way-finding or navigation. The aspect of migration eliciting the greatest wonder is "how do birds navigate or find their way ?" Various explanations or theories of navigation have been given for what determines the direction and course of migration.

(a) Visual landmarks. The sense of direction has been attributed to obvious *topographical features* or *landmarks*, such as great rivers, river valleys, coastal lines, chains of oceanic islands, mountain ranges, etc. But a vast majority of birds migrate at night when they cannot easily make use of landmarks. Moreover, for birds crossing great stretches of seas, there are no sea-marks for them to follow.

(b) Experience. A few naturalists have suggested that the birds learn by *experience*. Some older members, benefiting by a tradition following a path in past several years, become leaders to guide the younger generations. However, birds certainly do not learn their route from elders, as some of them do not fly in flocks at all. In many cases, young birds make their first journey independently, without the guidance of the adult parents. They are evidently guided by instinct impressed on their nervous system in some way through countless generations.

(c) Telluric currents. Others have suggested the action of *telluric currents*. Certainly the air-currents, which would lead the birds straight to their destination, must be very obliging and highly ingenious.

(d) Homing instinct. Some have spoken of a *homing instinct*, enabling the birds to return to a goal, as in the case of ants, bees and carrier pigeons. But homing experiments with carrier pigeons have proved the importance of vision in navigation.

(e) Earth's magnetic field. S....e ...rk..rs, such as Von Middendroff and Henry L. Yeaglev, advanced the idea that birds navigate through responses to the *earth's magnetic field* and their inner ear reacts to the mechanical *Coriolis effect* produced by the rotation of the earth. But there is no reliable evidence of a magnetic or any other esoteric direction sense in birds.

(f) Celestial bodies. The late Gustav Kramer, a German Ornithologist, claimed in 1949, that the birds which travel by day use the sun as compass for orientation (Fig. 12). Experimenting with starlings, in closed cages, he also made the sensational discovery that birds even possess an internal time sense or *time clock*, with which they make necessary adjustments in their course according to the changes in the angle or position of the sun as the day progressed. He proved this by altering the direction of flight by using mirrors to give a false apparent direction of the sun. The instinct has to be inherited because young birds, that have never migrated before, make similar navigational orientations to sun when travelling independent of their parents.

Another young German, Franz Sauer, who experimented with night-flying old-world warblers, made the astounding discovery that the nocturnal, migrants navigate by the constellations of the stars (Fig. 13). However, the conclusion, that the birds

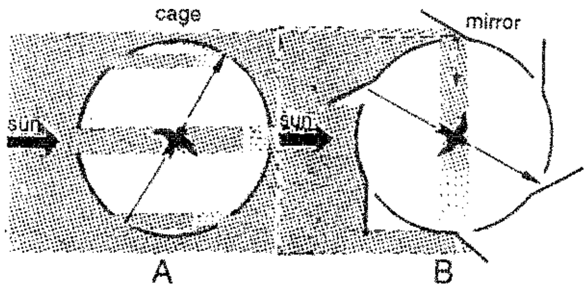

Fig. 12. Gustav Kramer's experiment with starlings to show that day migrants use sun as a compass.

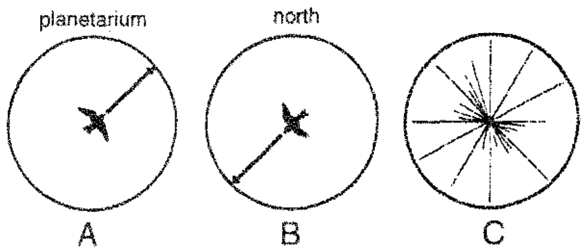

Fig. 13. Franz Sauer's experiment with warblers in a planetarium to show that night migrants use stars for guidance.

orientate by the sun during the daytime and by the stars at night, is subject to grave doubts. In short, the problem of how migrating birds find their way remains unknown.

2. Origin of migration. What started migration ? The basic or remote originating cause is still a matter of much speculation. One theory assumes that the original home of the birds was in the Northern Hemisphere. During Pleistocene, a mild climate prevailed suitable to live for the birds. However, by the end of Pleistocene, there was glaciation so that the Northern Hemisphere was covered by ice sheets. With advancing glaciers, birds were forced South, but came back when glaciers receded. Today's migration shows a brief recurrence of the ice-age event. Still another theory assumes that the ancestral home of the birds was in the South, rather than in the North and they returned to South for nesting and breeding purposes.

The most convincing theory explains the process of migration as an evolutionary one. In the past, tropical birds probably spread out in colder northern latitudes, where food was abundant, but were forced South when winter came. The event or series of events became an inborn custom through the long history of the race. According to William Rowan, the best explanation of the present day movements of birds is provided by Lamarckianism, that acquired characters can be inherited.

3. Stimulus or immediate causes for migration. What are the immediate causes, whether an internal clock or external clock stimuli, which prompt individual birds to start migration at approximately the same time each year ? It is likely that there are always immediate causes which prompt the instinct, such as scarcity of food, the shortening of daylight and the increasing cold in the case of most birds which migrate in autumn. In some cases, the migration has been correlated with a sudden rise in barometric pressure. In a general way, migration is a part of the sexual cycle. Birds begin to move northward as their gonads begin to swell. By the time they reach the breeding grounds, the glands are active. However, it does not follow that the sex hormones are the cause of migration. Increase in light in spring, or its decrease in the fall acts upon the pituitary gland. This, in turn, stimulates the gonads which then affect the nervous system, bringing about the urge to migrate. Many species show restlessness and deposition of fat in their body before migration. Which of the factors is the exact stimulus or trigger is unknown.

4. Purpose or advantages of migration. The purpose or gross advantages of migration are obvious and logical.

Migration helps birds avoid harsh climatic extremes. Migration from higher altitudes and latitudes (breeding areas in the north) during winter affords protection from cold and stormy weather, shorter days available for searching food and scarcity of food.

The migrants get more food and better conditions in their winter quarters in temperate or tropical regions than they would if they stayed at home.

Whereas a return in summer to the breeding areas in north once again provides suitable and unconquered nesting grounds, abundance of food, with minimum efforts, and long hours of day-light for searching food at a time when their population is increasing greatly.

Thus, birds migrate in order to utilize the food supply of both the hemispheres and to exploit new areas for nesting purposes, till the conditions become inclement for them.

5. Sustenance during migration. All long-distance migrants must fly for several hundreds of miles without food or drink. It is here that the importance of the pre-migratory deposition of fat comes in. There is a physiological advantage of fat over glycogen as a storage product, as fat produces more energy per unit weight. It also produces more water to cope with the high rates of metabolism and breathing, as there must be much evaporation from the lungs.

Economic Importance of Birds

Birds occupy an important position in the animal kingdom, specially in relation to man. Economically, they are both useful and harmful to man's interests.

[I] Beneficial birds

Some of the important uses of birds to mankind are as follows :

1. As food. The demand of flesh and eggs of birds has given rise to the paying poultry industry. Fowl is supposed to be a delicacy and its eggs are considered to be the best standard food, second only to milk. They are also used in toffies, pastries, cakes and biscuits, etc. Several birds have been domesticated and hybridized by man, some for many centuries. Hundreds of varieties of fowls, pigeons, turkeys, ducks and geese, have been raised to produce better qualities of feather, flesh and messengers, etc. In China, the nests of a particular species of swift are edible. These nests are made entirely by the saliva of the bird. Besides man, certain other animals, such as snakes, cats, civets, mongoose, etc., also prey largely upon small birds and their eggs. Great mortality occurs during migration when birds fly in clusters and can easily be captured or killed with less efforts.

2. In industry, art and ornamentation. Feathers of birds have been a great boon to mankind. They have been used extensively for pillows, quilts, blankets, clothing, and sleeping bags. The down feathers of water birds, such as ducks and geese, provide the warmest insulation and much used for Arctic clothing, ski attire and for sub-zero sleeping bags. Feathers with beautiful and distinctive colour or shape serve native peoples and modern women for ornamentation and adornment in a variety of ways. Decorative feathers now come from domesticated poultry, ostriches and rheas. Many natives apply feathers to their arrows so that they may go farther. Tail feathers of rheas are used as feather dusters in Brazil and Argentina. Feathers of peacocks are used in a variety of manners; the long rachis is matted into fans and toys. Feathers of ostrich are also employed in various arts and ornaments. Badminton shuttlecocks are manufactured out of feathers.

3. As currency. In Santa Cruz Island in South Pacific, the scarlet feathers of the tiny honey-eater are woven into belts, which are still used as currency by the natives. Ten such belts can buy even a bride.

4. As fertilizer. The faecal matter of birds, called *guano*, has been extensively used as *fertilizer* as it contains nitrogen, phosphates, calcium and iron, etc. On islands off the coast of Chile (South America), where little rains fall and which are breeding places for billions of migratory and seabirds, the guano accumulates in enormous quantities which is mined and exported to other countries.

5. As pollinators. Many humming birds, living in groves and meadows on flowering plants aid in their *pollination*. The fruit-eating birds help in the dispersal of the fruit-seeds.

6. In biological control. Birds are good friends of farmers as they exercise *biological control* over injurious crop pests. Insectivorous birds, such as flycatchers and woodpeckers, consume millions of tons of harmful insects, while seed-eating birds do a similar favour by eating thousands of tons of noxious weed seeds annually. Birds of prey such as hawks, eagles and owls, kill and devour countless thousands of rodents, such as field-mice, hares, rabbits and ground-squirrels, etc., that might otherwise overrun agricultural crops.

7. As predators. Peacocks, eagles, kites, and other carnivorous birds are destroyers of several venomous and injurious creatures, such as scorpions and snakes, etc.

8. As scavengers. Carrion eating birds, like vultures, hawks, eagles and crows, are of great sanitary value, as they feed upon the dead bodies and decaying organic substances. Some birds, such as cattle-egrets on hippopotamus, oxpeckers, rhinoceros birds, African starlings and crocodile-birds of India, scavenge for parasites upon these animals and render a valuable service to these unweildy beasts.

9. In medicine. Flesh and feathers of birds have been used in many *Ayurvedic* and *Unani* medicines. Their bodies are warm and so in Unani system it is prescribed to keep them in contact with the chest in lung diseases. The egg of fowl is used in tonics and various medicines. Flesh of pigeon is said to be good for the patients of paralysis. The egg of fowl has great experimental value, being used as a medium to grow cultures of viruses, bacteria, fungi, nematode larvae, etc.

10. As messengers. Pigeons have been trained and used as messengers in wars and love affairs from very early days.

11. As signals. Many birds profess changes in seasons. In India the appearance of cuckoo suggests the onset of spring. The peculiar voice of peacocks in cloudy weather indicates rainfall. Besides, some birds help the hunters by giving *danger signals*. Some sparrows cry before carnivorous animals such as tigers hidden in the bushes. The typical path sparrows cry along the path of the king cobra. The golden oriole a local migratory bird migrates from South to North India during summer months. Its arrival is considered a signal for the arrival of the monsoon.

12. For amusement. Millions of hunters all over the world find great recreation in hunting game birds. Ducks, quails, herons, etc, have been sought as *game* in Europe for centuries. Many birds produce beautiful songs we all love to hear. Many of them have been domesticated for their ability as *singers*, a conspicuous example being canary. For centuries man has kept parrots, mainas, parakeets and several other birds as *pets* in cages and aviaries, for their plumage and their ability to repeat human words. Pigeons, cocks and partridges have been tamed for *play*. Certain birds (parrots, bulbuls, etc.) are trained to perform strange *feats* in public and earn money for the juggler.

13. Aesthetic value. From the aesthetic viewpoint, birds are hard to surpass. No other group of animals can equal the variety and beauty of the colours of birds which, in nature, is surpassed only by the colours of flowers. Bird-study with field glasses and cameras has provided a never-ending healthful outdoor recreation for millions of bird watchers all over the world.

[II] Injurious birds

On the contrary, many birds cause tremendous damage to mankind.

1. Menace to agriculture. The insectivorous birds may destroy beneficial insects as well as injurious ones. Some birds damage crops by eating newly planted seeds, young plants, or mature seeds, fruits and berries.

2. Destroyer of game birds and other animals. Many hawks, owls and other birds are killed because of their occasional depredations in the poultry yard and their attacks upon game birds and song birds. The New Zealand parrot (*Nestor notabilis*) has acquired the habit of digging out the kidneys and fat of sick and weakened sheep. Fisheating birds, such as herons, cause great damage to fish industry.

3. Pests of fruits and stored grains. Frugivorous birds, like parrots, cause immense loss to the fruits in the gardens. They not only eat ripe fruits, but also cut and throw upon ground the unripe fruits, as if in play. Sparrows are the commonest pests of stored grains in the granaries, where they go not only for grains, but also for the insect pests.

4. Spread of disease. Many birds feed upon insects and worms carrying noxious germs in their bodies. Thus they serve as secondary hosts of disease germs and help in spreading the diseases.

5. Pests of honey bees. Honey-guides are dingy little birds allied to woodpecker, found chiefly in Africa. They feed on grubs of bees and wasps. When the bird finds a hive, it guides a badger to it. The badger, confident in sting-proof hide and coat of coarse hair, breaks it open and eats the honey while the bird feeds on the luckless grubs, which are tumbled pell-mell into the open. Sometimes a man notices the bird-animal procession and joins it and takes his share of honey.

6. As hazards to aeroplanes. Birds are sometimes sucked into the rear part to the plane and cause accidents which is a great loss. It is, therefore, these days the area near about the aerodromes is kept free of bird population. Food and nesting material is removed from such areas and the villages around the aerodromes are instructed not to leave any dead animal in the near vicinity.

By and large, however, the balance sheet on birds has always tipped favourably towards the credit side.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Write an essay on—(i) Economic importance of birds, (ii) Flight adaptations of birds, (iii) Migration of birds, (iv) Origin and ancestry of birds, (v) Ratitae.
2. "Comparative anatomy, embryology and palaeontology unite in telling the story that the bird are glorified reptiles'. Discuss.
3. Give an account of structure and affinities of *Archaeopteryx*.
4. Give an account of flight mechanism in birds.
5. Describe various modes of flight in birds.

» *Short Answer Type Questions*

1. Differentiate between Ratitae and Carinatae in a tabular form.
2. Discuss birds as a flying machine.
3. Describe the various types of beaks or feet found in birds.
4. Describe the principle types of palates met with in birds.
5. Write short notes on—(i) *Archaeopteryx*, (ii) Kiwi (*Apteryx*), (iii) Fossil birds, (iv) Migratory birds, (v) *Tinamous*.

» *Multiple Choice Questions*

1. Which of the following reptiles possesses gizzard :
   (a) Crocodiles (b) Lizards
   (c) Snakes (d) Turtle
2. The fossil record of *Archaeopteryx* have been discovered from :
   (a) Britain (b) Germany (c) France (d) USA
3. Probable ancestors of present day Ostrich is :
   (a) *Archaeopteryx* (b) *Ictyornis*
   (c) *Eleuherornis* (d) *Hesperornis*
4. Birds are glorified :
   (a) Vertebrates (b) Fishes
   (c) Amphibians (d) Reptiles
5. The most common mode of flight :
   (a) Flapping (b) Gliding
   (c) Soaring (d) Hovering
6. Beak in sparrows is :
   (a) Cutting type (b) Seed eating type
   (c) Fruit eating type (d) Tearing and piercing type
7. Skull in members of ratitae is :
   (a) Schizognathous (b) Desmognathous
   (c) Dromaeognathous (d) Aegithognathous
8. Champion long distance migrant is :
   (a) Snow Patridges (b) Chicades
   (c) European white stork (d) Arctic tern

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d).

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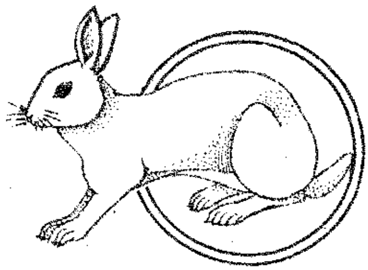

Type 11. *Oryctolagus* : The Rabbit

Mammals are the most highly evolved and the most important group in the animal kingdom. They belong to the class *Mammalia* (L., *mamma*, breast), that includes all the forms in which the female possesses mammary glands for the production of milk with which they nourish their young. Besides, they are warm-blooded like birds, possess a hairy covering on their body, a diaphragm separating the thoracic and abdominal cavities, and bring forth their young alive (*viviparous*) instead of laying eggs.

Study of Rabbit

The representative mammalian types generally prescribed for study, and also described in Zoology books, are rat, rabbit, guinea-pig, cat, foetal pig and man. Rabbit furnishes an excellent material for dissection. It is of good size, clean to handle, harmless and free from vermin. It is easy to obtain for large classes and can also be reared in the laboratory. It bears a close structural similarity to man. For these reasons, rabbit is still prescribed by most of the Indian universities as a mammalian type for study.

Systematic Position

Phylum	Chordata
Subphylum	Vertebrata
Superclass	Tetrapoda
Class	Mammalia
Subclass	Theria
Infraclass	Eutheria
Order	Lagomorpha
Family	Leporidae
Type	*Oryctolagus cuniculus* (Rabbit)

Natural History

Distribution. The European grey rabbit, *Oryctolagus cuniculus,* is almost cosmopolitan or word-wide in distribution. Its original home had been Western Europe and Africa, from where it was carried by man to various parts of the world including India. Several domestic varieties have been raised from the wild form differing in colour, size and texture of fur.

Habitat. In its wild state, rabbit occurs in the fields, grasslands and open woodlands.

Habits. Rabbit usually leads a *fossorial* life, although it can live above ground in dense undergrowth. It digs a *burrow*, called the *warren*, in soft ground with the aid of strongly clawed forelimbs. A burrow may be extensive with several side branches or tunnels with many outlets. There is no regularity in their arrangement. The burrow serves as a shelter for retiring or in time of danger from predators and to rear its helpless newborn young. It does not normally wander far from its burrow.

Rabbits are *gregarious* animals. They live and move in groups or families. They are *herbivorous* in diet, feeding on green vegetation, usually near the warren. They are *crepuscular* in habit, that is, coming out of burrows for feeding in twilight, chiefly at dawn and dusk. They resort to *refection* or *coprophagy*, by eating their soft night droppings without mastication. The same food thus passes twice through gut to provide maximum nourishment.

Rabbit is timid and defenceless but very clever, agile and a fast-runner. On seeing danger, it thumps hindlegs on ground to produce a warning sound so that others may also run to safety. It moves by walking, running and leaping and covers a distance of about 40 km in one hour.

Rabbit is *polygamous* and one male lives in the company of several females. *Fertility* is very high. A female reaches maturity at the age of 6 months only. During an average life span of 8 years, the female breeds at least 4 times every year, each litter comprising 5 to 8 young ones. At the time of birth, the young are blind, deaf, naked (hairless) and helpless. They are fed on milk by the mother who shows *parental care*. At the time of danger, the young ones are shifted to some safer place. When a young one dies, it is removed immediately from the burrow.

Economic importance. Rabbits are both useful as well as harmful to mankind. They provide food for snakes, predatory birds (owls, hawks, buzzards) and mammals (stoats, foxes, wolves, cats) which are their natural enemies. They are caught by man for the value of their fur and flesh by shooting, netting, snaring and trapping. Their fur or felt is used for the manufacture of purses, gloves, caps, etc. Many domestic varieties are also a source of valued meat which is palatable and very delicious. They form a useful laboratory animal for study and research. The domestic pets provide entertainment, especially to younger people.

On the other hand, they consume growing crops and pastures intended for cattle. The grassy meadows befouled by their excreta become unfit for grazing. They gnaw the bark of young trees in orchards and damage them. Rabbits also serve as carriers in spreading some human diseases.

Rabbits and Hares

The order Lagomorpha (Gr., *lagos*, hare) literally means hare-like. It includes rabbits, hares and picas. Rabbits and hares closely resemble and the two names are often used in confusion for the same type. The common rabbit is *Oryctolagus cuniculus*, which has a worldwide distribution. The North Indian hare is, *Lepus ruficaudatus* while the South Indian hare is, *L. nigricollis*. The chief differences between rabbit and hare have been given in the Table 1.

External Features

[I] Shape, size and colour

The rabbit is a small, squatty and bilaterally symmetrical animal of the size of a cat. The length is about 40 cm from mouth to anus. The whole body is covered by a soft uniform hairy coat or fur. It conserves body heat, and keeps the body temperature constant (38.8°C). It also gives the wild rabbit its characteristic colour which is dusty-brown with a white patch under the tail. Colour is protective since it serves as camouflage with the surroundings. Colour of domestic varieties is usually white or black and white.

[II] Division of body

The body of rabbit is made of 4 distinct parts—head, neck, trunk and tail.

Table 1. **Differences between Rabbit and Hare.**

	Characters	Rabbit *(Orgctolagus)*	Hare *(Lepus)*
1.	Size	Usually smaller than hare, 30-45 cm long	Usually larger than rabbit, 50-70 cm long
2.	Body colour	Brownish grey above, white below	Brown above, white below
3.	Snout	Narrower	Broader
4.	External ears or pinnae	Comparatively shorter and of same colour	Comparatively longer with black tips
5.	Fore limbs	Shorter than hind limbs	Fore and hind limbs almost equal
6.	Hind limbs	Comparatively smaller	Comparatively larger
7.	Claws	Strong for digging	Not so strong
8.	Radius	Shorter than humerus	Longer than humerus
9.	Posterior nasal openings	Narrower than palatal bridge	Wider than palatal bridge
10.	Interparietal bone of skull	Distinct	Fused with supra-occipital
11.	Upper front incisor teeth	Have longitudinal grooves on outer surface	Longitudinal grooves lacking
12.	Nasal bones, chambers and passages	Narrower	Broader
13.	Young ones in a litter	5 to 8	Only 2
14.	New born young	Weak, naked and blind	Strong, covered with fur and eyes open
15.	Habits	Gregarious (living in groups), fossorial (burrowing), and crepuscular (feeding in morning or evening)	Solitary, nomadic or vagabond, living in temporary shelters and nocturnal
16.	Burrow	Has branching tunnels with several exits	Temporary excavation on surface, under a bush or in grass, and called a 'form'
17.	Nature	Docile, can be domesticated	Wild, can not be domesticated
18.	Speed	About 30-40 km per hour. Fast runner	About 60 km per hour. Runs faster
19.	Danger signal	With sound produced by striking ground with hind limbs	With sound produced by grinding incisor teeth against one another

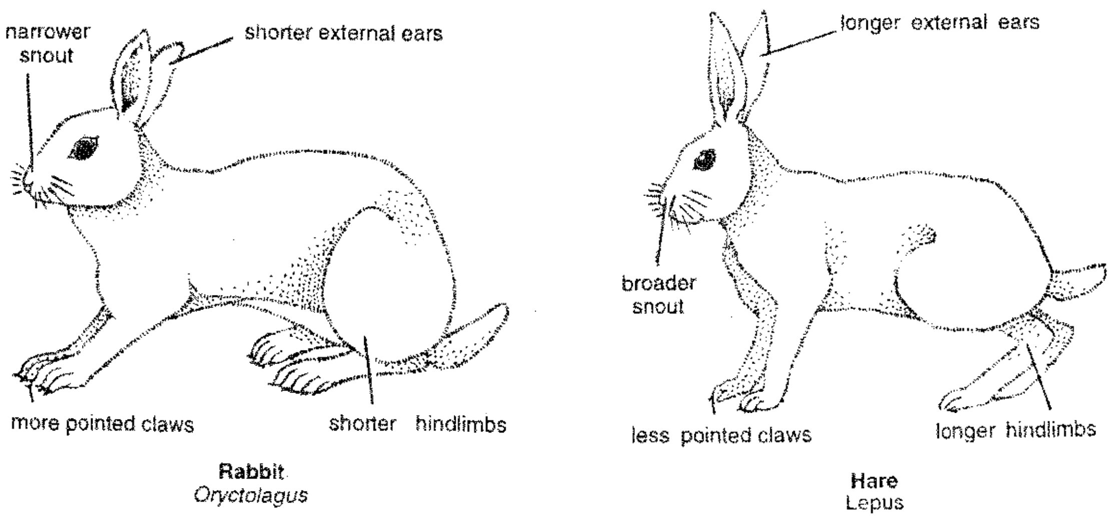

Fig. 1. Comparison of rabbit and hare.

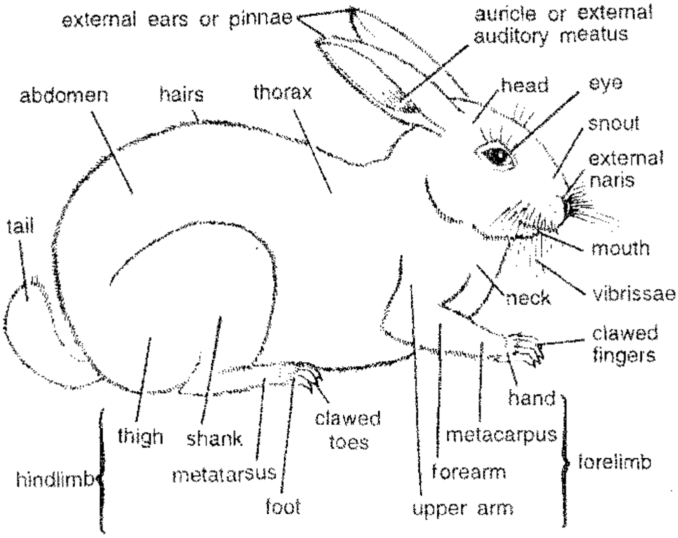

Fig. 2. Rabbit. External features in side view.

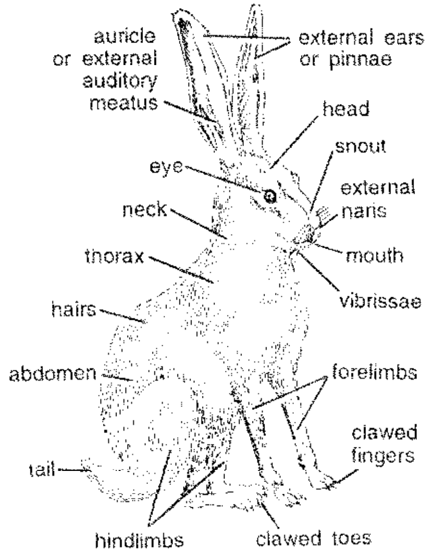

Fig. 3. Hare. External features.

1. Head. The head is large, pear-shaped and pro uce anteriorly into a large lunt *snout* or *muzzle* with a fleshy tip. The head bears the mouth, vibrissae, external nares, eyes and external ears.

(a) Mouth. The lower end of snout carries terminally a small transverse slit-like *mouth* opening. It is bounded by the soft, fleshy and movable upper and lower *lips*. The large upper lip is also calle. *hare lip*. It is divided .y a median vertical cleft into two lateral halves. The cleft exposes the large upper incisor teeth which remain outside the buccal cavity, even when the mouth is closed.

(b) Vibrissae. Large, stiff, tactile hairs, called *whiskers* or *vibrissae*, are present on the two lateral halves of upper lip and near the eyes. Each vibrissa has a coil of sensory nerve ending round its base of follicle.

(c) External nares. The external nares or nostrils are a pair of large oval slits at the fleshy tip of the snout. They are surrounded by a moist bare area of skin, the *rhinarium*. They open into the large olfactory chambers.

(d) Eyes. Two large prominent oval eyes are located one on either lateral side on the middle of head. Each eye has movable upper and lower *eyelids* bearing very fine and short *eyelashes*.

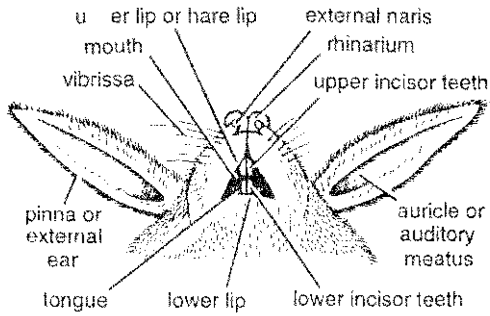

Fig. 4. Rabbit. Head in ventral view.

Lying in the anterior corner of each eye is a small white third eyelid or *nictitating membrane*. It can be drawn across the cornea for safety from dust particles.

(e) External ears. On either posterior lateral side of head is present a large prominent movable fold of skin, the *external ear* or *pinna*. Its basal part surrounds a short tubular *external ear opening* or the *external auditory meatus* closed below by a *tympanic membrane* or *ear drum*. The two pinnae are held upright when the animal is on the alert but are laid back when it is frightened or running. Pinnae can be moved independently and collect sound waves from any direction.

2. Neck. The head is connected at a slight angle to the trunk by a short but distinct neck. It is quite flexible and permits the animal to move freely its head in all directions. Neck does not contain coelom and any bulky viscera.

3. Trunk. The large and cylindrical trunk is further differentiated into two parts : (i) the anterior narrow stiff chest or *thorax*, and (ii) the posterior broad soft-bellied *abdomen*. The thorax forms a firm bony cage, supported laterally by *ribs* and ventrally by *sternum*.

(a) Teats. The female has 4 or 5 pairs of mammary or milk glands. Their ducts open on small projections, called *teats* or *nipples*, along the ventral surface of thorax and abdomen. Teats are poorly developed or rudimentary in male.

(b) Anus. There is no cloaca. Instead, the posterior end of abdomen just under the base of tail carries a small rounded aperture, the *anus*. It is the external opening of the rectum. On either side of anus is a hairless depression, the *perineal pouch*, into which opens a *perineal scent gland* on a small papilla. The secretion of these glands has a strong odour characteristic of rabbit.

(c) Urinogenital aperture. In the male rabbit, the urinogenital aperture lies in front of anus at the tip of a small, cylindrical, muscular, skin-covered copulatory organ, the *penis*. The testes of male are lodged in two loose, thin-walled skin-bags, called *scrotal sacs*, which lie one on either side of penis.

In the female rabbit, penis and scrotal sacs are absent. Instead, the slit-like urinogenital aperture, or *vulva*, lies at the base of a small rod-like *clitoris*, which is homologous to the penis of male.

4. Tail. A small, bushy or furry tail is attached to the hind end of trunk. It serves as a balancing organ during movements. A white patch on the lower surface of tail is used to give a warning signal in case of danger.

[III] Limbs or appendages

The trunk bears 2 pairs of *pentadactyle* limbs. They are disposed in a crouching position when the animal is at rest or feeding. Forelimbs are shorter, while hindlimbs are longer and stronger. Palm and sole are both hairy.

1. Forelimbs. Each forelimb arises from the level of pectoral girdle and consists of 3 parts — proximal upper arm or *brachium*, middle forearm or *antebrachium* and distal hand or *manus*. The hand further includes wrist or *carpus*, palm or *metacarpus* and 5 *fingers* ending in sharp pointed horny claws. Forelimbs are used for digging burrows and for absorbing the shock of alighting after a leap.

2. Hind limbs. Each hind limb arises from the level of pelvic girdle and also consists of 3 parts — proximal *thigh* or *femur*, middle *shank* or *crus*, and distal *foot* or *pes*. The foot further includes ankle or *tarsus*, sole or *metatarsus*, and 4 clawed *toes*. First toe or *hallux* is absent. Hind limbs are mainly used in leaping.

The rabbit use to walk on digits and keep remaining part of hand and foot elevated. This mode of walking is called digitigrade. It can run at speed of 30 Km/hr to 70 Km/hr. Rabbit is capable of moving in three different ways viz., walking, running and leaping.

Skin or Integument

[I] Structure of skin

As in all vertebrates, the skin of rabbit is also built of two main parts or layers : an outer *epidermis* and an inner *dermis*. Below the skin, lymph spaces are absent and it is connected with muscles with the help of specialized connective tissue called, *areolar connective tissue*.

1. Epidermis. It is the outer thin stratified epithelium developed from the embryonic ectoderm. It does not contain blood vessels. The complex epidermis is primarily made of two zones : the deeper *Malpighian layer* and the superficial *cornified layer*.

(a) Malpighian layer. The Malpighian layer, or *stratum Malpighii*, rests upon the dermis. It is made of living cells and is further subdivided.

(i) Stratum germinativum. The *germinal layer* is the innermost layer in contact with the basement membrane secreted by the underlying dermis. Its cells are columnar, arranged in a single

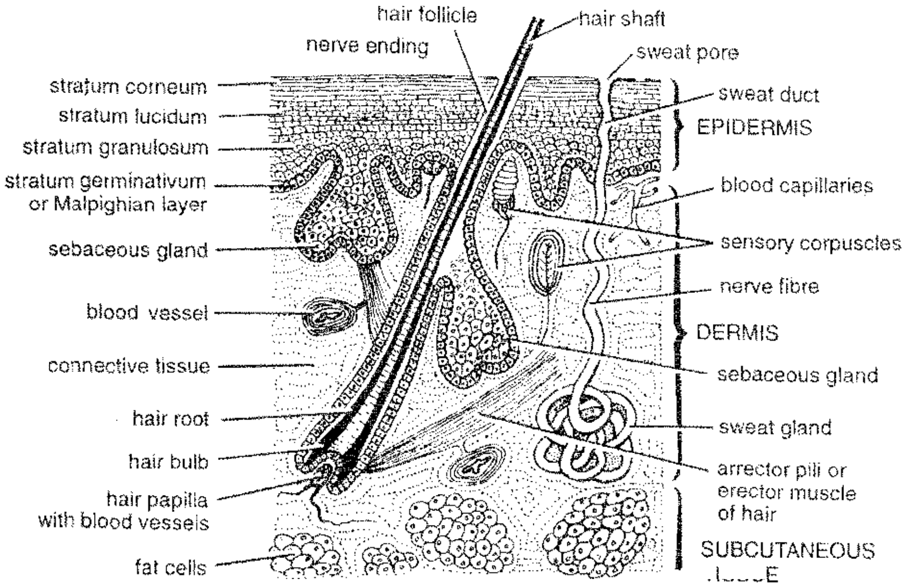

Fig. 5. Rabbit. V.S. of hairy skin.

row one cell thick, and continually divide mitotically adding new cells to the epidermis. All the glands and keratin structures are derived from this layer.

(ii) Stratum spinosum. It lies above the germinal layer and is also referred to as the *transitional layer.* It is several layers thick and made of polyhedral cells. As these cells are gradually pushed outwards, they become flattened and keratinized due to deposition of a horny scleroprotein known as *keratin.*

(iii) Stratum granulosum. The cells in the upper part of stratum spinosum form the *granular layer* containing keratohyalin granules. It is particularly developed in parts of the body having thick epidermis such as the palms and the soles.

(iv) Stratum lucidum. Above granular layer in palms and soles only, this is a conspicuous, hyaline, non-stainable layer of shiny and refractile cells.

(b) Cornified layer. The outermost cells on the skin surface are thin, dead and fully keratinised. They form a horny or cornified layer called *stratum corneum.* It is especially thick on soles and palms. The outer portion of this layer is constantly being worn away, the dandruff is a familiar example. New cells are constantly added from below when the granular cells become horny and die. This dead layer is tough, prevents mechanical injuries and fungal and bacterial attacks, and reduces water loss from the body.

The outer surface of epidermis contains minute openings of sweat glands and hair follicles.

2. Dermis. It is the inner layer of skin, derived from the embryonic mesoderm. It is composed of dense fibrous connective tissue beneath the epidermis. It contains many blood vessels, lymph vessels, nerve fibres, muscle fibres, elastic yellow fibres and pigment cells. The elastic fibres present bring the skin back to shape when it is stretched or distorted. When tanned the connective tissue fibres of dermis produce leather. The blood vessels send *capillary loops* into finger-like papillae of dermis projecting into epidermis. The blood vessels play an important role in nutrition and temperature regulation. *Nerves* and microscopic *sense organs* that receive stimuli of touch, pressure, temperature and pain are abundant in the dermis. Only a few *nerve endings* penetrate the epidermis. Pigment cells present in the outer layers of dermis contain *melanin* which protects the underlying tissues from the damaging effect of ultraviolet rays. These melanin containing cells the melanocytes constitute a self maintaining unit and are differentiated from melanoblasts which originate from the embryonic neural crest cords. From such cords the melanoblasts migrate throughout the body and on arrival at their destination differentiate into pigment forming cells. There are also *muscle fibres* attached to the hair follicles. *Fat* is stored in lobules of fat cells in the deeper parts of dermis and in the subcutaneous tissue. T..is .atty layer is calle. *stratum adiposus* and serves as a reserve food supply, as a heat insulator, and as a cushion against mechanical injury.

[II] Skin derivatives

1. Hairs. Hairs are specialized, elongated, thread-like, cylindrical outgrowths of the epidermis. A hair lies within a pit in the skin called *hair follicle*. It is a tubular downgrowth or invagination of the Malpighian layer reaching deep into the dermis, supported by the surrounding fibres. The base of the follicle is dilated and evaginated to form the *hair papilla*. Blood capillaries and nerves from dermis pass into the papilla and nourish the adjacent epithelial cells which proliferate rapidly forming a *bulb*. From the bulb arises a cylindrical shaft of cornified cells, the *base* or *root* of the hair. Constant addition of cells causes the hair base to extend through the follicle and pierce through the skin as a column of cells. As the hair cells quickly become horny and die, only the base of the hair is living while above the skin surface it is a dead structure. The hair is prevented from being brittle by the oily secretion of a *sebaceous gland* opening into the follicle. Associated with each follicle is also a small smooth muscle, the *erector pili*, which erects the hair.

In a cross-section, a typical hair shows 3 regions. The outer *cuticle* is made of overlapping microscopic scales. The middle *cortex* making the bulk contains shrivelled cells and pigments. The inner *medulla* forming the central core contains air spaces in larger hairs. The colour of the hair is produced by pigment within the intercellular spaces of the cortex, white colour is due to the absence of pigment together with the refraction of

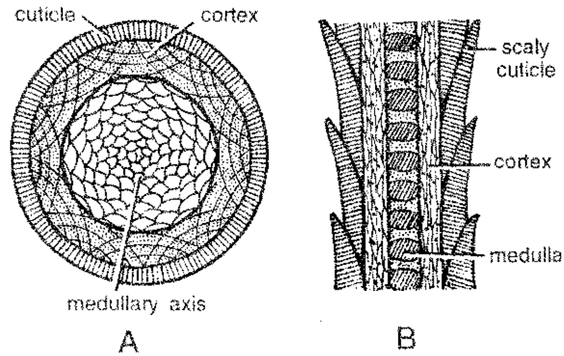

Fig. 6. Hair shaft. A—In T.S. B—In L.S.

light from air spaces between the cells of the medulla.

Uses of hairs. Some of the notable uses of hairs in mammals are as follows :

(1) Hairs impart colour and camouflage.
(2) Hairs form an insulating sheat by trapping air which prevents undue loss of heat from body.
(3) In furred mammals (rabbits, rats, etc.), the hairy covering or pelage forms a kind of portable blanket for survival in cold.
(4) Vibrissae act as tactile receptors, having several nerve endings round their bases.
(5) Eyelashes and hairs in and around nostrils prevent dust particles.
(6) Long tail hairs of cow or horse help in getting rid of flies and other harmful insects.

2. Epidermal glands. Integumental glands are quite abundant and peculiar of mammalian skin. The five major types are : sebaceous, sweat, lacrimal, mammary and scent. They are all multicellular. They are present in the dermis, but are all epidermal in origin.

(a) Sebaceous glands. These are flask-shaped, alveolar glands. They are formed as epithelial outgrowths of the upper parts or necks of hair follicles into which they open. Their oily secretion, called *sebum*, keeps the hairs and skin soft, supple, greasy and water-proof. It makes the surface of skin acidic as it contains lactic acid and other fatty acids. This acidic surface creates a hostile environment and prevents the growth of various microbes trying to enter through it.

(b) Sweat glands. Each sweat gland is a much coiled tube which lies deep in the dermis, surrounded by a network of blood capillaries. Its long spiral duct opens on to the skin surface as a *sweat pore*. The gland separates a saline fluid from blood, called *sweat*, which is both a secretion as well as an excretion. It is a secretion because it contains water which when poured over the skin surface and evaporated, cools down the body. It is an excretion because it contains harmful urea which is eliminated. Sweat also contains useful salts such as sodium chloride. In tropical countries, people who perspire or sweat much, need to take extra salt in diet, to maintain the proper salt and water balance of their body.

Sweat glands are absent in the skin of rat.

(c) Mammary glands. These are modified sebaceous glands that produce milk. They develop in both sexes from ventro-lateral milk ridges in the foetus. They are much branched tubular glands with their ducts opening on small projections of the skin surface, called *nipples* or *teats*. As already described, there are 4 to 5 pairs of nipples in the female rabbit. Mammary glands remain undeveloped and functionless in the male mammals. But they become well developed and produce milk only in sexually mature females, particularly when nursing young ones.

(d) Other glands. In addition to the above described glands, the mammalian skins may also contain the following types :

(i) Lacrimal glands. Associated with the eyes, they secrete *tears* which keep the eyes and eyelids clean and moist.

(ii) Meibomian glands. Opening into the follicles of eyelashes, their oily secretion lubricates and keeps them soft and flexible.

(iii) Scent glands. These vary greatly in location and function in different mammals. Their secretions serve to attract members of opposite sexes or for protection against enemies.

(iv) Wax glands. These are found in the auditory canals. Their fatty secretion, called *earwax* or *cerumen*, lubricants and protects the tympanic membranes.

[III] Uses of skin

Skin or integument is the main barrier between an organism and its environment. It has rightly been called a 'jack-of-all-trades,' as it serves a variety of important functions in mammals.

1. Shape. Skin helps in giving a particular shape of the body.

2. Protection. The horny and impermeable skin protects the underlying tissues from mechanical injury, too much water loss, the effect of ultra violet light, and invasion by bacteria and fungi.

3. Defence. The skin derivatives such as claws, nails, hoofs, horns, etc., serve as tools (e.g. digging) or weapons (e.g. offence and defence). Protective colouration provides camouflage.

4. Homoiothermy. It helps in the maintenance of a fairly constant body temperature irrespective of the environment.

5. Sensation. The sense organs of skin detect touch, pain and changes in temperature, moisture and pressure.

6. Vitamin D synthesis. Vitamin D can be synthesised in the skin of mammals through the effect of ultra violet light.

7. Sexual function. Integumentary modification lead to *sexual dimorphism*. Special cutaneous glands attract the opposite sex and help in *sexual selection*.

8. Excretion. Skin acts as an accessory excretory organ for eliminating some urea in sweat.

9. Secretion. Mammary glands secrete milk for feeding the young ones. Other skin glands secrete oil and tears to lubricate hairs and eyeballs, and earwax for lubrication of tympanic membranes.

10. Other functions. To some extent, skin helps in *storage* (e.g. subcutaneous fat), *absorption* (e.g. ointments, iodine), *respiration*, and *formation of bones* and *teeth*.

Endoskeleton

The endoskeleton of rabbit has been dealt with in chapter 40 in the Section on Vertebrate Osteology.

Body Wall, Coelom and Viscera

1. Body-wall. The outermost layer of the vertebrate body is the *skin* or *integument*. Below the skin is a layer of *muscles*, which is internally

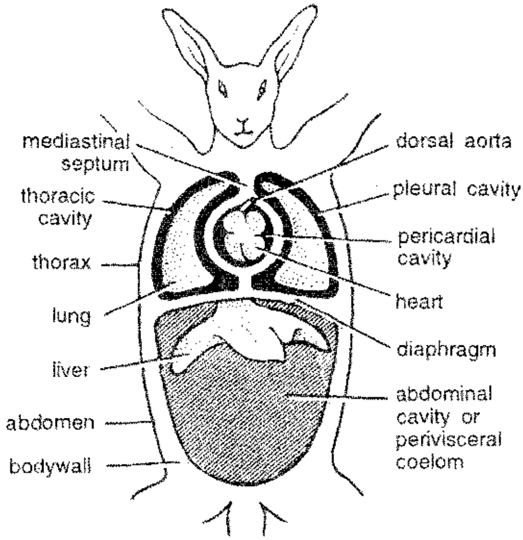

Fig. 7. Rabbit. Division of coelom or body cavities.

lined by a thin, shining membrane of flat mesodermal cells, the *peritoneum* or *coelomic epithelium*. The *body-wall* is the name collectively given to the skin, muscular layer and peritoneum.

The body-wall encloses the spacious coelom and viscera, maintains a constant internal environment, and protects the delicate internal organs against mechanical and chemical injuries.

2. Coelom. In vertebrates, the body trunk contains a large mesodermal body cavity, or *coelom*. It contains most of the internal organs or viscera. It is lined by coelomic epithelium which is extended as epithelial sheets, or *mesenteries*, to cover the visceral organs. The coelom, containing a coelomic fluid, facilitates the expansion, contraction and other functional movements of the viscera.

In mammals, a transverse muscular partition, the *diaphragm*, divides the coelom into an anterior smaller compartment, or thoracic cavity, and a posterior larger compartment, the *abdominal cavity*. The mammalian thoracic cavity is further divided into three parts : two lateral *pleural cavities* in which lie the lungs, and a median *pericardium* containing the heart. A fine partition, the *mediastinal septum* stretches from the heart to midventral line. It is made up of two medial walls of right and left pleural cavities in contact with each other, after reaching at the level of heart. The *abdominal cavity* houses the digestive and the urino-genital organs.

3. Viscera. The soft internal organs of the body are collectively called *visceral organs*, or simply *viscera*. These are grouped into 9 major organ-systems. These are integumentary, muscular, skeletal, digestive, respiratory, circulatory, nervous, urino-genital and endocrine systems.

Digesti¨e System

The digestive system includes organs concerned with mastication, swallowing and digestion of food and elimination of undigested matter. It consists of the *alimentary canal* and the associated *digestive glands*.

[I] Alimentary canal

The alimentary or digestive tract of rabbit (mammals) is more specialized than that of lower vertebrates. It is a long and coiled tube of varying diameter, extending from mouth to anus. The various parts included are : mouth, vestibule, buccal cavity, pharynx, oesophagus, stomach, small intestine, caecum, large intestine and anus.

1. Mouth. The mouth is a relatively small, transverse aperture, present rather subterminally at the tip of the snout. It is bordered by two soft, fleshy and movable lips, which remained covered with hairy skin on the outside and lined with mucous epithelium on the inside. The inner surface of each lip is equipped with *labial glands*, which secrete mucus to keep the inner surface of the lips moist. The upper lip is divided by a median vertical cleft running up to the nostrils, whereas the lower lip is not divided. Because of this cleft, the large and sharp upper incisors are exposed externally even when the mouth is closed. This arrangement enables the rabbit to gnaw effectively.

2. Vestibule. The mouth opens into a narrow, vertical, slit-like space, the *vestibule*. It is bounded externally by the lips and cheeks, and internally by the gums of jaws. Mucous glands are found in its lining.

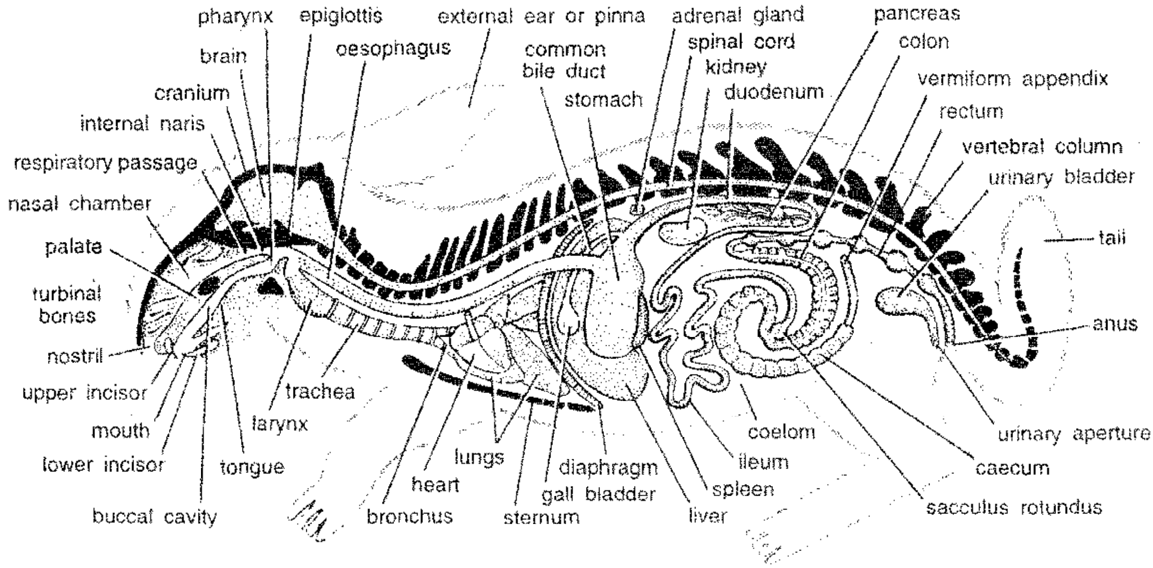

Fig. 8. Rabbit. Diagrammatic sagittal section of body to show general anatomy.

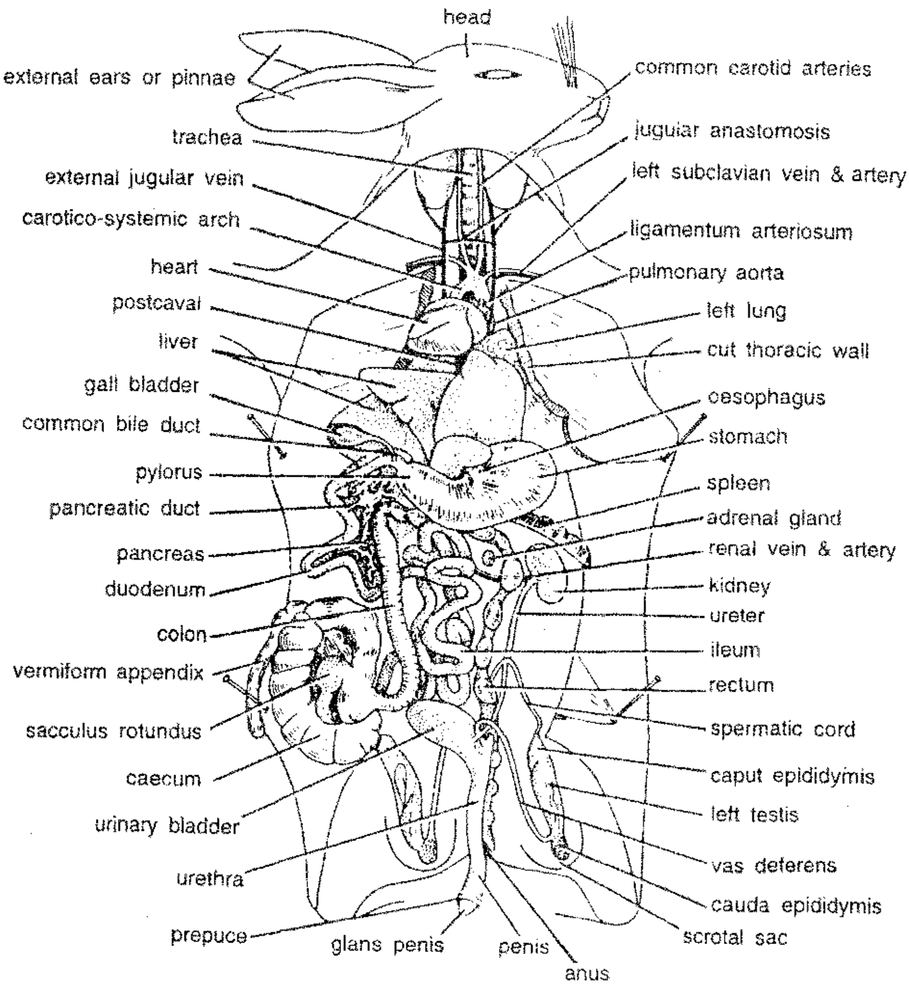

Fig. 9. Rabbit. Ventral dissection of male showing general anatomy.

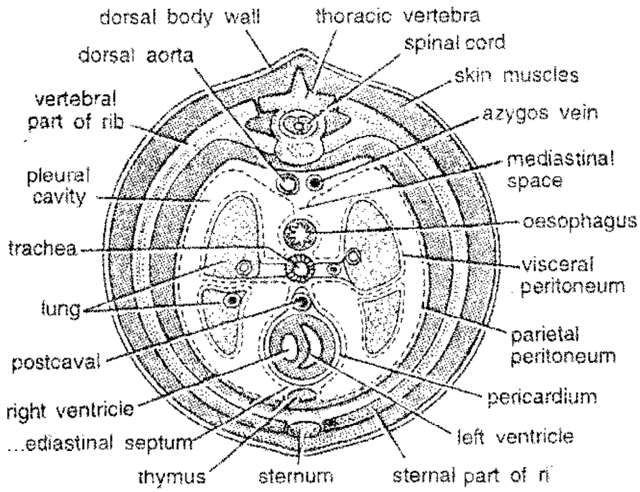

Fig. 10. Rabbit. T.S. Thorax through ventricle of heart.

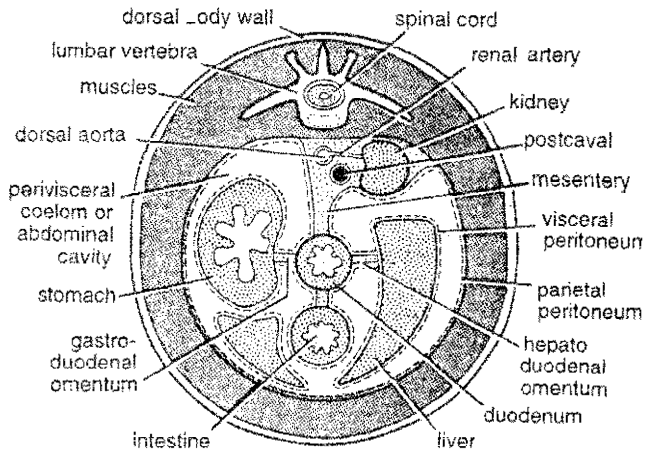

Fig. 11. Rabbit. T.S. Ab/omen through liver.

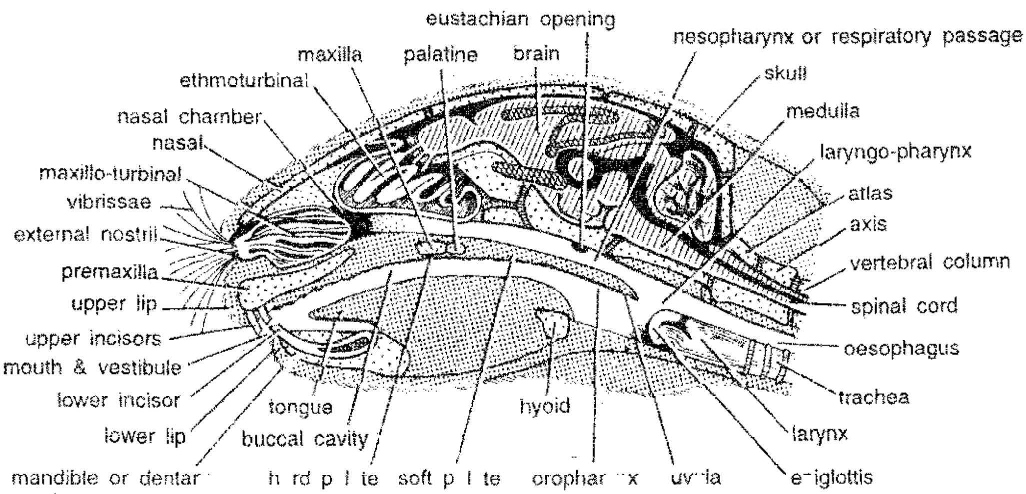

Fig. 12. Rabbit. Head in diagrammatic sagittal section.

3. Buccal cavity. The vestibule leads behind into the *oral cavity* or the *buccal cavity.* It is widest in the region of the molar teeth. It is lined with mucous membrane and contains the following structures :

(a) Palate. The roof of the oral cavity is formed by the palate. Its anterior part is called the *hard palate* which is formed by the palatine processes of premaxillae and maxillae and the horizontal plates of the palatines. It divides the original buccal cavity into a *nasal passage* above and a *food passage* below. The lower surface of hard palate bears prominent transverse ridges called the *palatal rugae* which prevents the escape of food from mouth cavity. The hard palate is extended back as the flexible, smooth and fleshy *soft palate.* The soft palate is lined by mucus membrane having numerous *palatine glands* which secrete the mucus to keep the buccal cavity moist. Its posterior end hangs down freely into pharynx as a small flap called *uvula.* Near its anterior end, the hard palate is perforated by a pair of small openings of *nasopalatine ducts* or *canals,* leading into nasal or olfactory chambers. Each canal lodges a sensory *Jacobsons' organ,* the function of which is to recognize different types of food.

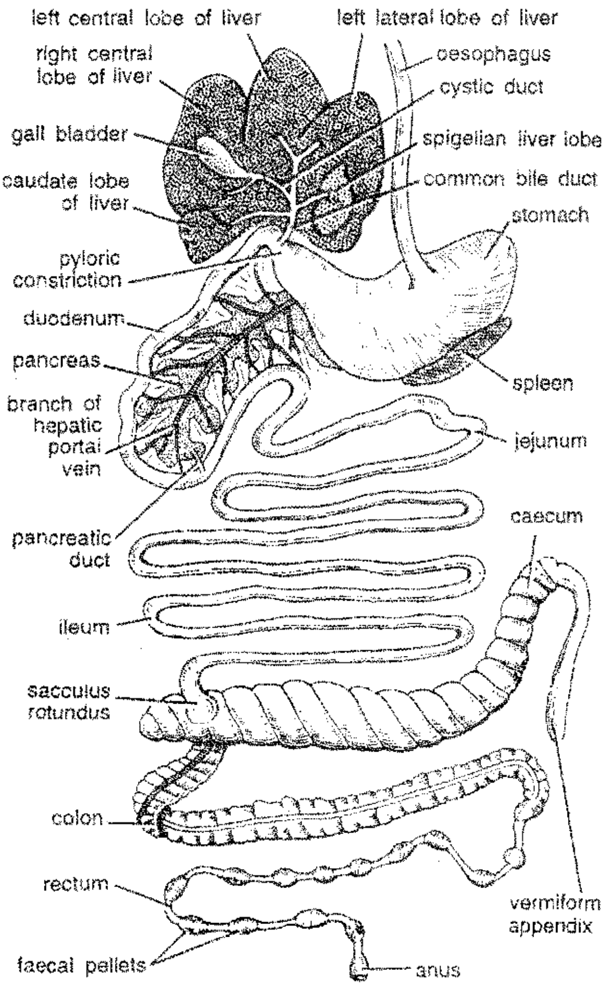

Fig. 13. Rabbit. Alimentary canal with associated glands.

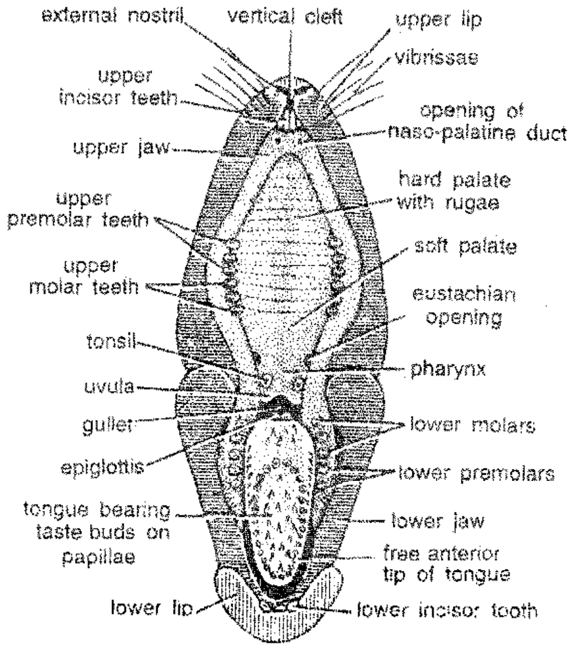

Fig. 14. Rabbit. Bucco-pharyngeal cavity.

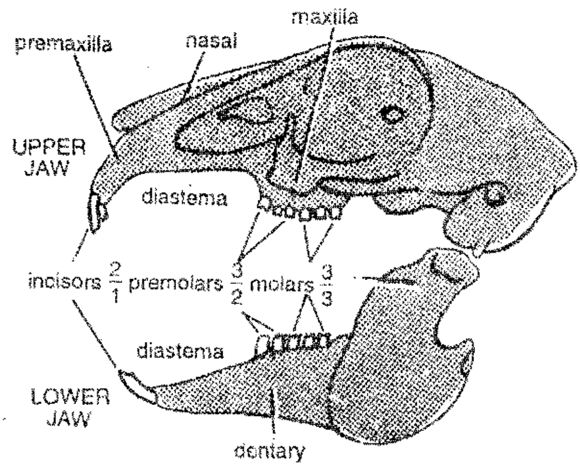

Fig. 15. Rabbit. Dentition. Arrangement of teeth on jaws.

(b) Tongue. Most of the floor of the buccal cavity is occupied by a large, mobile and muscular tongue. Its under surface remains largely attached to buccal floor except for the free rounded anterior end. Its dorsal surface is marked by a median groove. The dorsal surface also bears numerous papillae containing *taste buds*. According to their shape and size, these papillae are of 4 kinds—*fungiform, filiform, circumvallate* and *foliate*. The chief function of the tongue in rabbit (mammals) is the manipulation of food and mixing of saliva with food in the mouth cavity.

(c) Teeth. Teeth of rabbit are present on both the jaws. They are borne by the premaxillae and maxillae of upper jaw and dentaries of lower jaw. They differ from those of frog in several respects. Teeth are *thecodont* (L., *theca*, case or sheath + G., *odous*, teeth), that is, they are firmly embedded in cup-like sockets of the jaw bones. Teeth of rabbit are *diphyodont*, that is, only two sets are present throughout life. The first set is known as *deciduous* or *milk dentition*. It is lost in youth and replaced in the adult by the *permanent dentition* which cannot be replaced. Teeth are also

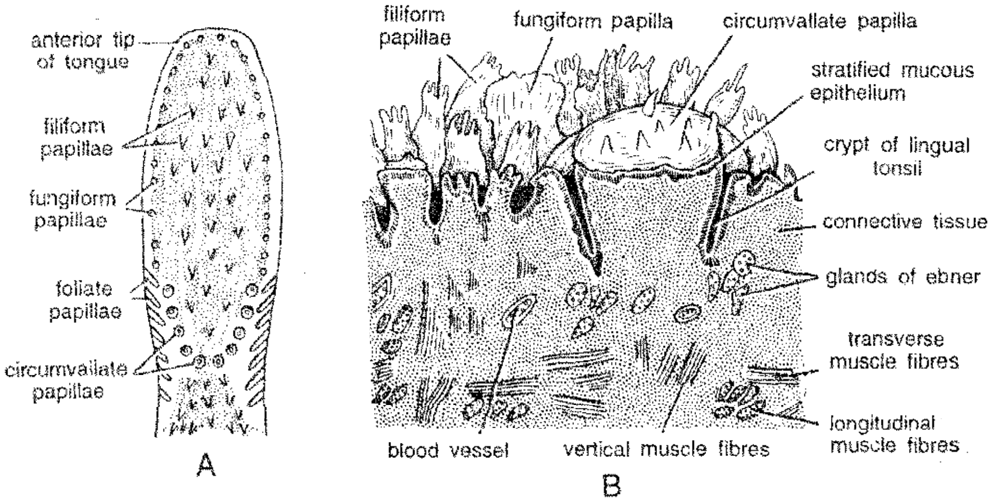

Fig. 16. Rabbit. Tongue showing different types of papillae. A—Entire tongue in dorsal view. B—V.S. of tongue.

heterodont (Gr., *heteros*, different), i.e., they are of different types. Among mammals, teeth are generally differentiated into 4 kinds-*incisors, canines, premolars* and *molars*. The *dental formula* of rabbit is : $i\frac{2}{1}, c\frac{0}{0}, pm\frac{3}{2}\ m\frac{3}{3} = 28$ or $\frac{2033}{1023} = 28$. Each half of upper jaw has 2 incisors borne by premaxilla, while each half of lower jaw has a single incisor at the tip of dentary. *Incisors* of rabbit are characteristically elongated, sharp and *chisel-like*, meant for gnawing or cutting food. To compensate for wear, the incisors of rabbit grow throughout life since they are open-rooted. *Canines* are absent in both the jaws and the wide toothless gap left due to their absence is called *diastema*. These permit the two halves of upper slip to be drawn behind the upper incisors as chip deflectors. Each half of upper jaw has 3 premolars and 3 molars, while each dentary bears only 2 premolars and 3 molars. Premolars and molars are called *cheek teeth* or *grinders*. They are similar having broad crowns with sharp transverse enamel ridges and are meant for grinding food.

4. Pharynx. The buccal cavity merges behind into a short, narrow chamber, the *pharynx*, into which occurs the crossing of several apertures. The soft palate divides the pharynx incompletely into 3 parts. The *nasopharynx* lies dorsal to the soft palate, the *oropharynx* below the soft palate, and both communicate behind with the *laryngopharynx*, round the freely hanging uvula. Just anterior to free border of soft palate, on the either side, a small pit called, *tonsillar fossa* is present which contains a small lymphoid tissue called *palatine tonsil*. Anteriorly the nasopharynx communicates with the nasal chambers through the *internal nares*, while laterally it has a pair of oval *eustachian openings* leading to the tympanic cavities through the eustachian tubes. Just behind the tongue, the floor of laryngopharynx carries a median vertical slit, the *glottis*, leading into the larynx. It is guarded by a bilobed thin cartilaginous flap of tissue, the *epiglottis*, arising from its anterior border. During swallowing, it covers the glottis and prevents the entry of food into it. The laryngopharynx leads posteriorly into the oesophagus through a wide aperture, the *gullet*.

5. Oesophagus. The oesophagus is a long, narrow, elastic and muscular tube. It runs straight down through the neck, dorsal and parallel to the trachea. It traverses the thorax dorsal to the heart and lungs and some what to the left of the median plane. After piercing the diaphragm, it enters the abdomen and joins the stomach through its inner concave side. The inner wall of oesophagus is raised into several longitudinal folds. The longitudinal muscles of the oesophagus are arranged some what spirally which facilitate the onward movement of the food material to the stomach.

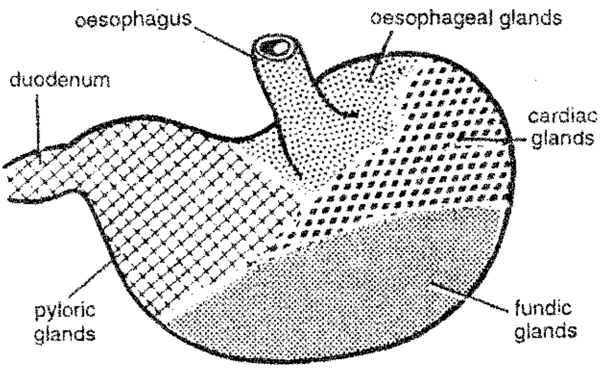

Fig. 17. Rabbit. Stomach showing distribution of gastric glands.

6. Stomach. Stomach is the broadest part of the alimentary canal. It is situated on the left side in the anterior part of the abdominal cavity. The bean-shaped stomach has a smaller inner concave surface and a larger outer convex surface, known as the *lesser* and *greater curvatures*, respectively. The larger anterior part of stomach is known as the *cardiac stomach* and the smaller posterior part as the *pyloric stomach*. The oesophagus enters the inner concave side of the cardiac stomach through the cardiac opening which is provided with a *cardiac sphincter valve* made by circular muscles. The end of pyloric stomach is externally marked by a circular groove, the *pyloric constriction*. Internally, it has the distal opening of pyloric stomach into duodenum, called *pylorus*, which is guarded by a circular *pyloric sphincter valve*. The cardiac and pyloric openings are closer to each other. Close to the outer curve of stomach is a red elongated body, the *spleen*.

The stomach performs 3 main functions—(i) storage of food, (ii) mechanical churning of food, and (iii) its partial digestion.

7. Small intestine. The small intestine following stomach is a long, narrow and much convoluted tube made of three parts—*duodenum*, *jejunum* and *ileum*.

(a) Duodenum. It is the smallest first part following the pyloric end of stomach. It is devoid of a mesentery. It forms the typical U-shaped loop containing the pancreas. A *bile duct* opens into the beginning of its proximal limb, while a *pancreatic duct* opens into the beginning of its distal limb. The location of pancreatic duct is unusual in mammals. The wall of duodenum contains intestinal glands (*crypts* of *Lieberkuhn*) and also characteristic branched *Brunner's glands*.

(b) Jejunum and ileum. Behind the duodenum is jejunum followed by ileum. There is no clear morphological distinction between the two although they can be differentiated histologically. Both are more than 2 metres long, greatly coiled [illegible] *mesenteries*. Their internal lining is raised into innumerable minute finger-like processes, called *villi*, which increase the inner absorptive surface. Elevations of submucosa, villi and intestinal glands are larger in jejunum than in ileum.

The distal end of ileum is expanded to form a small spherical sac, the *sacculus rotundus*. It opens into the caecum through an *ilio-caecal valve*. Digestion is completed and its end products absorbed in the small intestine.

8. Caecum. At the junction of ileum and colon is present a wide, about 50 cm long, thin-walled tube, the *caecum*. It is at once recognisable due to its peculiar external spiral constriction which marks the presence of an internal *spiral valve*. Distally caecum terminates in a small, about 15 cm long, narrow, thick-walled blind tube, the *vermiform appendix*. Cellulose of plant material is broken by bacterial action inside caecum.

9. Large intestine. The large intestine is more than one meter long and consists of two regions : colon and rectum.

(a) Colon. Near the sacculus, ileum is continued into colon, which is wide, about 45 cm long, with regularly sacculated or constricted wall.

(b) Rectum. It is the narrow terminal part about 75 cm long. Faecal pellets present inside give it a beaded appearance.

10. Anus. Rectum opens to the outside through *anus*, situated at the base of the tail. It is guarded by an *anal sphincter*.

Large intestine serves to absorb water from food and helps in the formation and elimination of faecal pellets.

[II] Digestive glands

The glands associated with the digestive system are : *mucous, salivary, gastric, liver, pancreas and intestinal.*

1. Mucous glands. The mucous glands occur throughout the mucous lining of the digestive tract. They are mainly found in the lining of the vestibule. They secrete a viscous slimy secretion, called *mucus*. If contains *mucin* which is a mixture of some proteins. The mucus helps in the moistening, lubrication and swallowing of food in the buccal cavity. It also coats the mucous lining throughout the alimentary canal and protects it from the action of enzymes.

2. Salivary glands. Four pairs of salivary glands open by their ducts separately into buccal cavity. They are named according to their position. *Parotid glands* are situated at the base of external ears or pinnae. Their long ducts, *stenonian duct* leaves the gland from its anterior border and open behind the upper incisors. *Infra-orbital glands*, lie below the orbits. Their ducts open near the upper molars. The largest of all are the *submandibular* or *submaxillary glands*, lying near the angles of mandible is a compact rounded mass of red colour. Their large ducts, called *wharton's duct* leaves from the outer side of the gland and open just behind the lower incisors. *Sublingual glands* are present below the tongue are elongated flattened reddish gland. They open by several short ducts anteriorly below the free part of the tongue.

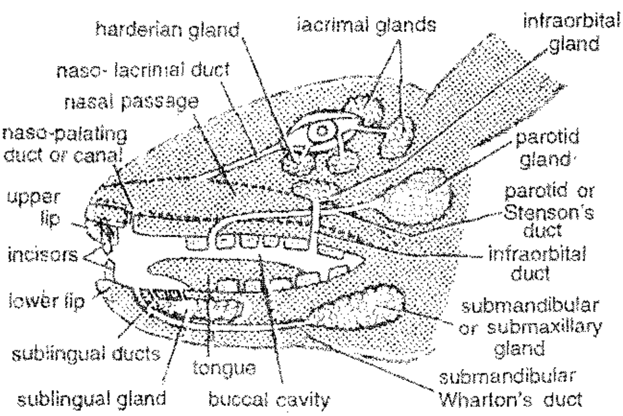

Fig. 18. Rabbit. Position of salivary glands in lateral view of head.

The secretion of salivary glands is an alkaline watery liquid, called *saliva,* which mixes with the food masses in the buccal cavity. Its main function is to provide a lubricant to make swallowing easier. It also contains an enzyme, called *ptyalin,* which converts starch into maltose.

3. Gastric glands. These are found in the mucous membrane of stomach. They are microscopic, innumerable and simple or branched. Their secretion, called *gastric juice*, mixes with the food in the stomach. Besides mucus, it contains a proenzyme called *pepsinogen,* an enzyme called *renins* and *hydrochloric acid.*

4. Liver. It is the largest gland in the body attached to the posterior concavity of diaphragm by a fold of peritoneum called *falciparum ligament.* Liver is partly divided into 5 lobes. Three lobes on the left side are a small *spigelian, left lateral,* and *left central* while two lobes on the right side are *caudate* and *right central* or *cystic.* An elongated dark green, thin-walled, *gall bladder* is embedded in a groove on the posterior face of right central lobe. Liver cells secrete a greenish fluid, the *bile,* which is stored in the gall bladder. A *hepatic duct* arises from each liver lobe. These unite with the *cystic duct* from gall bladder to form a common *bile duct.* It empties into the proximal arm of duodenum near pylorus. Its opening is guarded by a sphincter. The fundamental histological structure and the functions of liver are the same as in all other vertebrates. *Bile* is alkaline and mainly serves to emulsify fats in the duodenum.

5. Pancreas. It is an irregularly branched pinkish gland, held in the mesentery in the U-shaped duodenal loop. Its single duct opens into the distal limb of duodenum. The histological structure of pancreas is fundamentally similar to that in other vertebrates. The cells of pancreatic acini (alveoli) secrete an alkaline *pancreatic juice.* It contains several enzymes, such as *trypsinogen, amylase* and *lipase,* which act on proteins, starches and fats, respectively.

In the connective tissue between acini are present clusters of cells, called *Islets of Langerhans,* which are endocrine glands. They secrete the hormone *insulin*, which plays an important role in the metabolism of carbohydrates.

6. Intestinal glands. Numerous, microscopic, simple and tubular intestinal glands are found in the mucous lining of the small intestine, opening between the bases of the villi. Their secretion called *intestinal juice* (succus entericus) includes several enzymes which act on all types of food.

[III] Food and ingestion

1. Food. Rabbit is a *herbivorous* animal. Its food consists mainly of green leaves, vegetables, grasses, cereals, roots and barks, etc.

2. Gnawing. Its food is cut into smaller pieces by means of its sharp incisor teeth which have a thick layer of enamel on their anterior face only. As the posterior face wears down more rapidly, the incisors acquire a chisel-like form. In gnawing the upper and lower incisors work against one another like chisels. Food pieces are taken into buccal cavity by the movable lips through mouth.

3. Mastication. Inside the buccal cavity, the premolars and molars grind or chew the fragments of food. Their flat surfaces traversed by transverse enamel ridges are well-adapted for mastication.

4. Swallowing. The masticated food is manipulated by the tongue. Mucus and saliva are mixed to moisten and lubricate food which changes into a small ball or *bolus*. It is easily swallowed through oesophagus into stomach. Bolus is pushed down the oesophagus by a wave of muscular contraction of its wall called *peristaltic movement*. During swallowing, the epiglottis closes the glottis and the soft palate pushed upwards to prevent entry of food into larynx and nasal passage, respectively.

[IV] Physiology of digestion

Digestion of food commences in the buccal cavity (saliva) itself, continues in the stomach (gastric juice) and it is completed in the intestine (bile, pancreatic juice and intestinal juice).

1. Action of saliva. In the buccal cavity the food mixes with *saliva* secreted by the salivary glands. It contains the enzyme *ptyalin* which converts starch to maltose and dextrin. The pH of saliva is close to neutrality (approximately 6-7) which is suitable for the action of ptyalin.

2. Action of gastric juice. The food is retained in the stomach for some time. The muscular wall of stomach undergoes contractions. As a result the food is churned, broken into smaller bits (mashed) and thoroughly mixed with the *gastric fluid* secreted by the gastric glands. The gastric juice contains mucus, HCl, and the enzymes *renin*, *pepsin* and *gastric lipase*.

The *hydrochloric acid* (i) kills bacteria of the food, (ii) stops the action of ptyalin which cannot work in an acid medium, (iii) activates the proenzyme pepsinogen into pepsin, (iv) provides an acid medium (optimum pH 1.5) for pepsin to work, and (v) stops contractions of the stomach.

The enzyme *renin* coagulates soluble milk protein *caseinogen* into insoluble *casein*. The enzyme *pepsin* partially breaks down proteins into simpler *peptones*. The function of gastric lipase is not yet clear.

The semidigested food in the stomach is called *chyme*. In the beginning of gastric digestion, the pyloric sphincter (opening into duodenum) remains closed. As the chyme becomes more and more acidic, the pyloric sphincter opens from time to time so that little by little the chyme is forced into duodenum by the peristaltic contractions of the stomach wall.

Once in the duodenum, the chyme mixes with three digestive juices : *bile, pancreatic juice* and *intestinal juce.*

3. Action of bile. The bile, secreted by the liver, has no enzymes, but it performs the following important functions :

(1) The bile contains certain salts, such as *sodium glycholate* and *sodium taurocholate*, which bring about *emulsification* of fat, that is, split larger fat molecules into smaller ones, for more effective digestion.

(2) Bile is alkaline, containing sodium bicarbonate. This neutralizes the acid of the chyme and makes it alkaline (pH_8). This is necessary because the enzymes of pancreatic and intestinal juices can operate only in an alkaline medium.

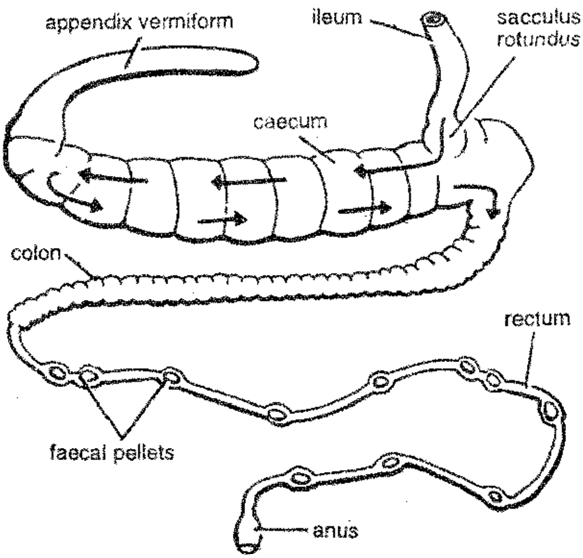

Fig. 19. Rabbit. Large intestine showing passage of food in caecum.

(3) The colour of bile is due to the presence of *bilirubin* and *biliverdin*. These are excretory products derived by the disintegration of haemoglobin of the dead red blood corpuscles.

(4) Bile salts kill bacteria to prevent putrefaction of chyme.

(5) Bile salts help in the absorption of fats and fat soluble vitamins such as A, D, E and K.

4. Action of pancreatic juice. The presence of acid chyme induces the duodenal epithelial wall to secrete the hormone *secretin*. It reaches pancreas through blood stream and stimulates the secretion of the pancreatic juice. It is strongly alkaline (pH 8.8) and, like bile, neutralises acidity of chyme. It contains the following enzymes :

(a) Steapsin. A fat-hydrolysing lipase, which converts fats to fatty acids and glycerol.

(b) Amylase. A diastatic enzyme which converts starch to maltose.

(c) Trypnisogen. A proenzyme activated by intestinal enterokinase into the proteolytic *trypsin* which converts peptones into amino-acids.

5. Action of intestinal juice. The intestinal juice, or *succus entericus*, secreted by intestinal glands, is also alkaline. It contains several enzymes such as :

(a) Enterokinase which activates trypsinogen into trypsin.

(b) Erepsin which converts peptones to amino-acids.

(c) Maltase which changes maltose to glucose.

(d) Invertase which changes cane sugar (sucrose) to glucose and fructose.

(e) Lactase which changes milk sugar (lactose) to glucose and galactose.

6. Digestion of cellulose. A large part of food of rabbit consists of cellulose. Digestion of cellulose occurs in the caecum which is specially well-developed in rabbit and all herbivorous mammals. It is inhabited by a vast number of symbiotic bacteria and Protozoa. These break up cellulose into soluble sugars and, in return, get nitrogenous food from rabbit. These bacteria furnish an example of symbiotic relationship between plant and animal.

As a result of intestinal digestion, the *chyme* is converted into an alkaline watery emulsion, the *chyle*, much of which is absorbed into the lymphatic system through lacteals.

[V] Absorption of products of digestion

The end, products of digestion are amino-acids, fatty acids, glycerol and simple hexose sugars. Their absorption occurs mainly in the ileum. The passage of digested food from ileum into the blood and lymph by diffusion is termed *absorption*. The efficiency of the process is increased because of three factors. Firstly, the food (chyle) passes slowly through the ileum. Secondly, the wall of ileum is folded internally into ridges which bear innumerable finger-like villi, which greatly increases the surface area for absorption. Thirdly, the wall of ileum rhythmically contracts to ensure that the liquid food which is in contact with the villi is constantly changing.

Each *villus*, contains a network of blood capillaries just below its surface. Hexose sugars, amino-acids, water, minerals and vitamins are absorbed from the gut into the capillaries of villi and taken to liver by the hepatic portal vein. A lymph vessel called *lacteal* is also present within each villus. Glycerol and fatty acids pass from the

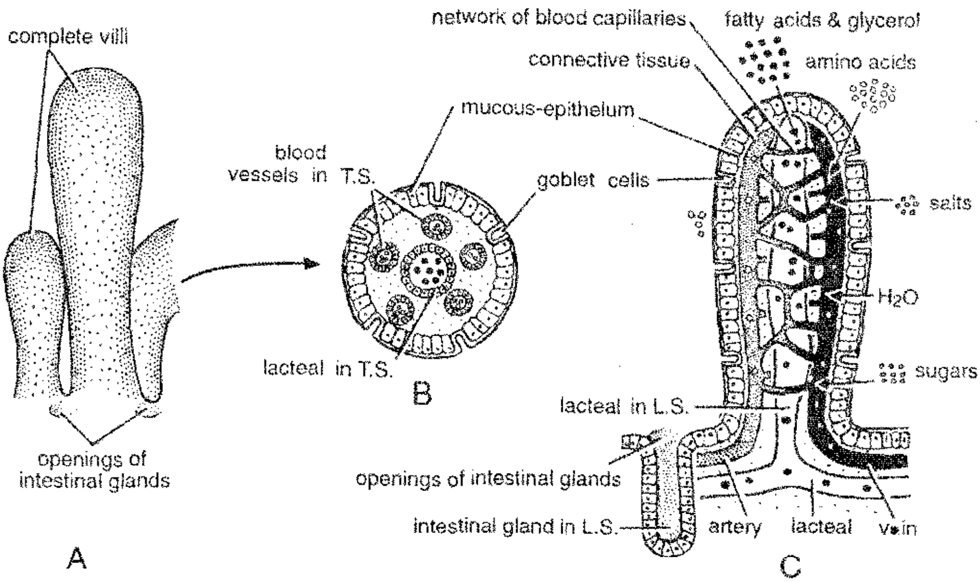

Fig. 20. Rabbit. Absorption of food through villi. A—Entire villi. B—A villus in T.S. C—A villus in L.S.

gut into the lacteal and carried into the blood system via the lymphatic system.

[VI] Egestion or defaecation

After absorption in the ileum, the residual food reaches into the large int-stin-. In includ-s wat-r anu solid indigestible remains of food such as vegetable fibres and cellulose for the digestion of which there are no appr priate enzymes. Muc' of the water is absorbed in the colon, leaving the solid material as faeces. In the *rectum*, the faeces form small dehydrated *pellets* which are peri dically eliminated through the anus. This is known as *egestion* or *defaecation*.

Coprophagy. As mentioned earlier in this chapter, rabbit is *coprophagus* in habit, eating its own faeces, in order to get maximum amount of nutriment form its food. Faeces produced during night alone are eaten up which are soft and moist due to incompletely digested cellulose. Thus passing through the gut once more, the faeces are subjected once again to digestion and absorption. Faeces produced during day are dry and hard and not at all eaten.

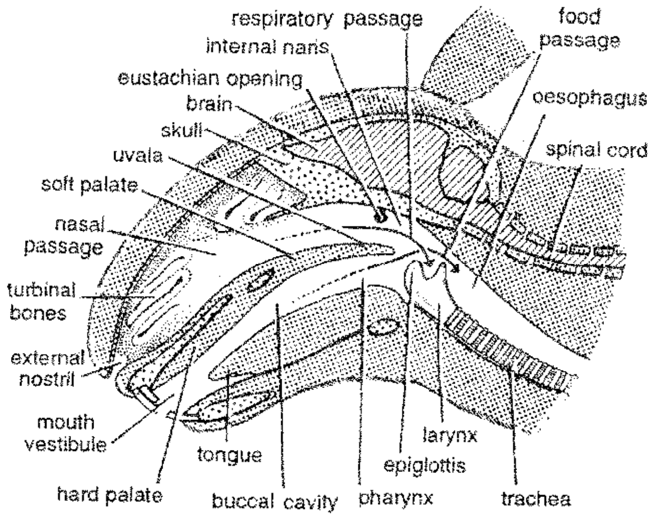

Fig. 21. Rabbit. Head in diagramatic V.L.S. showing respiratory tract.

[VII] Regulation of digestive function

Extreme anterior and extreme posterior ends of the digestive tract are provided by striated muscles and are thus under the voluntary control of the animal. The smooth muscle cells of the digestive tract show a great deal of contractility to facilitate mixing, churning and moving the contents forward. The overall patterns of movement are integrated by nerve plexuses which are present in t' e wall of the digestive tract and by their connections to the central nervous system. Autonomic nerves play great role in regulating the motility of the digestive tract. The stomach wall shows relaxation when food approaches it from the oesophagus. When the anterior region of the intestine is empty the stomach contracts to eject the contents into the small intestine. Besides neural control, the chemical control also helps in re_ulation of the digestive activity. The food materials may after partial digestion stimulate gland secretion. Cells of the wall of the stomach small intestine _n_ other gastrointestinal regions form endocrine secretions (secretin, enterogastrone, cholecytokinin). These hormones reach through the blood to the muscle and gland cells of the stomach, small intestine, liver, gall bladder and pancreas and produce the response of these structures as per the requirement. H[illegible] secretion pr[illegible] by th[illegible] d[illegible]l mucosa is absorbed by the blood when acidic materials enter the duodenum from the stomach. Secretion then travels through the blood to the pancreas and liver and stimulates them for secretion. When fatty materials enter the duodenum from the stomach their inhibiting hormone enterogasterone is released from the intestinal mucosa and acts on the stomach to inhibit gastric secretion.

Respiratory System

Rabbit is a terrestrial animal having pulmonary respiration, that is, breathing air by lungs only. As in all vertebrates, the respiratory system of rabbit can be described in two parts : (i) Air conducting system or *respiratory tract,* and (ii) essential system or *respiratory organs* (lungs).

[I] Respiratory tract

The respiratory tract serves as the passage for the entry of fresh air into the respiratory organs (lungs) and the exit of foul air after gaseous exchange. It includes the following parts :

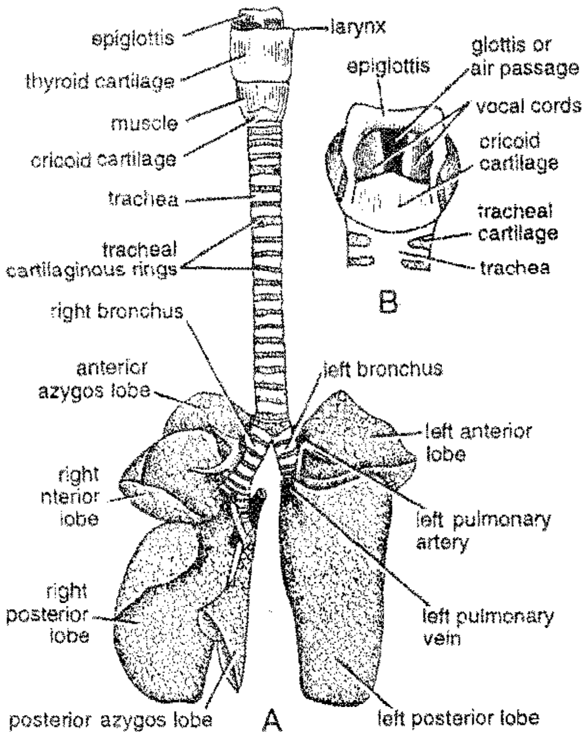

Fig. 22. Rabbit. A—Respiratory system in ventral view. B—Vocal cords in dorsal view of larynx.

1. External nares. The air is drawn through the two external nares, opening near the fleshy tip of the snout.

2. Nasal chambers. From external nares, the air travels through the olfactory or nasal chambers. The two nasal chambers are separated from each other by a median, vertical, bony nasal septum, and from the buccal cavity by the hard palate. The internal surface of each nasal chamber is greatly increased by thin, scroll-like *turbinal* bones. The chambers are lined with vascular mucous epithelium and serve as olfactory organs (smell). The chemical substances, present in the air passing through them, dissolve in the film of moisture (mucus) covering the olfactory organs and stimulate them.

Besides, the nasal chambers also help in respiration by acting as an air conditioner. The air passing through them becomes moist and warm. It is freed of its large particles by hairs acting as a sieve.

3. Internal nares and nasopharynx. Posteriorly, the two nasal chambers open through *internal nares* into the *nasopharynx* present dorsally above the soft palate. The nasopharynx communicates behind with the laryngopharynx.

4. Glottis. On the floor of laryngopharynx lies a median, vertical slit-like aperture of larynx, the *glottis*. It is covered during the swallowing of food by a special cartilaginous bilobed flap of skin, the *epiglottis*.

5. Larynx. The larynx is a small, semi-rigid expanded chamber at the top or upper end of wind pipe or trachea. Its wall is supported by four cartilages : *thyroid, cricoid* and a pair of *arytenoid*. The *thyroid* is a large, shield-shaped or girdle-like cartilage, which supports the larynx ventrally and laterally. Immediately posterior to thyroid is the signet ring-like *cricoid* cartilage. It is broad on the dorsal side but narrow ventrally. The paired, small and curved *arytenoid* cartilages are present on the dorsal side of larynx. A small nodule-like *cartilage of Santorini* is attached to the anterior tip of each arytenoid cartilage. The externally visible 'Adam's apple' in the human neck is formed by the protrusion of larynx.

Larynx and sound-production. The larynx is not only a part of the respiratory passage, but it also serves as the *voice box* or the organ of *sound production*. A pair of membranous folds, the *vocal cards,* extend dorso-ventrally in the laryngeal cavity from arytenoid to thyroid cartilage. These arise from the lateral wall of the larynx and consist of elastic connective tissue, covered by mucous membrane. The glottis of mammals is the opening between the inner free edges of the vocal cords. In normal or resting condition, the vocal cords lie apart at an acute angle, so that the glottis remains widely open to allow free passage of respiratory air. For sound production, the cords lie close together, so that they vibrate when the air rushes out through the narrowed, slit-like glottis under pressure from the lungs. This results in *phonation* or *production* of *sound*. Changes in the tension of vocal cords brought about by the action of intrinsic laryngeal muscles, are responsible for the pitch and quality of sound produced. Rabbits, however, mostly keep quiet and make little or no sound. The meaningful sound or *speech* in human beings is made by the combined action of vocal cords, tongue, pharynx, mouth and lips.

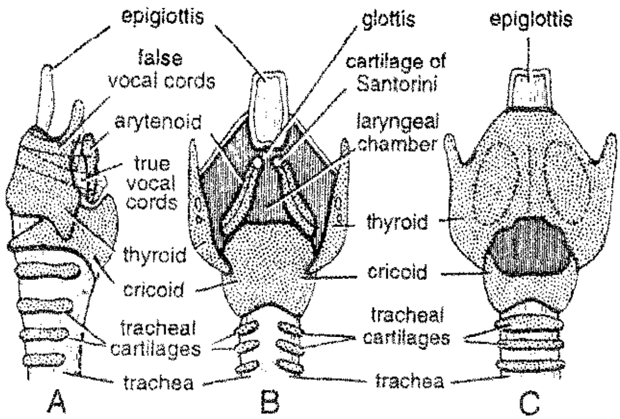

Fig. 23. Rabbit. Different views of larynx. A—Lateral. B—Dorsal. C—Ventral.

Sometimes, a pair of more delicate *false vocal cords* may be located anterior to the normal or *true vocal cords.* For example, the purring sound in cats is due to vibration of the false cords. True vocal cords may also be absent in a few mammals such as the hippopotamus.

6. Trachea. From larynx extends posteriorly a long tubular *wind pipe* or *trachea.* It runs down the neck, beneath the oesophagus. Within the thoracic cavity, dorsal to the heart, the base or lower end of trachea bifurcates into two *primary bronchi* or right and left *bronchial tubes*. Each bronchus enters the lung of its side.

The trachea and the two primary bronchi are supported by numerous C-shaped *cartilaginous rings,* incomplete dorsally and united by smooth muscles. These cartilaginous rings provide flexibility and keep the passages open by preventing their collapse, so that air can move freely back and forth. The trachea, bronchi and bronchioles are internally lined with ciliated mucous epithelium. The mucus keeps the surface moist and slimy and also holds bacteria and dust particles, which are swept up towards pharynx by cilia.

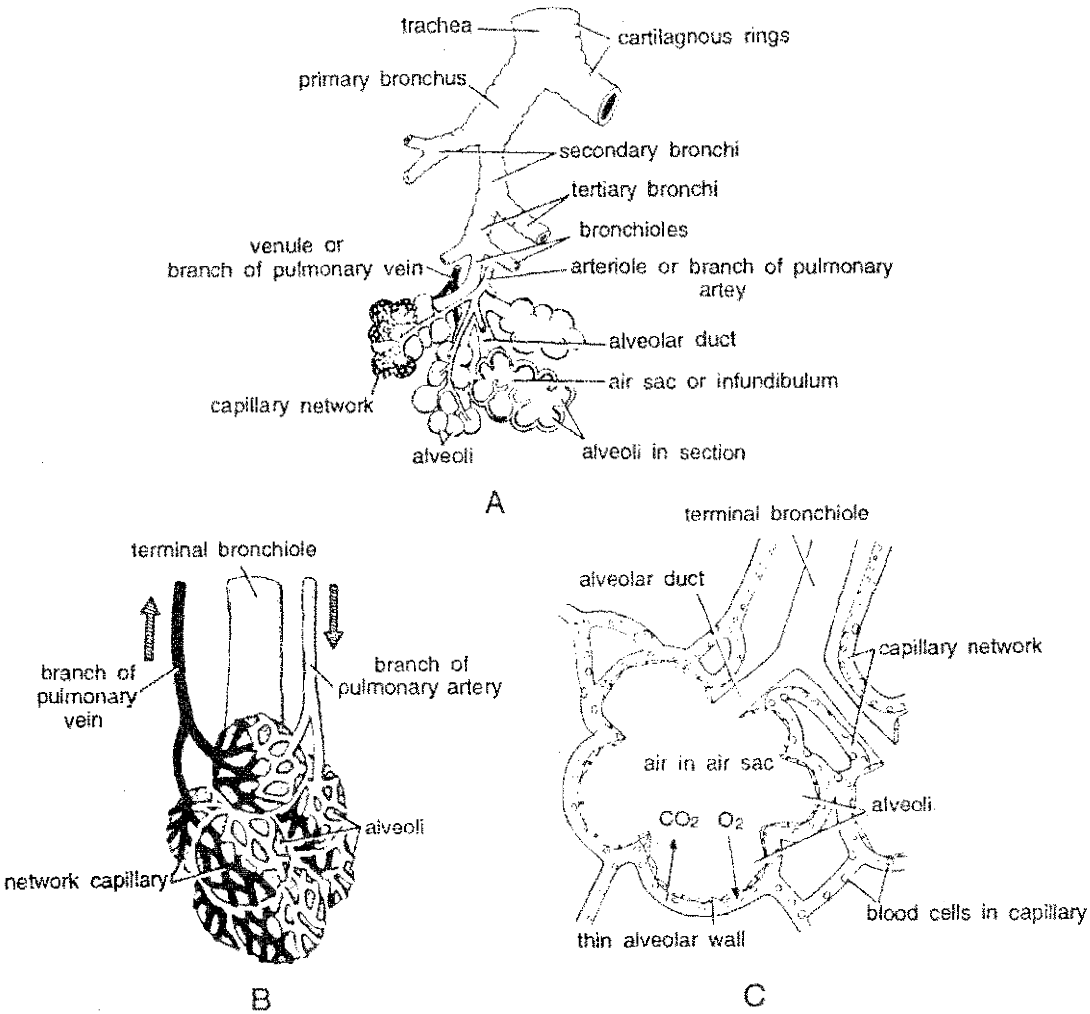

Fig. 24. Functional structure of a mammalian lung (diagrammatic). A—Branching of a bronchus upto alveoli. B—Alveoli magnified showing blood supply. C—Section through alveoli to show gaseous exchange between lung and blood capillaries.

[II] Respiratory organs (lungs)

1. Position. The essential organs of respiration are a pair of *lungs,* placed one an either side of heart in the thoracic cavity. Each lung is enclosed in a lateral, airtight compartment of thoracic cavity, called *pleural cavity.* The lung lies freely suspended within its pleural cavity, attached only by its root through which a bronchus, a pulmonary artery, a pulmonary vein and nerves enter the lung. The pleural cavity is lined by peritoneum and contains a watery lubricating *pleural fluid.*

2. Structure. The lungs are pink-coloured, soft, spongy, elastic and highly vascular organs. The right lung consists of 4 lobes, namely the *anterior azygos, right anterior, right posterior* and *posterior azygos*. The left lung consists of 2 lobes only, the *left anterior* and *left posterior.*

After entering a lung, the *primary bronchus* divides repeatedly into smaller *secondary* and *tertiary bronchi.* Terminal branches are called *bronchioles* which lack the cartilaginous rings. Each terminal bronchiole divides into still finer branches, the *alveolar ducts,* each terminating into several branching delicate blind *air sacs* or *infundibula.* The wall of each air sac is evaginated to form tiny, pocket-like sacculations, or *alveoli,* which a ear like a cluster of miniature grapes. Each alveolar sac contains 6-8 alveoli. The walls of alveoli are extremely thin, made of elastic connective tissue fibres and surrounded by a fine network of capillaries from pulmonary vein and artery. It is these millions of alveoli that provide the great surface area for gaseous exchange. It occurs by diffusion between the air in the alveoli and the blood passing through the capillaries.

[III] Mechanism of respiration

Mechanism of respiration concerns breathing movements, which bring about the ventilation of the lungs. The breathing mechanism of rabbit is typically mammalian. The diaphragm and the ribs play a primary role in respiration in mammals. The whole process can be divided in two stages : *inspiration* and *expiration.*

1. Inspiration. The lungs are in direct contact with the atmosphere through the respiratory tract. Inspiration or breathing in is an active process during which fresh atmospheric air containing oxygen is taken into the lungs. Flattening (lowering) of *diaphragm* due to contraction of its radially arranged muscles increases the length of the thoracic cavity. At the same time, the contraction of the obliquely arranged *external intercostal muscles* causes the rib cage to more forward and outward, thus increasing the diameter of the thoracic cavity. This increase in volume lowers the pressure within the thoracic cavity causing the lungs to expand and drawing air into them through the respiratory tract, due to atmospheric pressure. Air rushes into the lungs till the pressure of air inside them becomes equal to that of the air outside.

The inspired air ultimately reaches the lung alveoli, where exchange of gases takes place. O_2 of air diffuses into blood and CO_2 of blood diffuses out into air through the extremely thin (1μm thick) alveolar wall. Diffusion of both the gases occurs simultaneously.

2. Expiration. Expiration or breathing out is a passive process. It involves relaxation of muscles of the diaphragm which regains its normal dome-shaped position. The external intercostal

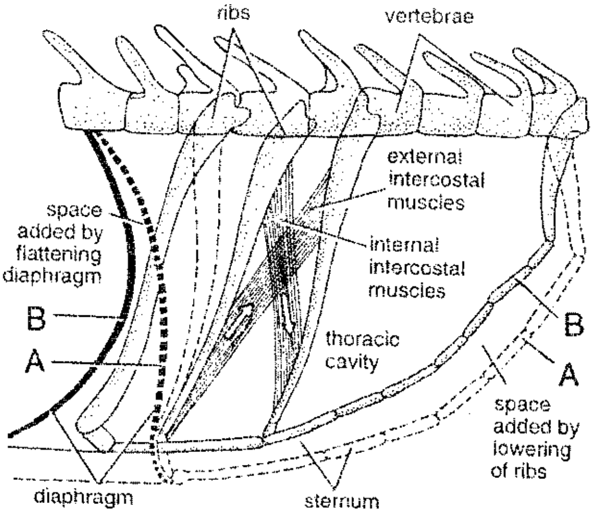

Fig. 25. Rabbit. Mechanism of breathing showing positions of diaphragm, ribs and sternum. A—During inspiration. (dotted lines). B—During normal position or expiration (solid lines).

muscles also relax. At the same time, the *internal intercostal muscles,* arranged at right angles to external muscles, contract lowering the rib cage which is returned to its normal position. Decrease in the volume of thoracic cavity puts pressure upon the lungs, the elastic walls of which shrink and passively expel the air out through the respiratory tract.

The lungs never become completely empty after each expiration. They always retain some stale *residual air* which mixes with the fresh air after every inspiration. As a result, the alveolar air in a mammal always has a lower O_2 content and a higher CO_2 content than in the atmospheric air. Therefore, it is obvious that a mammalian lung, having respiratory surfaces in the form of blind air sacs (alveoli), is less efficient than that of a bird.

Circulatory System

The body needs a transport or circulatory system for distributing digested food, water, oxygen, numerous secretions and waste products throughout the body. The chordates have a completely *closed* circulatory system. It includes (i) the *blood vascular system,* and (ii) the *lymphatic system.* The *blood* vascular system consists of closed tubes or

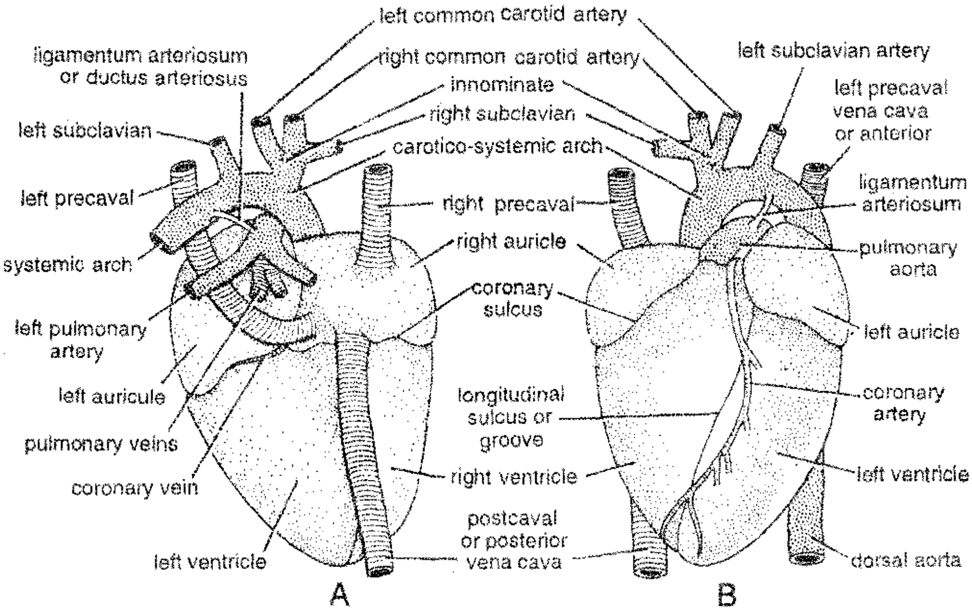

Fig. 26. Rabbit. External features of heart. A—Dorsal view. B—Ventral view.

blood *vessels* (arteries, veins and capillaries), inside which a transporting fluid, the *blood,* is kept in circulation by a definite pumping organ, the *heart.* Thus, the blood vascular system of rabbit is composed of : (i) the heart, (ii) *arterial system,* (iii) *venous system* and (iv) *blood.*

[I] Heart

The heart of rabbit lies mid-ventrally between the two lungs inside the median space of the thoracic cavity, called *mediastinum.*

1. External features. The heart is a small, pear-shaped, muscular and hollow, four-chambered organ of reddish colour. It is placed somewhat obliquely. Its broad base is directed anteriorly towards right and the pointed apex posteriorly towards left.

(a) Pericardium. The heart is completely enclosed by a transparent thin-walled and two-layered sac, the *pericardium* which is connected to the ventral thoracic wall and the posterior diaphragm to keep the heart in position. The two layers of pericardial sac, inner visceral and outer parietal, enclose a narrow space, the *pericardial cavity,* filled with a watery *pericardial fluid,* which allows free movements of the heart and also protects it from external shocks and mechanical injuries.

(b) External division. The heart is exposed on the removal of pericardium. A distinct transverse groove divides the heart into an anterior smaller and dark red *auricular part* and a posterior larger and paler *ventricular part.* This is known as the *auriculoventricular groove* or *coronary sulcus.*

(c) Auricles. The auricular part is divided into *right* and *left auricles* of which the left one is smaller than the right. The mammalian heart has *no sinus venosus* which is incorporated into the right auricle. Each auricle is produced behind into a swollen flap, the *auricular appendix,* which slightly covers the ventricle of its side.

(d) Ventricles. The ventricular part is also divided into *right* and *left ventricles* by a shallow *longitudinal interventricular groove.* It runs behind from the base of the heart somewhat obliquely towards right, without reaching the apex. Consequently, the right ventricle remains smaller whereas the left ventricle becomes larger and forms the rounded apex of the heart.

The mammalian heart has no *conus (truncus) arteriosus,* which is merged with the ventricles. The primitive *ventral aorta* has also been split in

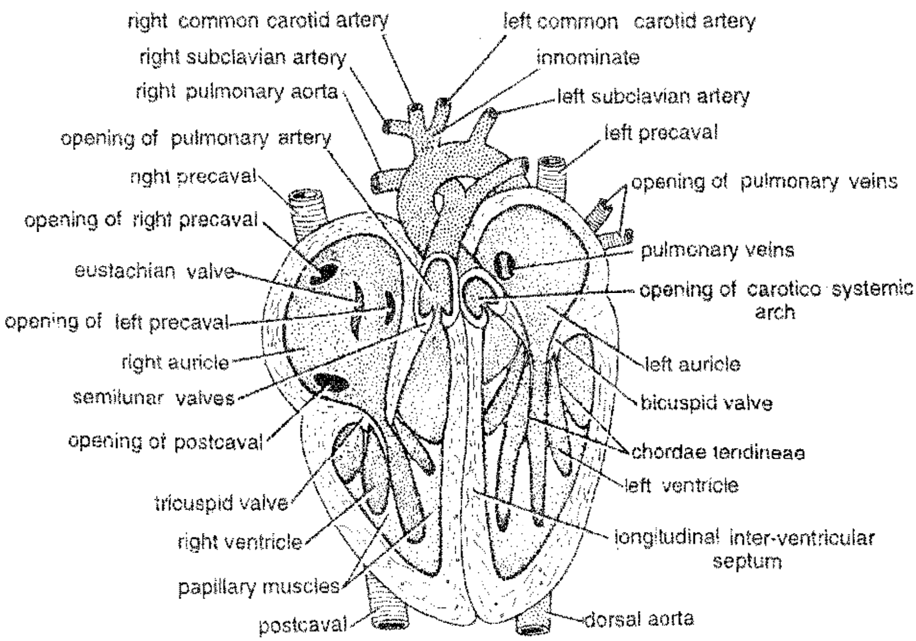

Fig. 27. Rabbit. Internal structure of heart in ventral dissection.

such a way that the pulmonary artery leads from the right ventricle while the remainder part or *carotico-systemic* aorta connects with the left ventricle.

2. Internal structure. The main internal features of the heart can be seen in its longitudinal dissection, or removal of its ventral side wall. Internally, the heart is completely four-chambered divided into two anterior auricles and two posterior ventricles.

(a) Auricles. The two *auricles* or *atria* are thin-walled chambers, completely separated from each other by a thin, muscular and vertical partition, the *inter-auricular septum*. In the embryo, this septum bears an opening, called *foramen ovale,* through which both the auricles communicate with each other. But in the adult, this aperture is closed and represented by a small oval depression, the *fossa ovalis*. The inner lining of auricular wall forms a network of low muscular ridges, the *musculi pectinati*. The left auricle has thicker walls and is rather smaller than the right auricle.

The right auricle receives venous blood from different parts of the body through two precaval and one postcaval veins, having separate openings. The opening of postcaval is guarded by a rudimentary membranous fold, the *eustachian valve*. Near it lies the remnant of embryonic sinus venosus, called *sinuauricular node*.

The left auricle receives a single common *pulmonary opening* of the pulmonary veins returning oxygenated blood from the lungs. It has no valve.

Each auricle opens behind into the ventricle of its side through an *auriculo-ventricular aperture*. Each aperture is guarded by a valve made of a sheet of tough connective tissue. The *right auriculo-ventricular valve* consists of three triangular flaps or cusps and is known as the *tricuspid valve*. The left *auriculo-ventricular valve* consists of two flaps and is termed *bicuspid* or *mitral valve* because of its supposed resemblance to the miter (hat) worn by the bishops. Flaps of these valves are connected to *columnae cornea*, situated on the internal walls of ventricle with the help of *chordae tendinae*. These valves allow the flow of blood from auricle to ventricle only.

(b) Ventricles. Unlike auricles, the two ventricles are very muscular and thick-walled chambers. They are also separated completely by a thick, oblique and vertical *inter-ventricular septum.* The left ventricle is larger with thicker walls and almost circular in a transverse section. It also forms the posterior apex of the heart. The right ventricle is smaller and crescentic in a transverse section. From the inner surface of the ventricular wall project low, irregular, muscular ridges, called the *columnae carneae.* Besides, there are few large conical or nipple-shaped elevations called *papillary muscles.* The flaps of the two auriculo-ventricular valves hang freely into the ventricular cavities. The free edges of the flaps are attached to papillary muscles by long, tough, white connective tissue strands, called *chordae tendineae.* When the ventricles contract, these chords prevent the flaps of these valves from being inverted into the auricular cavities.

Two large arteries arise anteriorly from the ventricles, the *pulmonary arch* or *aorta* from the right ventricle and the *systemic arch* or *aorta* from the left ventricle. The point where two arches cross each other, communicate with one another through *ligamentum arteriosum.* Each arch or aorta has at its base three pocket-shaped or cup-like *semilunar valves,* to prevent the backflow of blood from the arch into the ventricle.

3. Working of heart and course of blood circulation. To understand the action of heart in mammals, and the course of circulation of blood, it is essential to know some of the following facts :

(a) Heart is a force pump. The blood is kept in circulation through the blood vessels because the heart works like a force pump and beats throughout life. During every beat or heart cycle, the auricles and the ventricles contract and relax in succession. Contraction of the heart chambers is known as *systole,* while their relaxation is called *diastole.* Thus one complete systole and diastole of the heart makes one heart beat or cardiac cycle.

(b) Control of heart beat. Striated and smooth muscles contract only when they are stimulated by nerves or hormones. But the *cardiac muscle,* forming the heart has an intrinsic nature for beating rhythmically. If the nerve supply of the vertebrate heart is cut off or even if it is removed from the body and placed in a proper nutrient solution, it continues to beat for hours. This clearly demonstrates that the cardiac muscle forming the heart has an inherent capacity for beating.

The wave of contraction in the heart is initiated by a specialized bundle of cardiac tissue present in the wall of the right auricle. It represents the remnants of sinus venosus of the lower vertebrates and is called the *sinu-auricular node* **(SA node).** This node beats at the fastest rate and is also called the *pacemaker.* If it is removed,

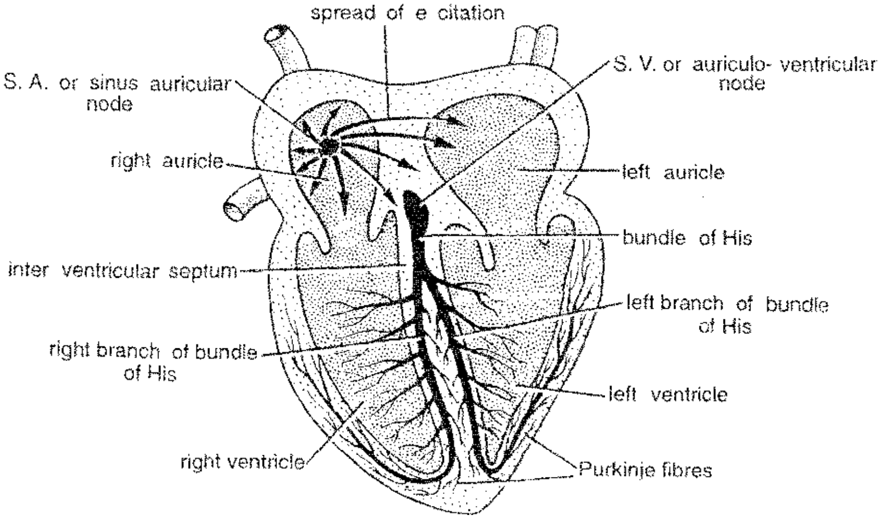

Fig. 28. Rabbit. Conduction of heart beat. Nervous control.

the heart will beat at a slower rate. When this pacemaker or SA node initiates an impulse, a wave of contraction, in the form of concentric rings, spreads over both the auricles which simultaneously contract (auricular systole).

The wave of auricular contraction cannot pass over the ventricles directly as their muscles are not continuous. The impulse travels from auricles to ventricles over a bridge called the *auriculo-ventricular node* (**AV node**). It is another strand of specialized cardiac muscle into the wall between the two ventricles. From AV node arises the *bundle of His* which bifurcates in the interventricular septum into *auriculo-ventricular bundles* (**AV bundles**) whose fibres *(Purkinje fibres)* ramify through much of the ventricular wall. The AV node imposes some delay in the transmission of the impulse so that the contraction of the ventricles (ventricular systole) follows some time after the auricular systole.

(c) Double circulation. The completely four-chambered mammalian heart actually comprises two separate pumps working in union. The right side of the heart serves as one pump. It contains only venous blood, received from the body and sent to the lungs through *pulmonary circulation*. The left side of the heart serves as the second pump. It contains only oxygenated blood received from the lungs and sent to the body through *systemic circulation*. Thus, there is no mixing of venous and oxygenated bloods in the heart, and the blood passes through the heart twice, once along the pulmonary circuit and second time in the systemic circuit. This is known as the *double circulation* of blood. This is characteristic of mammals and birds.

(d) Course of blood circulation. As already mentioned, the venous blood from the general body circulation is returned to the right auricle through the caval veins. At the same time the oxygenated blood from the lungs enters the left auricle through pulmonary veins. Simultaneously, the two auricles contract *(auricular systole)*, forcing their bloods into the corresponding ventricles through their auriculo-ventricular apertures. Venous blood from right auricle passes through tricuspid valve into right ventricle, while oxygenated blood from left auricle goes through bicuspid valve into left ventricle.

As the emptied auricles relax *(auricular diastole)*, the two ventricles contract with sufficient force *(ventricular systole)*. The great pressure closes the valves between ventricles and auricles preventing backward flow of blood into the auricles. At the same time the semilunar valves at the bases of aortic arches open. Thus the venous blood of right ventricle is forced into the pulmonary aorta and carried to the lungs for aeration. The oxygenated blood of left ventricle is pumped into the systemic aorta and distributed throughout the body. When the ventricles relax *(ventricular diastole)* the pressure of blood inside the aortae causes closure of the semilunar valves.

[II] Arterial system

The arteries supply oxygenated blood (exception pulmonary arteries) from heart to different parts of body. In mammals (rabbit) two large trunks or aortic arches arise directly from the heart : (i) *Pulmonary aorta*, and (ii) *left systemic aorta*.

1. Pulmonary aorta. Its origin is visible only in the ventral view of the heart. It originates anteriorly from the right ventricle and immediately curves dorso-posteriorly, dividing into *right* and *left pulmonary arteries* each carrying venous blood to the lung of its side. Near its bifurcation, the pulmonary aorta is connected to the systemic aorta by a cord of connective tissue, called *ligamentum arteriosum*, which represents the remnant of the embryonic *ductus arteriosus*.

2. Left systemic aorta. In mammals (rabbit), only the single left systemic or *carotico-systemic aorta* originates anteriorly from the left ventricle. It is the main vessel which distributes oxygenated blood through its branches to different parts of the body. While still within the pericardium, it gives off two small right and left *coronary arteries* to the wall of heart. The aorta now curves to the left, passing ventral to the trachea, and gives off

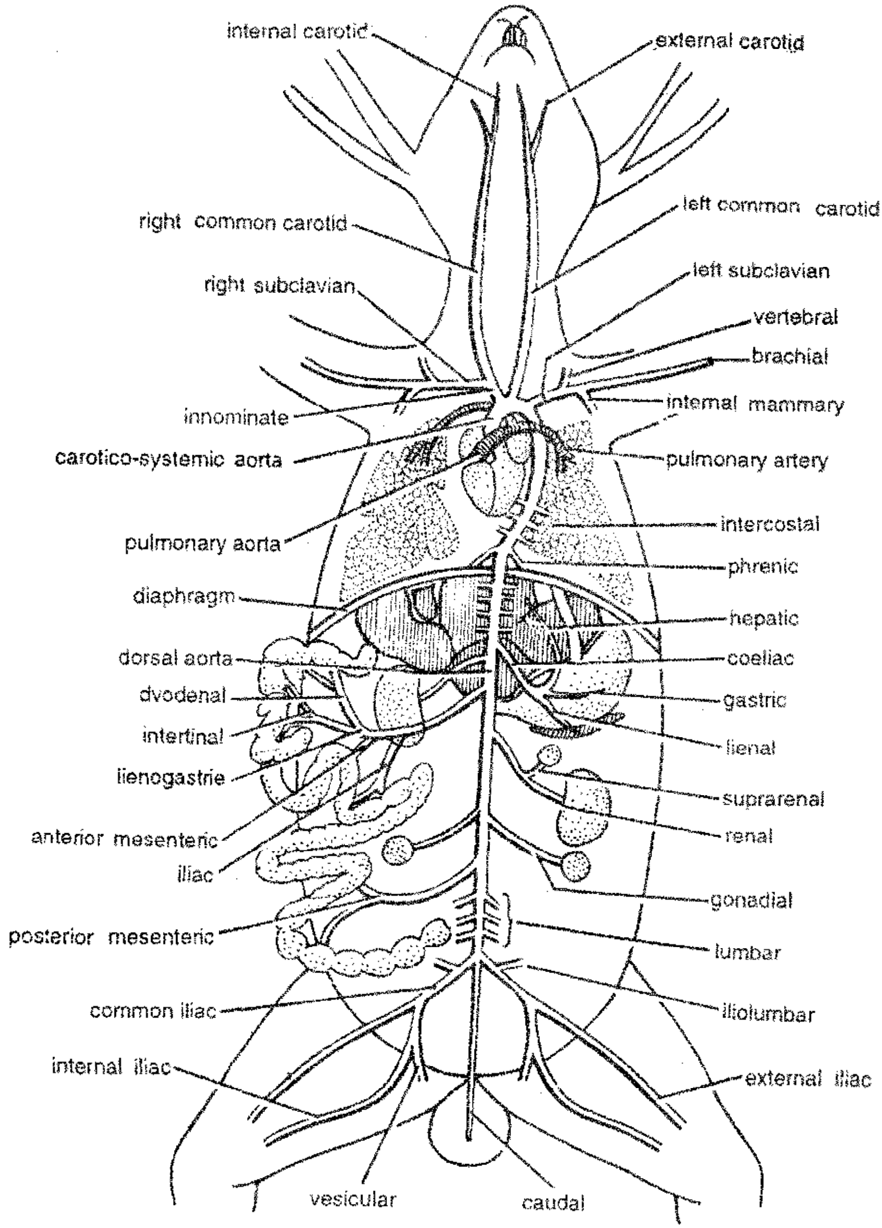

Fig. 29. Rabbit. Arterial system.

anteriorly two large arteries : *innominate* and *left subclavian*.

(a) Innominate artery. It is a short but stout artery which at once divides into three : *right subclavian* and *right* and *left common carotids*.

(i) Right subclavian. It runs outwards and gives off 3 main branches : *vertebral* to vertebral column, brain and spinal cord; *internal mammary* to ventral thoracic wall; and *brachial* to right forelimb.

(ii) Common carotids. The long right and left common carotids run anteriorly through neck almost parallel with the trachea. Near the angle of jaws each divides into an *external carotid* to

external parts of head, and an *internal carotid* to brain and deeper parts of head. Sometimes, left common carotid artery may arise directly from the aortic arch instead of innominate.

(b) Left subclavian artery. It originates independently from aortic arch. Its course and branches are similar to those of right subclavian artery.

3. Dorsal aorta. The left systemic aorta now loops round the left bronchus to become dorsal to the heart and runs straight backwards, middorsally beneath the vertebral column. It is now called the *dorsal aorta.* It pierces the diaphragm to enter the abdomen and extends up to the tip of the tail. On its way it distributes the following main branches in the sequence as given below :

(a) Intercostal arteries. Several pairs (5-7 pairs) of small arteries to the intercostal muscles of the ribs.

(b) Phrenic arteries. A pair of small arteries to the muscles of diaphragm.

(c) Coeliac artery. Large unpaired artery dividing into 3 branches : *left gastric* to stomach, *lienal* to spleen and *hepatic* to liver.

(d) Anterior mesenteric artery. Unpaired and largest, distributing blood to pancreas, duodenum, jejunum, ileum, caecum and colon.

(e) Renal arteries. Paired, one to each kidney. The right renal artery may arise from dorsal aorta even before the anterior mesenteric. Each renal sends a *suprarenal* branch to the suprarenal gland.

(f) Gonadial arteries. Paired arteries to the gonads, called *spermatic* in the male and *ovarian* in the female. The gonadial originates slightly anterior to the left one.

(g) Posterior mesenteric artery. A single median ventral artery supplying blood to colon and rectum. In some individuals, it may originate from dorsal aorta even before the gonadials.

(h) Lumbar arteries. A series of small arteries to lateral abdominal walls.

(i) Common iliac arteries. In the pelvic region, the dorsal aorta bifurcates into two *common iliacs,* each going into the hind limb of its side. Each common iliac branches into an *iliolumbar* to the dorsal abdominal wall, an *internal iliac* or *hypogastric* to dorsal pelvic region, a small *vesicular* to urinary bladder, ureter, seminal vesicle (male) or uterus (female), an *epigastric* to pubic region, and an *external iliac* or *femoral* to outer region of leg.

(j) Caudal artery. It is the thin, median and posterior continuation of dorsal aorta into tail. The *caudal* or *sacral artery* may originate mid dorsally, a little in front of the bifurcation of dorsal aorta.

[III] Venous system

Deoxygenated blood from various parts of the body is returned to the heart through veins. The venous system of a mammal (rabbit) consists of 4 groups of veins : (i) *pulmonary,* (ii) *coronary,* (iii) *caval veins,* and (iv) *hepatic portal system.*

1. Pulmonary veins. Pulmonary veins collect oxygenated blood from different lobes of the two lungs. They join together forming a common pulmonary vein which opens dorsally into the left auricle by a common aperture.

2. Coronary veins. These collect venous blood from the walls of different parts of the heart and open into the right auricle.

3. Caval veins. The venous blood from different parts of the body, except the lungs, is collected by three large caval veins. These are the right and left anterior venae cavae or *precavals* and the single posterior vena cava or *postcaval.* They open into the right auricle by separate openings.

(a) Precavals. The right and left precavals return venous blood from the anterior parts of body including head, neck, shoulders, forelimbs and thoracic wall. Each precaval is formed by the union of the following major branches :

(i) External jugular vein. It is the chief vein of the neck running below the skin. It drains blood of the head, neck and shoulder region through *anterior* and *posterior facial, deep external jugular* and *cephalic veins.* The right and left external jugular veins are connected by a *transverse anastomosis.*

(ii) Internal jugular vein. It is a slender vein collecting blood of the brain and occipital region of skull.

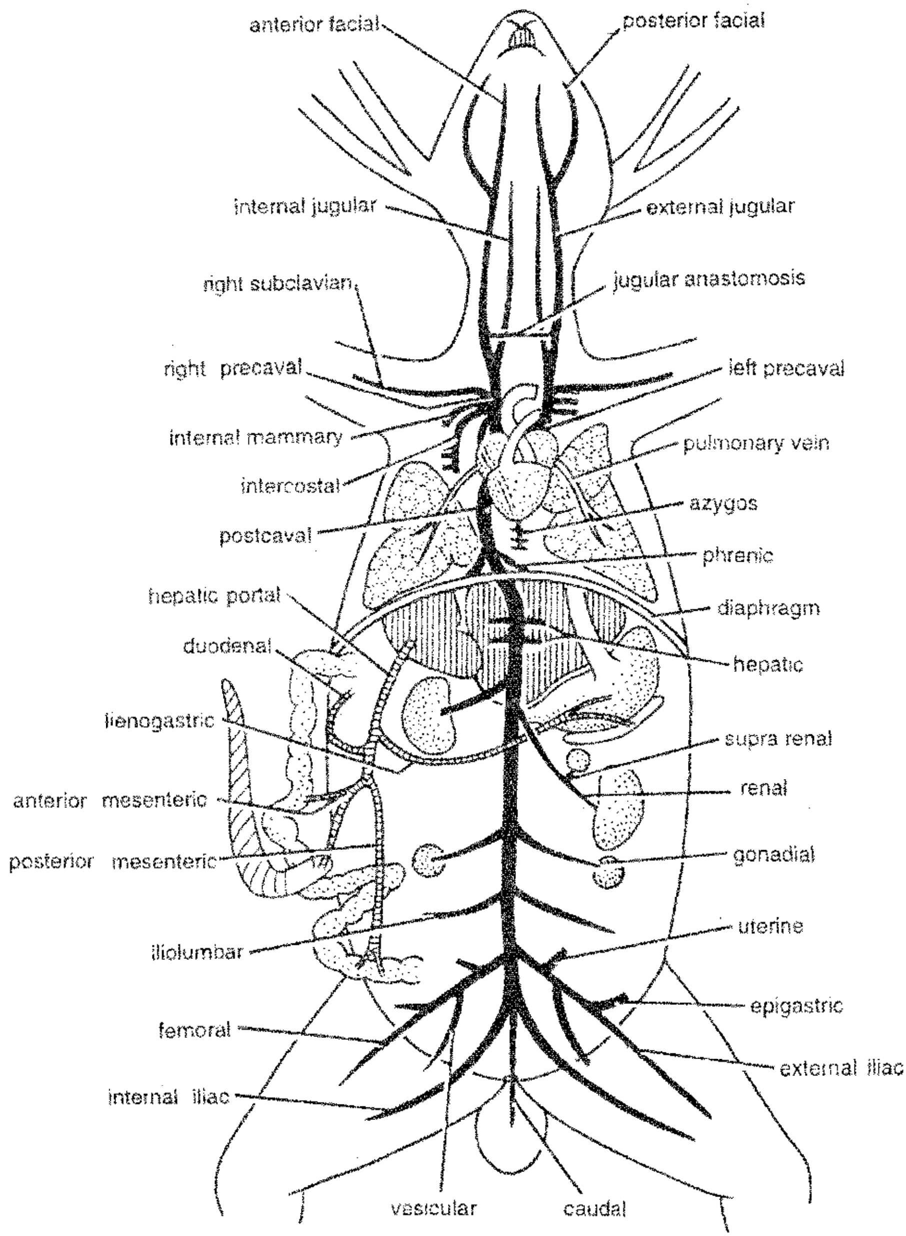

Fig. 30. Rabbit. Venous system.

(iii) Subclavian vein. It is a prominent vein returning blood from the forelimb and shoulder region.

(iv) Internal mammary vein. It collects blood from mammary glands to join the precaval.

(v) Anterior intercostal vein. It drains blood from the region of anterior ribs (5 to 6) to open into the precaval.

(vi) Azygos vein. It collects blood from between the posterior 8 or 9 ribs on both sides to

opens into the right precaval. 'Azygos' means not paired. However, on the left side, a few small veins unite to form a *hemiazygos vein.* It is connected with the azygos through a transverse anastomosis.

(b) Postcaval. The posterior vena cava or postcaval is a large median vein. It collects venous blood from the posterior half of the body, below the diaphragm. During its course, it receives several veins which run along with the corresponding arteries.

(i) Caudal vein. It is a slender vein collecting blood from tail. It marks the beginning of postcaval.

(ii) Internal iliac veins. A pair of small veins draining blood from the inner portions of the thighs.

(iii) External iliac veins. These are a pair of large veins. On either side, it is formed by the confluence of a large *femoral vein,* draining the outer part of the hindleg, a *vesicular vein* from bladder and seminal vesicle (male) or uterus (female), and a *posterior epigastric vein* from public region.

(iv) Ilio-lumbar veins. A pair of veins from the posterior dorsal abdominal wall (lumbar region).

(v) Genital veins. Paired, returning blood from gonads, called *spermatic veins* in male and *ovarian veins* in female.

(vi) Renal veins. A pair of prominent veins one from each kidney, each receiving a *supra-renal* branch from the corresponding suprarenal gland.

(vii) Hepatic veins. While passing through the liver, the postcaval receives two pairs of hepatic veins from liver.

(viii) Phrenic veins. While piercing through the diaphragm, postcaval collects its blood through one pair of phrenic veins.

Finally, the postcaval opens into the right auricle of the heart.

4. Hepatic portal system. A renal portal system is totally absent, while a hepatic portal system is well-developed in mammals (rabbit). The food-laden blood from various regions of the digestive tract is collected by 4 veins : (i) *lieno-gastric* from stomach and spleen, (ii) *duodenal* from duodenum, (iii) *anterior mesenteric* from small intestine, caecum and colon, and (iv) *posterior mesenteric* from rectum. These unite to form the *hepatic portal vein* which enters the liver and breaks down into capillaries. As already mentioned earlier, the blood of liver is drained by hepatic veins joining the postcaval.

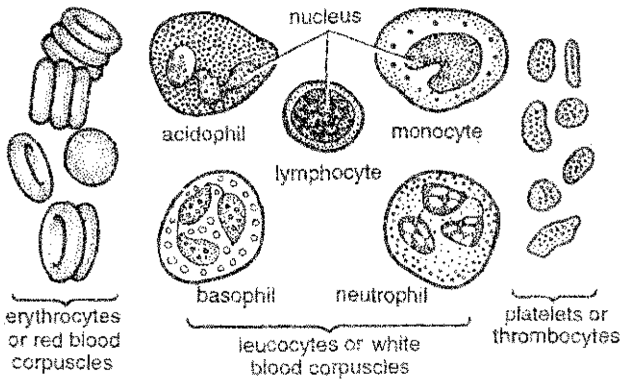

Fig. 31. Rabbit. Blood cells.

[IV] Blood

Like birds, the mammals are also warm-blooded or *homoiothermous,* with regulated body temperatures. Blood is a type of connective tissue. Its intercellular substance or *matrix* is a fluid called *plasma.* Suspended in the plasma are certain *formed elements* : red blood cells (R.B.C.) or *erythrocytes,* white blood cells (W.B.C.) or *leucocytes,* and *platelets.* The principal role of blood is the transport of various substances, such as cellular fuels, hormones, etc., to various parts of the body. The red colour of blood is due to the red blood cells (R.B.C.) containing an iron-containing pigment, the *haemoglobin,* which is involved in the transport of oxygen.

The blood of mammals (e.g., rabbit) is similar to the blood of other vertebrates (e.g., frog) in structure and function. But there are some minor differences :

(1) In other vertebrates the *erythrocytes* are large (about 25 μ), oval, nucleated, biconcave and less in number. In mammals, they are small

(about 8 μ), circular, without nuclei, biconcave and more in number.

(2) In frog the *platelets* or *thrombocytes* are spindle-like, nucleated and less in number. In mammals, they are irregular, non-nucleated and more numerous. The blood platelets are involved in the clotting of blood.

Some of the white blood cells or leucocytes are termed *granulocytes*, because of the presence of a large number of granules in their cytoplasm. On the basis of the reaction of granules to dyes, the granulocytes are divided into *acidophil* (eosinophil), *basophil* and *neutrophil*. The nuclei of the granulocytes are many-lobed.

The largest leucocytes present in blood are called the *monocytes* with a sausage-shaped nucleus and an abundant cytoplasm. These are phagocytic in nature and protect the body against invading micro-organisms.

[V] Lymphatic system

In addition to the blood vascular system, all vertebrates possess a *lymphatic system* which does not exist except in the phylum Chordata. It consists of *lymph, lymph capillaries, lymph vessels* and *lymph nodes*.

1. Lymph. Blood never leaves the arteries and veins as their thick walls are impervious to the contained blood. But the walls of the blood capillaries are extremely thin, a little more than an epithelium, and form permeable membranes. Therefore, by *ultrafiltration*, most plasma of blood seeps out readily through the capillary walls into the inter-cellular spaces of the tissues.

This colourless watery liquid that lies between and bathes the cells of the body is called *tissue fluid* or *lymph* (Latin for water). It is similar to plasma in constitution except that it does not contain some proteins (having larger molecules) and lacks the red blood cells. It does, however, contain considerably more *lymphocytes* than are present in blood. There is four to five times as much lymph in the body as there is blood.

2. Lymph capillaries. There is a continual renewal and absorption of the tissue fluid. Towards arterial end the capillaries ooze out fluid due to high hydrostatic pressure. But, towards the venous end some fluid is reabsorbed due to low hydrostatic pressure within. Only some lymph is returned to blood capillaries in this way. Most of the lymph, however, is drained into a network of blind-ending special *lymph capillaries* located in the tissue spaces. Their walls are composed of simple epithelium which is extremely permeable even to protein molecules. Fluid pressure within these lymph capillaries is nearly zero. They are not connected with blood capillaries and their diameter is also not uniform throughout.

3. Lymph vessels. The lymph capillaries lead into larger *lymph vessels*, rather like thin-walled veins. There is no pumping station (lymph hearts) in mammals such as found in lower vertebrates (e.g. frog). Movement of lymph is mainly due to squeezing pressure of the surrounding muscles. The vessels are also provided with valves which keep the lymph flowing in one direction. Eventually all the vessels join to form two main ducts, the *thoracic duct* and the *right lymphatic duct*, which open into the place of union of left and right external jugular veins and the corresponding subclavian veins, respectively.

4. Lymph nodes. In mammals only, the lymph vessels pass at certain places through *lymph glands*, or better, *lymph nodes*. These consist of a meshwork of connective tissue fibres enclosed in a capsule. The nodes produce the lymphocytes of the blood.

5. Functions. The *lymphatic system* serves as an intermediary (middle man) between the blood and the tissues. It handles the return of the excessive tissue fluid produced in the body, to blood. It is largely responsible for the absorption of fat through special lymph capillaries or *lacteals* in the intestinal villi.

The *tissue fluid* or the *lymph* passes on food, oxygen, hormones and other chemicals from the blood to the cells, and the waste products, carbon dioxide, etc. from the cells to the blood, thus maintaining a constant chemical environment around the tissues.

The *lymph nodes* produce and maintain the *lymphocytes* of the blood. They also act as *filters* of poisonous and foreign substances such as dust, debris, bacteria, etc., thus purifying the blood. Infection of lymph nodes causes them to swell up and become painful. Tonsils, adenoids and appendix provide such cases.

Excretory System

It has been customary (convenient ?) to describe the two systems, excretory and reproductive, together in vertebrates as the *urinogenital system*, as they are morphologically interrelated to some extent, because certain excretory ducts (urinogenital ducts in male) are also used for the discharge of gametes. We have followed this practice in the present work in the description of *Scoliodon, Rana tigrina, Uromastix* and *Columba*.

But functionally, these two systems have nothing in common. The kidneys help excrete nitrogenous wastes while the reproductive organs perpetuate the species. Besides, kidneys alone do not monopolize excretion in vertebrates, especially in mammals. As such we have deviated from this normal practice and described the excretory and reproductive systems separately in rabbit.

The excretory organs include a pair of *kidneys*, a pair of *ureters* and a *urinary bladder*. They are similar in both the sexes.

[1] Kidneys

The chief organs of excretion are the two metanephric kidneys.

1. External morphology. The two kidneys are small, reddish-brown, bean-shaped organs attached to the dorsal abdominal wall behind the pericardium, one on either side of the vertebral column. In mammals, the kidneys occupy much anterior position as against the metanephric kidneys of reptiles and birds which remain in the posterior part of the abdominal cavity. The right kidney is attached more anterior than the left. This asymmetry is just the reverse of that found in man. Each kidney is covered by peritoneum on its ventral surface only and is embedded in a mass of fat. The outer side of kidney is convex and the inner side deeply concave or notched bearing a depression or pit called *hilum* or *hilus*. The renal artery enters while the renal vein and ureter leave each kidney through its hilus.

2. Internal structure. If a kidney is cut longitudinally into two equal halves (sagittal section) by a sharp razor or scalpel, then each half shows the following parts visible to the naked eye :

(a) Capsule. An outer thin envelope of tough fibrous connective tissue *tunica fibrosa*.

(b) Cortex. This is the outer region, dotted or homogeneous looking and lighter in colour.

(c) Medulla. This is the inner region, striated and darker in colour.

(d) Pelvis. This is a large funnel-shaped space towards the concavity or hilus of the kidney. It collects urine which is drained off by the ureter.

(e) Pyramid. In the kidney of rat or sheep, the medulla projects into the pelvis as a single conical process, the *pyramid*. But in the kidney of rabbit or man, the medulla is lobulated forming a number of pryramids projecting towards hilus. The cortex is continued inside between pyramids forming *renal columns of Bertini*.

3. Histology. The histology of kidney or its detailed microscopical study can be made from a microtomical section. Histologically a kidney is made of innumerable, fine, long, much convoluted tubular units, called *uriniferous tubules* or *nephrons*. These are embedded in connective tissue along with blood vessels, lymph vessels, nerves and muscle fibres. One human kidney may contain about one million nephrons, each approximately 35 mm in length.

Structure of a nephron. A nephron or uriniferous tubule is made of two parts : (a) *Malpighian capsule* and (b) a *tubule*.

(a) Malpighian capsule. The proximal end of each nephron forms a blind or closed, enlarged and double walled cup, the *Bowman's capsule*, in the cortex. It is named after William Bowman (1816-1892), an English physiologist and histologist. The hollow of the cup contains a tuft or knot of blood capillaries, called a *glomerulus*. This composit structure including the Bowman's capsule, surrounding the glomerulus is known as a *renal corpuscle* or *Malpighian capsule*, after the Italian microscopist Marcello Malpighi (1628-1694).

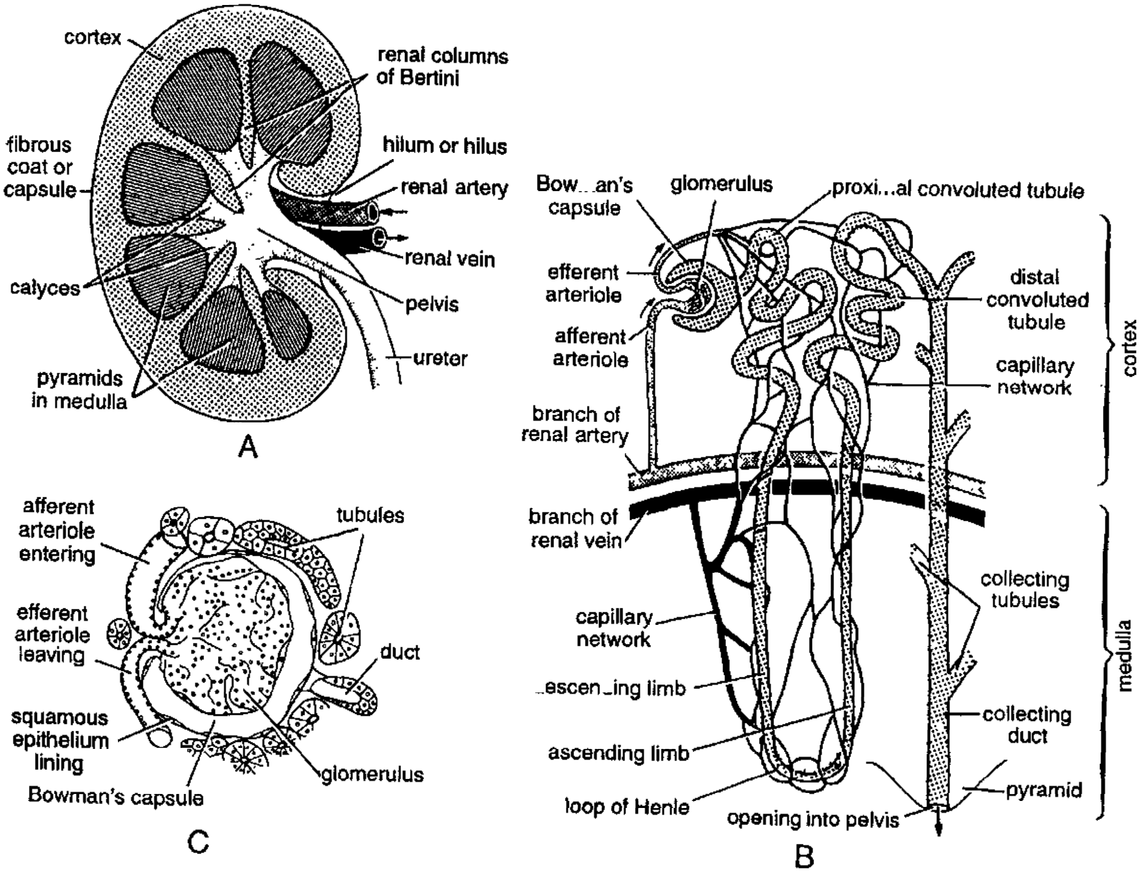

Fig. 32. Rabbit. Excretory organs. A—Structure of a kidney in sagittal section. B—Structure and blood supply of a single nephron or uriniferous tubule. C—A Malpighian capsule magnified.

(b) Tubule. The tubule leading from Bowman's capsule is differentiated in mammals into three regions. (i) The part leaving the cup makes a few coils in the cortex and is known as the *proximal convoluted tubule.* (ii) It straightens out and descends down into the medulla forming the *loop of Henle.* This is the thinnest part of the tubule. (iii) The ascending limb of the loop reenters the cortex to form more coils and this is called the *distal convoluted tubule.* It joins one of the larger collecting ducts collectively forming the pyramid and finally opening into the pelvis.

The wall of the Bowman's capsule is made of a single layer of squamous epithelial cells, and that of the tubule of cuboidal epithelial cells which become ciliated at intervals.

4. Blood supply of kidney. The *renal artery* after entering the kidney through *hilus* branches into smaller vessels called *arterioles.* An *afferent arteriole*, entering a glomerulus is about twice bigger in diameter than the *efferent arteriole* which leaves the glomerulus. The efferent arteriole then breaks up into a *capillary network* closely investing the uriniferous tubule. These capillaries reunite forming a *venule.* All the venules ultimately join to form the *renal vein* which comes out of the kidney through the hilus.

Inside the kidney, the blood vessels run along the junction of cortex and medulla, the arteries sending branches into the glomeruli and the veins receiving branches from the uriniferous tubules.

[II] Ureters

The pelvis of each kidney is directly continued into a thick-walled, narrow, cylindrical tube, called *ureter.* It runs from the hilus of the kidney backwards along the dorsal abdominal wall. Both the ureters open posteriorly into the neck of the urinary bladder on its dorso-lateral surface.

[III] Urinary bladder

It is a median, oval or pear-shaped, muscular sac situated below the rectum connected to the ventral abdominal wall by a suspensory ligament. The posterior narrower part of the bladder, or neck, has a circular sphincter muscle. The neck of the bladder opens into a thick-walled muscular duct, the *urethra.* In male, it is much longer and called the *urinogenital canal* which traverses and opens at the tip of the *penis.* In female, urethra is small and combines with vagina to form the *vestibule* which opens to the exterior by a slit-like *vulva.*

[IV] Physiology of excretion

Kidneys perform several functions in the vertebrate body, such as : (i) *urine formation* and (ii) *homeostasis.*

1. Urine formation. The chief nitrogenous end product in mammals is urea, formed in the liver. It reaches kidneys through blood circulation and excreted in the form of a watery solution, called *urine.* Urine formation involves the following three stages :

(a) Glomerular filteration. As we have already known, the diameter of the afferent arteriole entering the glomerulus is greater than that of the efferent arteriole leaving it. This means more blood enters than can leave, so that the blood in the glomerulus is relatively under great hydrostatic pressure. Since the walls of glomerulus and Bowman's capsule are extremely thin, permeable and in close contact, most of the constituents of blood, except the proteins, fats and cells, are filtered into the cavity of the capsule. The mechanism is known as *pressure filtration* or *ultra-filtration,* which is purely a physical process.

The filtered out fluid is known as *glomerular* or *capsular filtrate.* It contains mostly urea, dissolved in water besides glucose, amino-acids, sodium and potassium ions, uric acid, and so forth. The remaining constituents of blood, that is, cells, proteins and fats, pass on through the efferent arteriole without getting filtered.

(b) Tubular reabsorption. The ultrafiltrate contains many substances useful to the body. As the filtrate passes down the extremely long uriniferous tubule due to ciliary action, many selected substances are taken back into the blood of the capillary network which surrounds the tubule in close contact. This is called *tubular reabsorption* or *selective absorption.*

From studies by micropipette technique developed by A.N. Richards ($192O_S$), it has been concluded that, in mammals, all the glucose, amino acids and some urea are reabsorbed in the proximal convoluted tubule. Sodium chloride and bicarbonate ions are reabsorbed in both the proximal and distal convoluted tubules. About 99% of water in the filtrate is reabsorbed at many levels including the loop of Henle.

Tubular reabsorption occurs in two ways. Urea and water are reabsorbed by *passive diffusion.* Other substances (amino acids, sugars, salts, etc.) are actively taken up by the tubular cells and secreted into the capillary blood against a concentration (diffusion) gradient. This process is called *active transport* and requires expenditure of energy by the tubular cells. If the kidney is denied oxygen, reabsorption stops, although filtration proceeds normally.

(c) Tubular secretion. Some substances are added from the capillary blood to the filtrate by tubular secretion. These include creatinne, ammonia, hydrogen and potassium ions and various drugs.

The highly concentrated *urine,* resulting from tubular secretory exchange, contains water. urea, uria acid, creatinine, ammonia, etc. It also contains urochrome a pigment derived from the breakdown of haemoglobin, which imparts yellow colour to urine. From nephrons it passes into collecting tubules discharging into pelvis and taken by the ureter to the urinary bladder for storage before discharge.

2. Homeostasis. Kidney is not only an excretory organ. It also works as a homeostatic organ by regulating body fluids, such as blood and water. The term *homeostasis* means the tendency to regulate the stability of the normal conditions in the internal environment of a living organism.

(a) Regulation of water (osmoregulation). If the animal drinks a great deal of water, the excessive water is allowed to escape by producing much dilute urine. Conversely, if body has less water due to scarce drinking or loss in sweat, then scanty and more concentrated urine is produced after reclaiming a maximum amount of water from it. The volume of urine or water is controlled by an *antidiuretic hormone* (ADH) secreted by the posterior lobe of pituitary.

(b) Regulation of blood. By regulating the amount of water in the body, the kidney controls the osmotic pressure of the blood and tissue fluids. It helps in maintaining the right amount of salts in blood. Similarly, it helps in preserving a constant level of pH in blood by allowing to pass or retaining certain acid and basic substances. Many types of medicines, such as antibiotics, aspirin, vitamins and many others, are removed from the body via the kidney. Blood volume is also regulated by the kidney. Blood volume is also regulated by the kidney. During loss of blood, the blood pressure drops slowing urine production and retaining body fluids.

Nervous System

As in other vertebrates, the entire nervous system of rabbit also consists of 3 main subdivisions :

1. **Central nervous system** including *brain* and *spinal cord.*
2. **Peripheral nervous system** including *cranial* and *spinal nerves.*
3. **Autonomic nervous system** including *sympathetic* and *parasympathetic* nerves and ganglia.

[I] Brain

The brain of rabbit is essentially built on the same plan as that of frog or any other vertebrate. However, the mammalian brain is more highly evolved and the two cerebral hemispheres are very much larger than in the lower vertebrates.

The brain lies within the cranial cavity of skull. It is soft, white, somewhat flattened and nearly twice as long as wide.

Meninges. The brain is covered by three membranes collectively known as *meninges* (singular, *meninx*). The inner membrane, called *piamater,* is thin, soft, vascular and closely applied to the surface of brain. The outer layer, called *duramater,* is *thick*, very tough, and lines the inner wall of cranium. The middle layer, called *arachnoid,* is also delicate and highly vascular. The space between duramater and arachnoid is called *subdureal cavity* and the space between arachnoid and *piamater* is called *sub-arechnoid cavity.*

Cerebrospinal fluid and ventricles. The brain is hollow from within. The cavities of its various parts are called *ventricles.* These are filled with a lymph-like *cerebro-spinal fluid.* It is secreted by the anterior and posterior choroid plexuses. The narrow *sub-arachnoid* space between arachnoid and piameter is also filled with the cerebro-spinal fluid and crossed by fibres from arachnoid membrane.

Histology. Histologically, the brain is made of two types of nervous tissues. The outer part of brain, called *cortex,* is made of *grey matter.* It consists mainly of nerve cells besides nerve fibres, neuroglia (supporting structures) and blood vessels. The inner part of brain, called *medulla,* is made of *white mater.* It includes only nerve fibres and neuroglia.

Parts of brain. The three major divisions of brain are *forebrain, midbrain* and *hindbrain.* Their parts are essentially the same in all vertebrates, only their relative development varies greatly.

1. Forebrain. The forebrain or *prosencephalon* includes two olfactory lobes, two cerebral hemispheres and a diencephalon.

(a) Olfactory lobes. The two small, club-shaped *olfactory lobes* or *bulbs* are separate forming the anteriormost part of the brain. They are continued beneath the frontal lobes of cerebrum as the paired *olfactory tracts* connected with the hippocampal lobes. The remnant of an olfactory nerve can be seen at the anterior end of

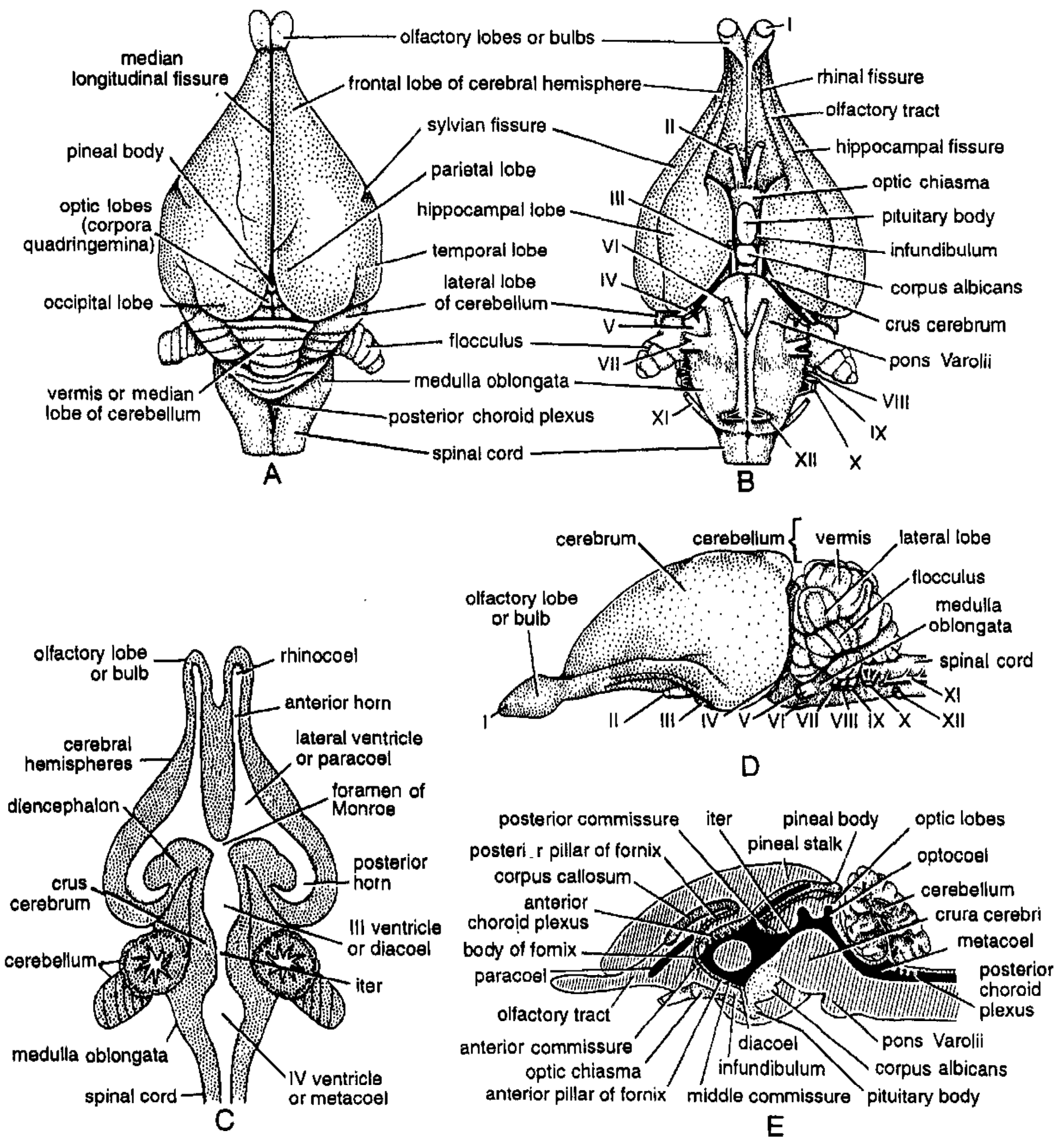

Fig. 33. Rabbit. Structure of brain. A—Dorsal view. B—Ventral view. C—H.L.S. showing ventricles. D—Lateral view. E—Sagittal section.

each olfactory lobe. The narrow cavity of each olfactory lobe is called the I ventricle or *rhinocoel*. It opens posteriorly into the cerebral hemisphere of its side. The sense of smell is controlled by the olfactory lobes.

(b) Cerebral hemispheres. The two cerebral hemispheres are separated by a deep longitudinal median fissure. They are narrow in front but broad behind and nearly smooth-surfaced. They are so large in mammals (rabbit) that they overlap the diencephalon and midbrain and almost touch the cerebellum behind. They form nearly 2/3 of the entire brain. A shallow lateral, somewhat oblique *Sylvian fissure* divides each hemisphere into a

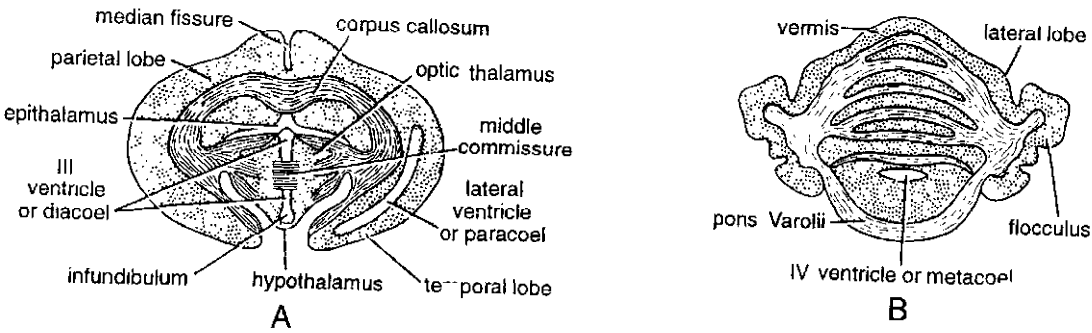

Fig. 34. Rabbit's brain. A—T.S. of cerebrum. B—T.S. of cerebellum.

larger anteromedian *frontal lobe,* and a smaller posterolateral *temporal lobe.* Ventrally a longitudinal *rhinal fissure* demarcates the olfactory tract, while another longitudinal *hippocampal sulcus* or *fissure* demarcates the *hippocampal lobe.*

Connecting the two hemispheres internally is a broad transverse band of nerve tissue, the *corpus callosum,* which is characteristic of placental mammals. It can be seen externally from dorsal side if the two hemispheres are pulled apart. Inner cavity of each hemisphere is called the *II ventricle* or *lateral ventricle* or *paracoel.* The two paracoels are connected with each other and with the diacoel through a passage called the *foramen of Monro.* The roof of paracoels is formed by the corpus callosum, while the lateral walls and floor by *corpus striatum.* The two corpora striata are connected by a transverse *anterior commissure.*

The cerebral hemispheres are the seat of highly complicated activities such as thought, reasoning, memory, intelligence, etc. They are not well developed in lower vertebrate animals having low faculties.

(c) ***Diencephalon.*** The small and depressed diencephalon lies covered below the backward extension of cerebral hemispheres. Its narrow internal cavity is known as the *III ventricle* or *diacoel.* The roof of diacoel is *epithalamus,* floor is *hypothalamus* and the lateral thickened walls are *optic thalami.* The two optic thalami are connected by a large transverse *middle commissure* which occupies the greater part of diacoel. It contains only nerve cells but no fibres. Dorsally, from roof of diencephalon, arises a slender *pineal stalk* carrying a small rounded *pineal body,* which is perhaps an endocrine gland. Rest of the roof is non-nervous but highly vascular and called the *anterior choroid plexus.* Ventrally, the floor of diencephalon (hypothalamus) projects into a median rounded *infundibulum.* Its lower end carries an oval *Rathke's pouch* or *hypophysis,* behind which is attached a small rounded body, the *corpus albicans.* Infundibulum and hypophysis together constitute the *pituitary body.* Just in front of the infundibulum lies the crossing of the two optic nerves, called *optic chiasma.*

Diencephalon controls perception of chemicals, temperature, reproduction, metabolism and autonomous nervous system.

2. Midbrain. The midbrain or *mesencephalon* is the small middle part of brain which is partly concealed below the cerebral hemispheres. It differs from that of other vertebrates in having on the dorsal surface four small rounded *optic lobes* collectively known as the *corpora quadrigemina.* The anterior two optic lobes are larger, called *superior colliculi.* They are homologous with those of other vertebrates and concerned with sight. The posterior two optic lobes are smaller, called *inferior colliculi,* and associated with acute hearing. The cavity of midbrain is a narrow longitudinal passage, called *iter.* Its floor is formed by thick tracts of fibres, called *crura cerebri,* which link the fore and hind brains together.

3. Hindbrain. The hindbrain or *rhombencephalon* includes cerebellum, pons Varolli and medulla oblongata.

(a) C-r-----um. The cerebellu... is very well developed and transversely elongated. It co sists of a large median lobe; the *vermis,* and two *lateral lobes* each with a ventro-lateral extension called *flocculus.* There is no cavity inside cerebellum, but its surface is much folded thus increasing its grey matter. Surface foldings of the cerebellum forms a number of elevations called *gyri* and groves called *sulci.* Cerebellum controls equilibrium and coordination of voluntary muscular movements.

(b) Pons Varolii. The ventral surface of hindbrain shows a stout transverse band of fibres. It connects the right and left halves of the cerebellum. It is named *pons Varolli* after the Italian anatomist Costanzo Varolio (1543-1575).

(c) Medulla oblongata. The medulla forms the last part of the brain. It is broad and triangular anteriorly but tapers back into the spinal cord. Its cavity is known as the *IV ventricle* or *metacoel* which is continuous with the central canal of the spinal cord. The roof of metacoel is non-nervous and vascular, called the *posterior choroid plexus.* Medulla oblongata and pons Varolii control the involuntary activities in the body such as digestion, respiration, excretion, circulation, etc.

[II] Spinal cord

Morphology. The spinal cord is a long, whitish, thick-walled tube of nervous tissued contained within the neural canal of the vertebral column. It starts from the medulla oblongata of the brain, gradually tapers upto 4th lumbar vertebra and then terminates into a non-nervous thread, the *filum terminale,* which extends into the tail. The cord shows two slight enlargements, the *brachial* and *sciatic swellings,* at the levels of fore and hind-limbs, respectively. Nerves to the two limbs arise from these swellings. The somewhat flattened surface of the cord is marked by two mid-longitudinal grooves or fissures. The *midvenral fissure* is much deeper and broader than the *mid-dorsal fissure* and also contains blood vessels.

Meninges. Like brain, the spinal cord is also surrounded by three membranes or *meninges— piamater, arachnoid* and *duramater—* with cerebrospinal fluid within the narrow subarachnoid space.

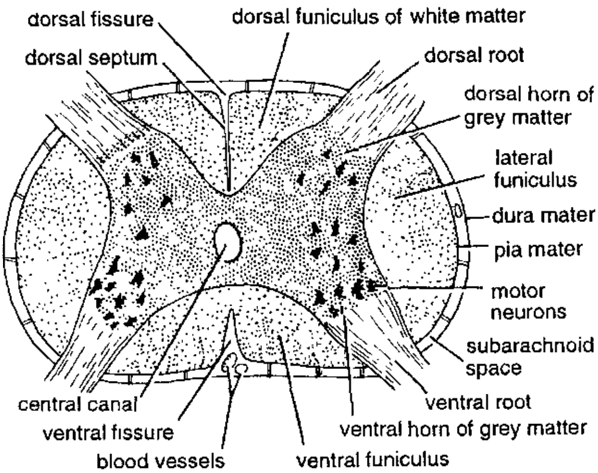

Fig. 35. Rabbit. T.S. spinal cord.

Histology. The histological structure of spinal cord, as seen in a T.S., is similar in all the vertebrates. Like brain, it is also made up of nervous tissue of two types : the *grey matter* largely made of nerve cells, and *white matter* of nerve fibres. However, the grey matter is internal in the spinal cord forming the butterfly-shaped or H-shaped central area perforated by a very small *central canal* in mammals. It is continuous with the IV ventricle of brain but is closed behind. It is filled with the cerebrospinal fluid. The grey matter is projected dorsolaterally and ventro-laterally into paired *dorsal* and *ventral horns* to which the roots of spinal nerves are attached. A thin vertical septum of connective tissue penetrates from dorsal fissure nearly to the central canal. The dorsal septum and the ventral fissure divide the spinal cord into two lateral halves.

The spinal cord mainly controls the reflex activity. It also conducts impulses to and fro the brain.

[III] Cranial nerves

The brain of a mammal (e.g., rat, rabbit) has connected to it 12 pairs of nerves. Out of these, the first 10 pairs of cranial nerves are essentially the same as those of the fishes and amphibians. The two additional pairs include the *spinal*

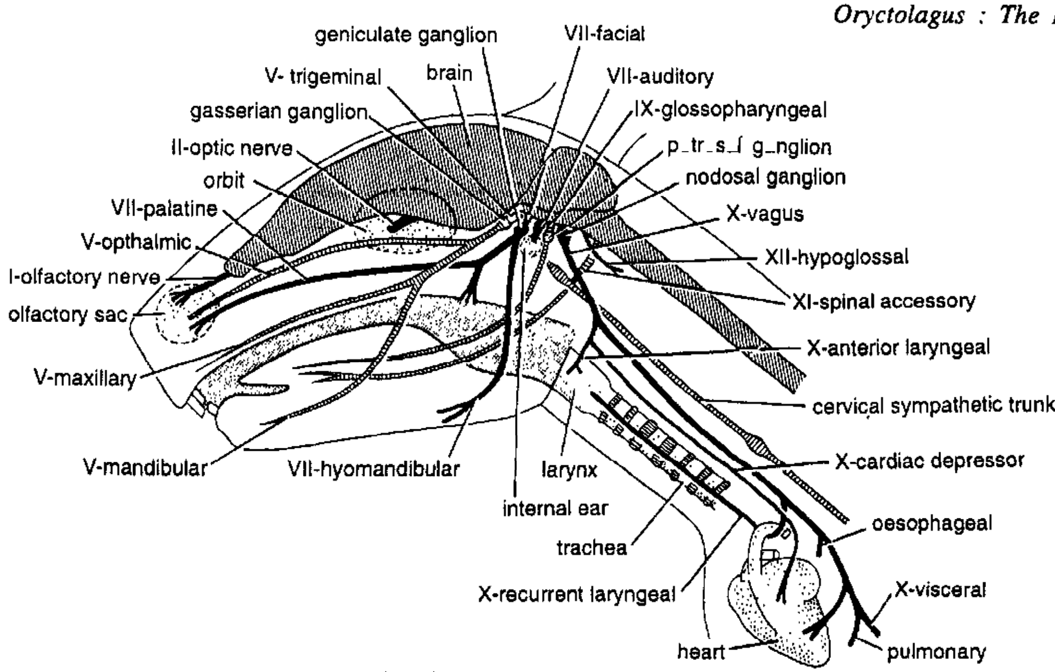

Fig. 36. Rabbit. Dissection of cranial nerves in left view.

***Table 2.* Cranial Nerves of Rat or Rabbit.**

Name with main branches		Origin from brain	Distribution	Nature
I.	*Olfactory*	Olfactory lobe	Olfactory epithelium	Sensory
II.	*Optic*	Optic chiasma	Retina of eye	Sensory
III.	*Oculomotor*	Crura cerebri of mid brain	Four muscles of eyeball, iris, ciliary body	Motor
IV.	*Trochlear (Pathetic)*	Midbrain	Superior oblique eye muscles	Motor
V.	*Trigeminal*	Pons Varolii	—	Mixed
	V_1 — *Ophthalmic*	—	Eye, eyelids, snout	Sensory
	V_2 — *Maxillary*	—	Upper jaw, vibrissae, nose, lower eyelid	Sensory
	V_3 — *Mandibular*	—	Lower jaw and lip, external ear, tongue	Mixed
VI.	*Abducens*	Pons Varolii	External rectus muscle of eyeball	Motor
VII.	*Facial*	Pons Varolii	—	—
	VII_1. *Palatine*	—	Palate	Sensory
	VII_2. *Chorda tympani*	—	Tongue, salivary glands, taste buds	Sensory
	VII_3. *Hyomondibular*	—	Lower jaw, neck, pinna, hyoid	Mixed
VIII.	*Auditory*	Medulla	—	—
	$VIII_1$. *Vestibular*	—	Internal ear	Sensory
	$VIII_2$. *Cochlear*	—	Cochlea	Sensory
IX.	*Glosopharyngeal*	Medulla	—	—
	IX_1. *Lingual*	—	Tongue, pharynx, salivary glands	Mixed
	IX_2. *Pharyngeal*	—	Pharynx, salivary glands	Mixed
X.	*Vagus*	Medulla	—	—
	X_1. *Anterior laryngeal*	—	Cricoid, thyroidmuscles of larynx	Motor
	X_2. *Recurrent laryngeal*	—	All muscles of larynx	Motor
	X_3. *Cardiac depressor*	—	Heart	Motor
	X_4. *Pneumogastric*	—	Lungs, oesophagus, stomach, ileum	Sensory & Motor
XI.	*Spinal accessory*	Medulla	Pharynx, larynx, neck, sthoulder	Motor
XII.	*Hypoglossal*	Medulla	Neck and tongue	Motor

accessory (XI) and the *hypoglossal* (XII). The *facial* (VII) of mammals is relatively small lacking ophthalmic, buccal and lateral branches. The *vagus* (X) is large. The main trunk *(Pneumogastric)* arising from its ganglion sends branches to various viscera. The other branches of vagus are an *anterior laryngeal* and a *posterior* or *recurrent laryngeal* to larynx, and a *cardiac depressor* to the heart. The *spinal accessory* (XI) supplies to muscles of neck, pharynx and larynx. The hypoglossal (XII) supplies a prominent branch to the tongue and a small branch to larynx. Table 2 provides a summary of the names with main branches, origin, distribution and nature of the cranial nerves of the rat or rabbit. Some cranial nerves carry only sensory impulses, some only motor impulses, while others carry both (mixed).

[IV] Spinal nerves

The spinal nerves of rabbit are in 37 pairs : 8 cervical, 12 thoracic, 7 lumbar, 4 sacral and 6 caudal. Each spinal nerve carries both sensory and motor impulses. Each arises from the spinal cord by two roots, dorsal and ventral. The *dorsal root* originates from the dorsal horn of grey matter. It consists of only sensory fibres. It bears the *dorsal root ganglion* containing only sensory cells. The ganglia of all the spinal nerves lie within the neural canal except that of the second cervical. The *ventral root* is the prolongation of the ventral horn of grey matter. It is made of motor fibres only and bears no ganglion. Both the roots unite in the neural canal and the single nerve thus formed is mixed in nature. It leaves the vertebral column through an intervertebral foramen and immediately divides into 3 branches or rami : dorsal, ventral and visceral. The small dorsal branch or *dorsal ramus* supplies the skin and muscles of back. The ventral branch or *ventral ramus* supplies the latero-ventral parts of body. The visceral branch or *ramus communicans* joins the sympathetic system supplying the visceral organs.

Plexes. In rabbit, the ventral branches of 4th, 5th and 6th *cervical* nerves in neck, the last four *cervical* nerves (5th, 6th, 7th and 8th) and the 1st *thoracic* nerves in the region of forelimbes, and 4th to 7th *lumbar* and first 3 *sacral* nerves in the region of hind limbs meet to form networks called *cervical, brachial* and *lambo-sacral* plexes, respectively. Cervical plexus on either side sends a *phrenic nerve* to muscles of diaphragm.

[V] Autonomic nervous system

The autonomic nervous system serves as the intermediary through which the central nervous system controls the involuntary visceral cardiac and glandular muscles. It is divisible physiologically into two systems : *sympathetic* and *parasympathetic*.

1. Sympathetic nervous system. It includes a pair of long *sympathetic trunks, cords* or *nerves.* They leave the brain through carotid canals in the cranium and pass down the thorax and abdomen on either side of the vertebral column, and enter the tail as fine filaments. In rat or rabbit, each sympathetic cord bears in all 24 enlargements or

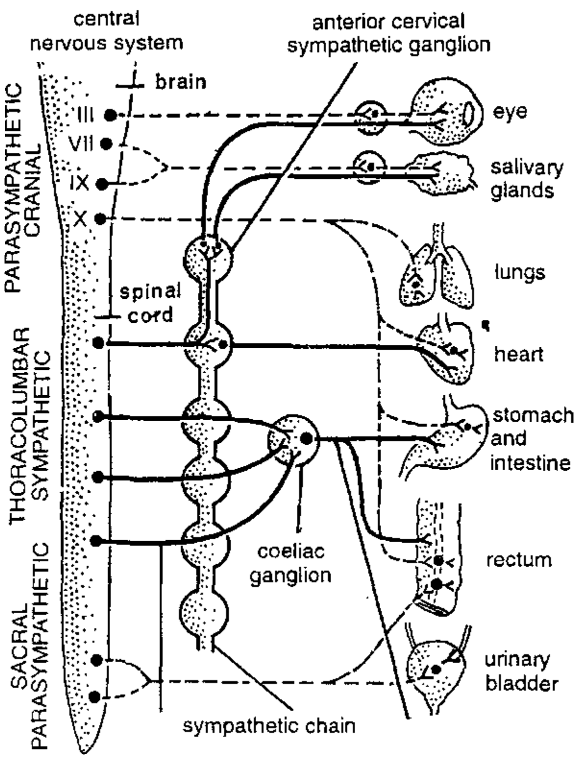

Fig 37. Rabbit Simple schematic representation of autonomic (solid lines) and parasympathetic (broken lines) nervous systems.

ganglia of which 3 are cervical, 10 thoracic, 6 lumbar, 4 sacral and 1 caudal. These sympathetic ganglia are connected with the corresponding spinal nerves through *rami communicantes* (singular, *ramus communicans*). Sympathetic nerves innervate the visceral organs, heart and glands.

2. Parasympathetic nervous system. The parasympathetic nervous system is formed by fibres from the III, VII, IX and X cranial nerves, and from II, III and IV sacral nerves. The parasympathetic ganglia lie in the head, neck and sacral region. They also, supply nerves to all the organs supplied by the sympathetic system.

Working. Sympathetic and parasympathetic nerves supply the same organs, but their effects are usually antagonistic (opposite). In general, the sympathetic stimulation mobilises the organs for action, while the parasympathetic stimulation calms them down. For example, sympathetic stimulation increases the heart beat, dilates blood vessels in muscles but constricts peripheral vessels thereby increasing the blood pressure, dilates iris of eye and bronchi, inhibits the activity of the gut, and so forth. Parasympathetic stimulation, on the other hand, slows down heart beat, decreases blood pressure, constricts the pupil of eye and bronchi, and speeds peristalsis of the digestive tract. The autonomous system also controls the secretion of glands, both exocrine as well as endocrine.

Sense Organs

Senses and sense organs. All environmental changes, external and internal, are known as *stimuli* or *senses*. The special organs of the body which detect these changes in the environment are called the *receptors* or *sense organs*. All types of senses in the body number to about twenty. But, traditionally, we recognise only five special senses and their receptors :

(1) Organs of *touch* or *tangoreceptors* (skin).
(2) Organs of *taste* or *gustatoreceptors* (tongue).
(3) Organs of *smell* or *olfactoreceptors* (nose).
(4) Organs of *sight* or *photoreceptors* (eyes).
(5) Organs of hearing and equilibrium or *statoacoustic receptors* (ears).

[I] Organs of touch (skin)

The skin in mammals (rabbits) is highly sensitive to touch. Cutaneous sense organs are microscopic, scattered throughout, and of several types, each normally concerned with a particular stimulus.

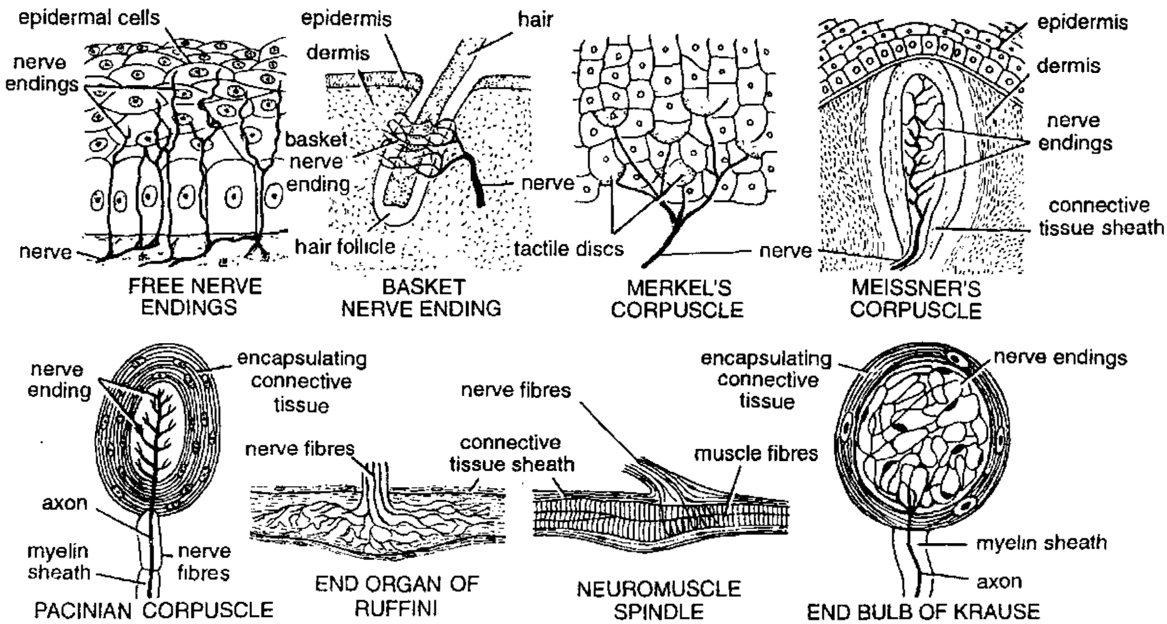

Fig. 38. Rabbit. Various types of cutaneous receptors in mammals.

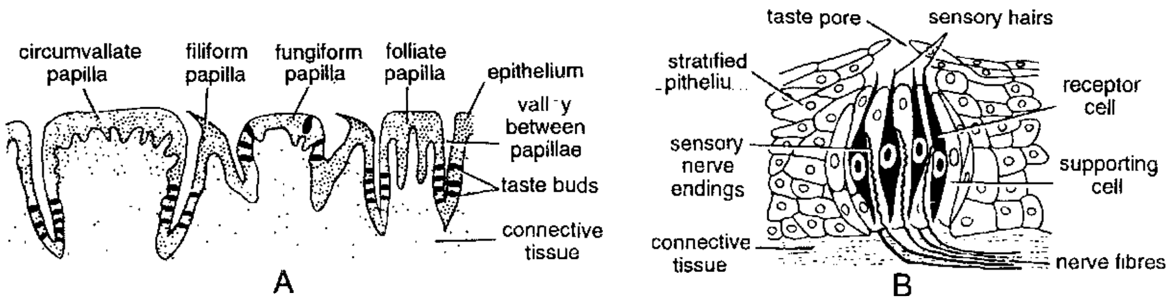

Fig. 39. A—Upper surface of mammalian tongue in V.S. showing 4 types of lingual papillae. Taste buds shown in black. B—A single taste bud in V.S.

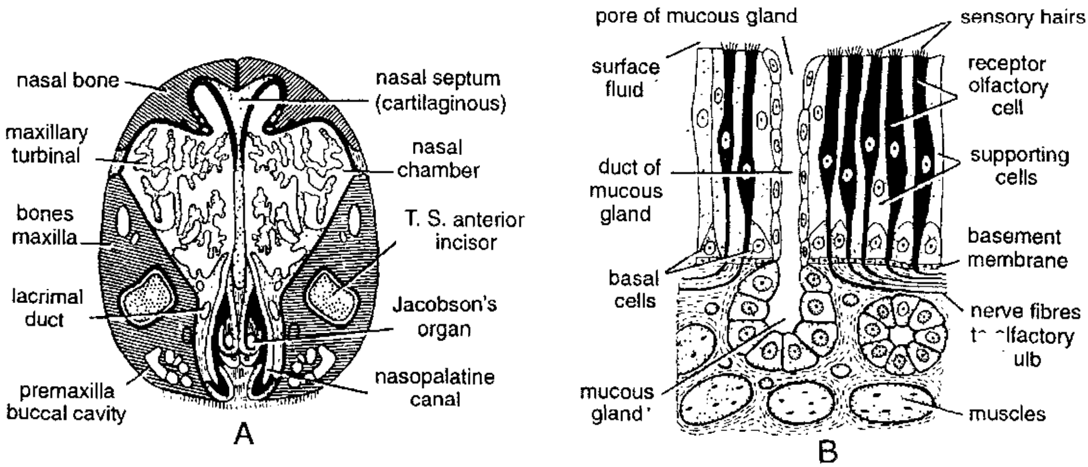

Fig. 40. Rabbit A—Snout in V.S. through nasal chambers and Jacobson's organs. B—Olfactory epithelium with a mucous gland in section.

1. Free nerve endings. Stimuli of touch, pressure, cold, warmth, pain, etc. are said to be received by free nerve endings. These consist of fine branching fibres of sensory nerves. They lie just below or even extend into the epidermis of skin.

2. Basket nerve endings. These are nerve endings forming a fine network around a hair follicle. Sense of touch results due to bending of skin or hair when touched.

3. Encapsulated nerve endings. These are found in hairless parts of the skin. *Meissner's capsules* are present just beneath the epidermis. Each consists of naked axons, entering an end bulb surrounded by a connective tissue capsule. These are assumed to be sensitive to touch.

The *Pacinian capsules* occur in dermis and many internal organs. Each is a large ovoid structure, made of a core of single axon ending inside an inner bulb surrounded by concentric lamellae of flattened connective tissue cells. These are sensitive to pressure.

4. Neuromuscular bundles. The sense of movement of contraction of a muscle is known as *kinesthetic sense* or *proprioception.* This is brought about by specialized nerve endings in bulbs or end organs called, *neuromuscle spindles* or *neuromuscular bundles* which are found in skeletal muscles, tendons and joints. They detect changes in the tensions of muscles.

[II] Organs of taste (gustatoreceptors)

The chemoreceptors of taste are the taste buds found on papillae of the tongue and on the soft palate. Each taste bud is a group of elongated spindle shaped *receptor cells* are *supporting cells.*

The inner free ends of receptor cells bear fine sensory hairs, while their outer ends are supplied by *nerve fibres* from VII and IX cranial nerves. Taste buds open by *taste pores* into depressions between tongue papillae. The taste buds are sensitive to dissolved substances which stimulate sensations of sweet, sour, bitter, salty, etc.

[III] Organs of smell (olfactoreceptors)

The sense of smell in mammals is very acute. The chemoreceptors of smell or olfactory organs are the spindle-shaped *olfactory cells* found with columnar *supporting cells* and *mucous glands* in the epithelial lining the roof of the nasal chambers and the scroll-like turbinal bones called *ethmoturbinals*, *maxilloturbinals* and *nasoturbinals*. The free ends of the olfactory cells bear numerous fine *olfactory hairs*. Their other ends give rise directly to olfactory nerve fibres, which enter the olfactory lobes of the brain.

Unlike gustatory stimuli, the olfactory stimuli are produced by chemicals in gas from (odours) and in very low concentrations. The gaseous molecules, entering the nasal chambers, dissolve in mucus covering the olfactory cells and stimulate them.

The olfactory sense is well developed in rabbits for locating food, sensing enemies and searching mating partners. Like most vertebrates, the rabbit also has *Jacobson's organ* in the roof of buccal cavity between nasal chambers, but opening into the mouth cavity. It is lined with olfactory epithelium and effectively smells the content of the mouth. Besides this, each nasal passage has an ovoid sensory pad having minute papillae and ridges. These pads are tactile and serve as distance receptor for testing the air.

The olfactory sensors are 'distance chemical receptors' stimulated by ultraminute concentrations of odour that reaches the basal mucosa through the air. In general the olfactory system is more sensitive, than the gustatory system. Quantitative estimates indicate that olfactory system is 10 to 20,000 times. This explains why we small food more than we taste it. When we have cold the food tastes flat because the nasal cavity is blocked with mucus and therefore, the flavour of the food is not detected.

[IV] Organs of sight or eyes (photoreceptors)

The sense of sight is due to stimulation of the *eyes*, which lie protected, one on either side of the head in the skull sockets called the *orbits*. They are relatively similar in all vertebrates. The main differences are in :

(1) The mechanism of accommodation (focussing).
(2) The detailed structure of retina.
(3) The method for judging the distance of observed objects.

The eyes of all mammals are alike in their main features. The textbooks mostly describe the human eye as an example because it is best known.

External features. The eye or *eyeball* is a hollow, spherical organ of which about four-fifth part remains concealed within its orbit. Movements of eye are brought about by six strap-shaped muscles, four *rectus* and two *oblique*. Each muscle is attached at one end to the eyeball and, at the other, to the orbit.

The frontal exposed or visible part of the eyeball is known as *cornea*. Movable upper and lower eyelids can close the eye, when required, and protect it from dust particles. Movement of upper eyelid is performed by a sheet of muscle called *levator palpebrae superioris* and the lower eyelid by, *depressor paplpebrae inferioris*. The stiff hairs or *eyelashes* present on the free edges of eyelids (and also eyebrows in human) also guard the eye against dust particles, rain, sweat and glare. In rabbit, a transparent *nictitating membrane* lies in the anterior corner of eye called canthus. It can be drawn across the cornea for cleaning it and for safety from dust particles and water. The nictitating membrane is vestigial in human eye and represented by a pink semilunar mass.

Glands. Three kinds of glands are associated with each eye : *Meibomian, Harderian* and *lacrimal*. Meibomian glands are minute and located on each side whereas the Harderian glands are situated below the lower eyelids. The oily secretions of Meibomian and Harderian glands lubricate the eyelids and cornea. The lacrimal gland is present under the upper eyelid towards its outer corner. It secretes a slightly saline and antiseptic watery fluid, the *tears*. Blinking spreads this fluid over the surface of eye (conjunctiva) keeping it moist, soft, clean and free from bacteria. Excess of tears accumulate towards the inner corner of eye and drained by a *nasolacrimal duct* into the nasal chamber.

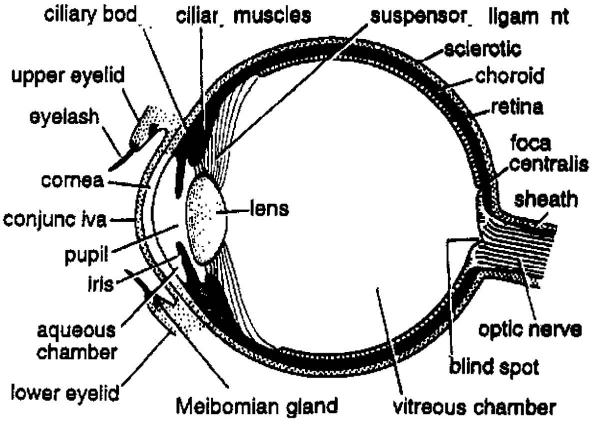

Fig. 41. Rabbit. Diagrammatic V.S. of eyeball.

Internal structure. A vertical section reveals that the eyeball is hollow from within. Its wall is made of three coats or layers of tissue in close contact : an outermost *sclerotic*, middle *choroid* and the innermost *retina*.

(a) Sclerotic. The sclerotic coat is made of dense connective tissue fibres giving strength to the wall. Most of this layer is opaque white and hidden, called *sclera*. But its small, anterior exposed part is transparent, through which light enters, and is called the *cornea*. It bulges out slightly and its external surface is intimately covered with a thin, transparent epidermal layer, the *conjunctiva*. It is supplied with free nerve endings and blood capillaries and is continuous with the epidermis lining the eyelids.

(b) Choroid. The middle layer or choroid is a much thinner connective tissue layer, heavily pigmented and richly vascular. Its dark pigmentation absorbs light rays reducing internal reflections that might blur the image. Its blood capillaries nourish the retina.

The choroid lines only the posterior region of sclera. Anteriorly, near the junction of sclera and cornea, the choroid enlarges to from the *ciliary body*. It contains *ciliary muscles* and projects into vascular folds called *ciliary processes*, which secrete the aqueous humour.

In front of the ciliary body, the choroid becomes widely separated from cornea, forming the *iris*, named after the Greek goddess of rainbow. It is visible from outside as an opaque brown disc, perforated in the centre by a round hole, the *pupil*. The iris contains two sets of smooth muscles, circular and radial. The pigmented iris prevents the light from entering the eye except through the pupil. The pupil can be constricted or dialated due to action of iris muscles, thus regulating the amount of light entering the eye. In the albino rat *(Rattus nonvegicus albinus)*, the eyes look pink because the iris is without pigment which allows reflection of retinal blood capillaries.

(c) Retina. The retina is the innermost transparent layer sensitive to light. It consists of an outer non-nervous pigmented layer closely applied with the choroid, and the inner nervous layer containing two main types of sensory cells, *rods* and *cones*, named because of the characteristic shapes of their receptor terminations. When stimulated by light, they generate electric impulses and relay the information to the brain by way of the *optic nerve*.

In a V.S. of retina, the various layers or parts forming it from outside are as follows : (i) pigment epithelium, (ii) receptive layer of rods and cones, (iii) external limiting membrane, (iv) basal cell bodies of rods and cones containing nuclei, (v) synapses, (vi) bipolar neurons, (vii) synapses, (viii) unipolar ganglion cells and (ix) layer of nerve fibres which converge to form optic nerve.

Rods are more sensitive to light of low intensity. They are suitable for right vision but the image formed is diffuse, lacking in details. *Cones*, by contrast, are sensitive to light of high intensity.

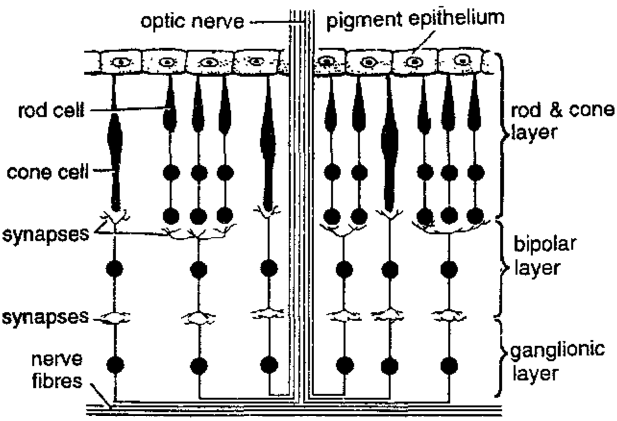

Fig. 42. Magnified structure of a portion of retina.

They are more suited for day vision and they produce a sharp image with fine details. As a further difference, cones are sensitive to lights of relatively narrow frequency bands so that they are associated with appreciation of colours. Colour perception in mammals is confined to man and other primates only.

The distribution of rods and cones within the retina is not uniform. Cones are more concentrated towards the centre, while rods are more numerous towards the periphery. The spot where all the nerve fibres converge and the optic nerve formed leaves the eye, there are no retinal cells present and so no image is formed. This spot is called the *blind spot.* Near it lies the *yellow spot* or *fovea,* marked by a slight oval depression along the *optical* or *visual axis.* It is the point of principal focus or brightest image, because it has only cones and no rods.

Lens. A crystalline, solid and biconvex lens is present just behind the pupil. It is composed of concentrically arranged layers of transparent fibres, enclosed within a thin transparent elastic *lens capsule.* It is held in position by *suspensory ligaments* which are radially arranged fibres connecting the lens capsule with the ciliary processes.

In old age some people suffer from *cataract,* in which the lens gradually becomes opaque causing blindness. It is cured by complete removal of lens by surgery and correcting sight with the help of glasses.

Chambers. The iris, lens and its suspensory ligaments divide the internal cavity of eye into two unequal compartments. Between the lens and the cornea is the smaller anterior *aqueous chamber.* It is filled with a clear lymph-like watery fluid, the *aqueous humour.* It is secreted continually by the ciliary body and drained through *canal of Schlemm* at the base of the cornea. Aqueous humour nourishes cornea and lens and maintains *intraocular pressure.* An imbalance in the intraocular pressure leads to a disease called *glaucoma* in which retina is injured.

Between the lens and the retina is the larger posterior *vitreous chamber.* It is filled with a gelatinous secretion, the *vitreous humour.*

Working of eye

(a) Image formation. There is a close similarity in the structure and working of an eye to a photographic camera. A camera can be opened or shut by its *shutter,* the eye by its *lids.* Both have convex *lenses* (cornea + lens in eye) which focus light rays on a *sensitive film* (*retina* of eye) forming an inverted image. In both, the amount of light entering the chamber is controlled by an *iris diaphragm.* The interior of a camera is painted black to avoid internal reflections which might blur the image. The eye also has a highly pigmented lining, the *choroid* coat. Finally the camera can be focussed by moving the lens to and fro, and the eye can also accommodate to see near and far objects.

However, there are some very important *differences* between the camera and the eye, such as :

(1) The sensitive film of camera is flat or plane, but the retina of eye is spheroidal. This enables the eye to have a wide angle of vision and at the same time largely to avoid the effects of spherical aberrations.

(2) The camera film requires only a short exposure to form an image, whereas retina of eye is capable of forming images continuously over a large period.

(3) Once a camera film is used up it is replaced by another. But the retina of eye can record continuously series of pictures without exhaustion of its sensitive cells.

(4) In the camera, the lens has a definite shape and it is moved to and fro until the image is in focus on the film. In the e_e the lens itself undergoes changes in shape for focussing near and far objects.

(b) Chemistry of vision (photochemistry). The rods of mammalian eye contain an extremely photosensitive substance called *rhodopsin* or *visual purple.* In the presence of light it breaks down into *retinene,* a derivative of vitamin A, and a protein *opsin.* Thus, photochemical reaction involves release of energy which stimulates a neuron causing it to send a nerve inpulse to the brain via optic nerve. Although the image formed on retina is small and inverted, the animal sees the object upright and its normal size. By a roundabout pathway, the retinene and the opsin rejoin with the aid of ATP, so that rhodopsin is resynthesized. In this way the rods are prepared to respond to light again. This cycle of breakdown and resynthesis of rhodopsin goes on continuously.

In dim light, a maximum amount of rhodopsin is present in the rods. On coming out of a dark cinema hall in bright day light, one feels dazzled until the level of rhodopsin is reduced in the rods. Conversely, one cannot see properly when going from a bright to a dark room until the level of rhodopsin has increased in the rods. Continued exposure to bright light sometimes causes much faster breakdown of rhodopsin than it can be regenerated, resulting in *snow blindness.* Vitamin A is readily converted into first retinene and then rhodopsin under the influence of an enzyme *(retinal isomerase).* Therefore, an acute deficiency of vitamin A in the body may result in *night blindness,* that is, difficulty in seeing in dim light.

(c) Colour vision. The exact nature of colour vision is not understood. It is known that cones of retina are stimulated by very strong light and they distinguish colours. That may be the reason why one cannot see colours in poor light, but only black and white or shades of grey. The light

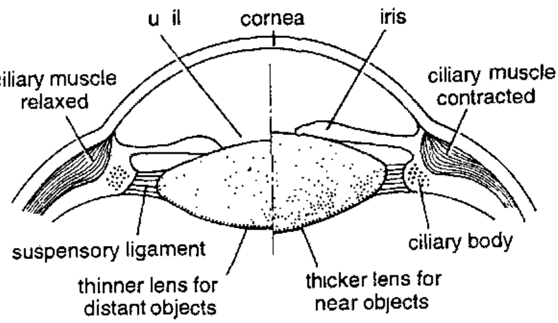

Fig. 43. Changes in curvature of lens during accommodation mammalian eye.

sensitive pigment of cones is *iodopsin.* It is presumed that there are three kinds of cones which are stimulated by different wavelengths of light corresponding to the blue, green and red parts of the spectrum. This hypothesis is supported by the three known types of *colour blindness.* Each type may be the result of a reduction in certain of the cones.

(d) Focussing or accommodation. The ability to sharply focus or clearly see objects placed at various distances is known as *accommodation.* In a camera, focussing is done by moving the lens. But the eye does so by changing the shape or curvature of its elastic lens.

In the normal eye, at rest the distant objects are in focus. The circular muscles of the ciliary body are fully *relaxed,* and the diameter of the ciliary body much increased due to the outward pressure of the fluid in the eyeball. This increases the tension of the suspensory ligaments which pull the lens capsule so that the lens becomes slightly thinner or flattened. In this state the eye is focussed for distant objects.

Accommodation for seeing near objects is accomplished by a reverse process of the above. The ciliary muscles *contract* reducing the diameter of the ciliary body. This slightly slackens the suspensory ligaments releasing their tension. This allows the elastic lens to regain its normal, thicker and more convex form. In this condition the lens has a short focal length to focus near objects. For this reason prolonged close work becomes tiring to the eyes because the ciliary muscles are continuously kept under contraction.

(e) Binocular (stereoscopic) vision. When the eyes are at the sides of the head, as in a horse, rabbit or rat, each eye covers a different field of vision with no overlapping. This is known as *monocular vision.* If the animal is looking in front, there is a blind area just in front of the head so that one can walk straight in this blind area to the animal without being seen.

In man and other primates, however, both the eyes face forward, so that they form two separate images of the same object. But two images are not seen due to overlapping of their fields of vision. As a result, the object is seen in three dimensions which also gives a sense of distance of the object in view. This type of vision in which the depth or distance is also judged is called *binocular* or *stereoscopic vision.*

[V] Organs of hearing or ears (stato-acoustic organs)

The senses of hearing and equilibrium are associated with a pair of *ears* which have reached their highest degree of development in mammals. For convenience in description a mammalian ear is divided into three parts : *external, middle* and *internal.* All the three parts are concerned with hearing, but only the internal ear with equilibrium.

1. External ear. The outer ear, variously known as the *auricle, concha* or *pinna,* is the visible, movable, oval, skin-covered cartilaginous projection from the side of the head. It surrounds the opening of a tubular passage, the *auditory canal* or the *external auditory meatus,* which leads into the skull terminating at a cone-shaped membrane, the *tympanum* or *ear drum.* The walls of auditory meatus are lined with skin containing hairs, oil glands and wax glands. The hairs, oil and wax, prevent dust particles and small creatures, such as insects, from entering and damaging the delicate ear drum.

In most mammals, including rabbit, the pinna is movable and designed to catch and concentrate sound waves. But the pinna of man is not so efficient because it is immovable. A person may cup his hand behind his ear to improve its sound collecting capacity.

2. Middle ear. Inside the ear drum is the air filled *middle ear* or *tympanic cavity* enclosed in a bony chamber. It is connected to the pharynx or throat by a tubular passage called the *Eustachian tube,* named after Bartolommeo Eustachio (1524-1574), an Italian anatomist. Its opening into pharynx normally remains closed, but when we swallow or yawn, it opens so that the air can pass

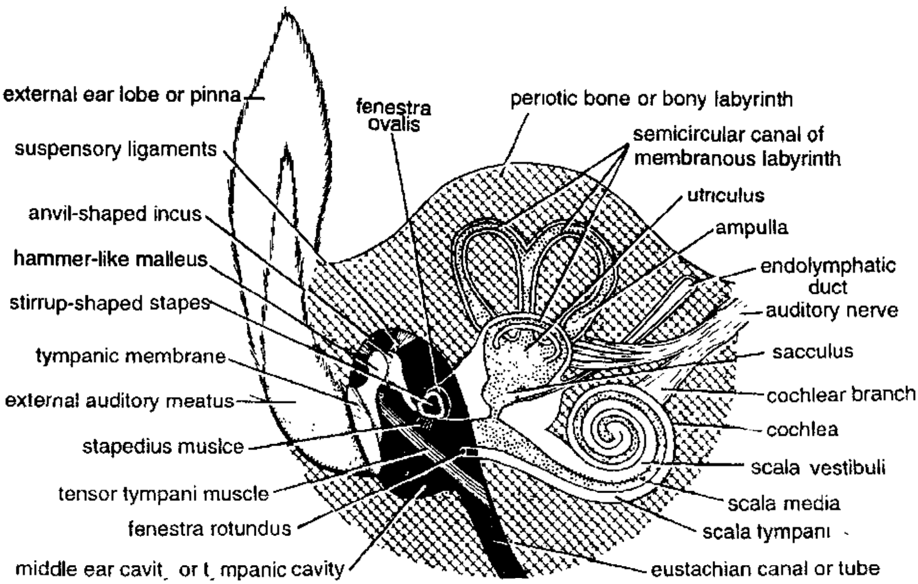

Fig. 44. Rabbit. Diagrammatic V.S. of head passing through ear region.

from pharynx into middle ear cavity, so that air pressure is equalized on both sides of the tympanum. This prevents distortion of tympanum by a pressure differential on the two sides.

If one climbs a high mountain or goes up a long steep hill in a car or rapidly gains height in an aircraft, the atmospheric pressure is suddenly reduced outside the ear drum. Similarly, if one goes down into a mine or goes for scuba diving, this pressure is increased. During such occasions, chewing of sweets helps to equalize air pressure on both sides of the ear drum via eustachian tube.

Besides being advantageous, the eustachian tube does have a disadvantage. If there is any bacterial infection in the mouth, throat or nose, it may spread via eustachian tube to the middle ear cavity causing ear ache or even leading to deafness.

In the wall between the middle and internal ears are two openings covered by thin membranes. The upper opening is called the *oval window* or *fenestra ovalis,* while the lower called the *round window* or *fenestra rotunda.*

The middle ear cavity in mammals characteristically contains a chain of three little bones or *ossicles*, extending between the tympanic membrane and the fenestra ovalis. These are called from outside as the *malleu.* (hammer), *incus* (anvil) and *stapes* (stirrup), so named because of their characteristic shapes. Homologically they represent the articular, quadrate and hyomandibular bones respectively of other vertebrates. The ear ossicles transmit vibrations of the tympanum to the internal ear through fenestra ovalis. It is known that only about 0.1% of the sound energy striking a fluid surface is able to penetrate into the flud, the rest 99.9% is simply reflected back. If all the sound waves would reach the fluid of the internal oar most of the the sound waves will be reflected back. At one end the malleus bone is embedded in the drum and at the other, the foot plate of the stapes coveres the oral window like a movable piston. The middle ear thus accomplishes the remarkable task of retrieving the otherwise lost sound energy by coordinated mechanical actions of the various parts.

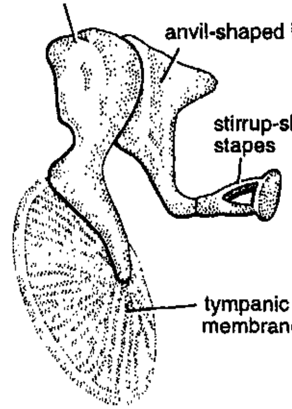

Fig. 45. Rabbit. Ear ossicles.

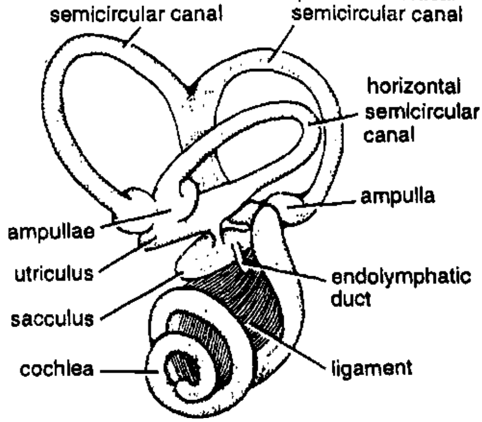

Fig. 46. Rabbit. Left membranous labyrinth in outer view.

3. Internal ear. The inner ear is the essential part containing the sensory cells from which impulses pass to the brain via the auditory nerve. It is a much complicated and delicate structure, comprising membranous walled sacs and canals and called the ***membranous labyrinth.*** It is hollow and contains a lymph-like fluid called ***endolymph.*** It is deeply embedded in the periotic bone in a narrow cavity of similar shape and appropriately called the *bony labyrinth.* The narrow space outside the membranous labyrinth is filled with another fluid called *perilymph.* It is not continuous with the endolymph at any point.

Membranous labyrinth. The membranous labyrinth is divided into three parts : the sac-like *utriculus* and *sacculus* (body proper), ***semicircular canals*** and *cochlea.*

(a) Utriculus and sacculus. The body proper is further differentiated into a larger upper chamber, the *utriculus,* and a smaller lower chamber, the *sacculus.* The two chambers are connected together by a small narrow *sacculoutricular duct.* The sacculus gives off a small slender *endolymphatic duct,* ending blindly against the cranium into an *endolymphatic sac.* Each chamber has a special group of sensory cells, called *macula,* with fine projecting hairs. The hairs are embedded in jelly also containing particles of calcium carbonate called *otoliths.* These sensory parts are called *macula utriculi* and *macula sacculi,* respectively. These help the animal to maintain the body posture or position of head. The bony labyrinth surrounding the utriculus and sacculus is known as *vestibule.*

(b) Semicircular canals. Attached to the ________ is a group of three narrow semicircular canals shaped like the handle on a tea cup. These are at right angles to one another, called *anterior vertical, posterior vertical* and *horizontal.* One end (the lower one) of each canal has a little swelling called the *ampulla.* Each ampulla has a group of sensory hair cells called *crista.* The hairs are embedded in a cone of jelly that may be disturbed by movements of the endolymph.

The cristae send information to brain about the accelerating and rotational movements. Their structure is similar to the maculae of utriculus and sacculus except that the crista has longer sensory hairs and lacks the otoliths.

(c) Cochlea. The membranous labyrinth of a mammal is similar to that of other vertebrates in many respects. But it differs chiefly by the addition of a long much coiled, tubular and blind outgrowth from the sacculus, called the *cochlear duct.* It is spirally coiled like a snail or a watch spring. The part of the bony labyrinth enclosing the cochlear duct is also similarly coiled and is called the *cochlear canal.* Together they form the cochlea which is the organ of hearing.

If the highly complex cochlea is uncoiled and straightened out, it forms a long and tapering tube. If cut in a cross section it shows three chambers or canals. The middle chamber or *scala media* is

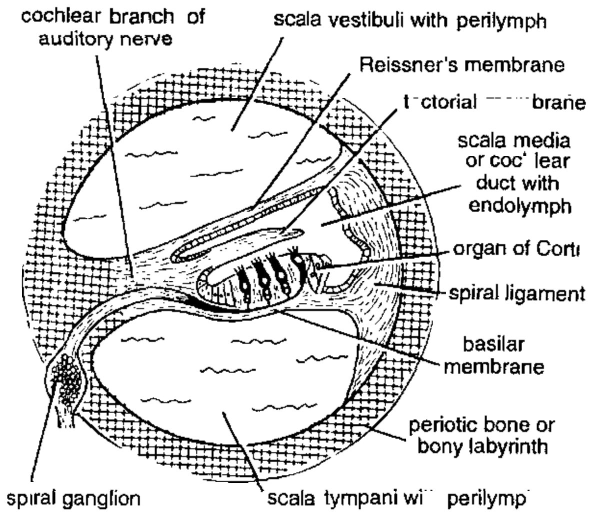

Fig. 47. Rabbit. T.S. of cochlea.

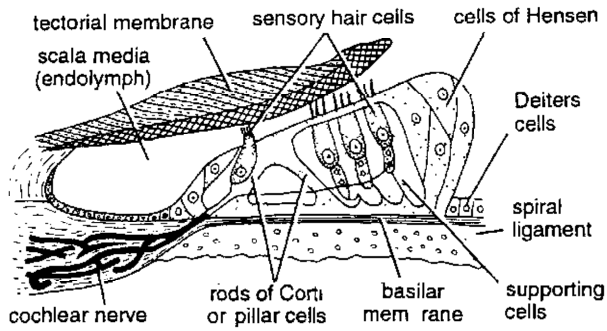

Fig. 48. Rabbit. V.S. organ of Corti.

the saccular outgrowth or cochlear duct filled with endolymph and terminating blindly at the apex of the spiral. The upper and lower chambers are the *scala vestibuli* and the *scala tympani,* respectively. Being parts of the bony labyrinth, both are filled with perilymph. Both remain separated longitudinally by a *spiral lamina,* but communicate around the tip of the spiral by a small opening called the *helicotrema.* At the basal end, the scala vestibuli communicates with the fenestra ovalis, and the scala tympani with fenestra rotunda.

The middle chamber of cochlea or scala media contains the organ of hearing named the *organ of Corti* after its discoverer. The epithelial lining of scala media, rests above (roof) on the *vestibular* or *Reissner's membrane* and below

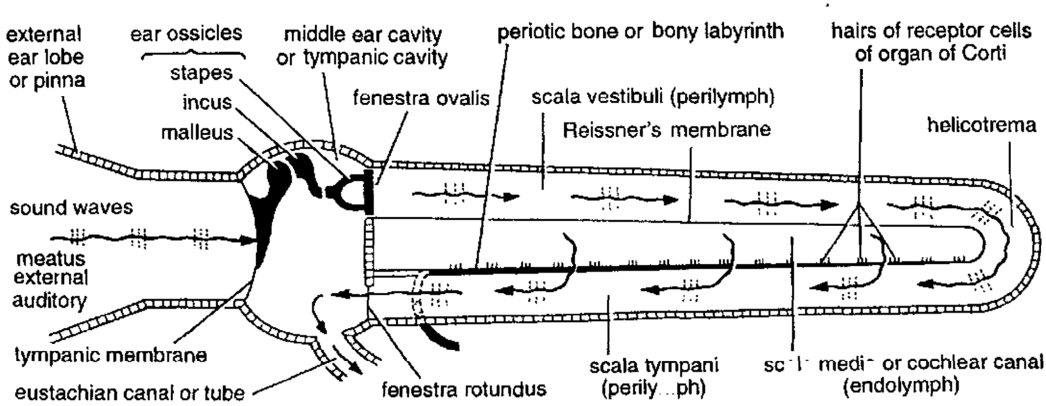

Fig. 49. Rabbit. Diagrammatic representation of the mechanism of hearing in the mammalian ear. Arrows indicate pathway sound vibrations.

(floor) on the *basilar membrane.* The latter is composed of tightly stretched transverse connective tissue fibres of varying lengths, shorter near the apex but longer near the base of the spiral. The basilar membrane bears a series of receptor *hair cells* with tall columnar supporting cells. The hair cells basally send out nerve fibres that make up the cochlear branch of the auditory nerve. A thin, gelatinous, ribbon-like sheet of connective tissue, called the *tectorial membrane,* overhangs the hair cells in close contact with their tiny hairs. The hair cells and the tectorial membrane collectively form the *organ of Corti.*

Working of ear (functions). The mammalian ear performs two different, unrelated functions, that of *hearing* and *equilibrium.*

(a) Hearing. *Cochlea* of the ear forms the organ of hearing. The sound waves collected by the *pinna* and travelling down the *external auditory meatus,* strike and cause the *tympanic membrane* or the *ear drum* to vibrate like the paper cone in a radio or television speaker. From tympanic membrane, the vibrations are transmitted mechanically across the middle ear through *ear ossicles* (malleus, incus and stapes) and *fenestra ovalis* into the *perilymph* of the inner ear. Due to lever action of the ear ossicles and due to smaller size of membrane covering the fenestra ovalis than the tympanic membrane, the force of vibrations received by the perilymph is increased manyfold (about 20 times). The vibrations in the perilymph pass through the *scala vestibuli* of cochlea, cross the *scala media* to reach the *scala tympani* and escape through *fenestra rotunda* back into the middle ear. The direct passage of vibrations from the perilymph of scala vestibuli to perilymph of scala tympani via *helicotrema* at the apex of the spiral is said to be negligible.

The increase or decrease in the pressure on the membrane of the fenestra ovalis, makes it to move into or out of the perilymph of scala vestibuli. Since liquids do not compress, the perilymph of scala tympani in turn causes the elastic membrane of fenestra rotunda to bulge out or in sympathetically with the increase or decrease in pressure. Thus the membrane of fenestra rotunda serves as a *pressure-relief-valve.* This arrangement prevents loss of perilymph from closed chambers as well as retains full vigour of vibrations until they are delivered to the sensory cells.

The alternating pressure changes in the perilymph set the endolymph and the *basilar membrane* into sympathetic undulations. The vibrations cause the *tectorial membrane* floating in the endolymph of scala media to brush the processes of the sensory hair cells of the *organ of Corti.* The nerve impulses produced are carried through cochlear branch of the auditory nerve to the brain where these are interpreted as sound.

Sound analysis by cochlea is very complex and not completely understood. The sound vibrations having different frequencies stimulate different parts of the basilar membrane. Higher notes (frequencies) seem to stimulate shorter fibres forming the basal part, while lower notes stimulate the longer fibres forming the apical part.

(b) Equilibrium. All vertebrates can perceive differences in the orientation of their bodies by responding to gravity and maintain their equilibrium. The *maculae* of utriculus and sacculus and the *cristae* of semicircular canals of the membranous labyrinth form the organs of equilibrium (balance and posture).

The *maculae*, as already mentioned, are special groups of sensory cells with fine projecting hairs in contact with a jelly with embedded particles of $CaCO_3$ or otoliths which are heavier than the surrounding endolymph. If the head is tilted, the otoliths bend the hairs to the side. As a result of this stimulation, the brain responds by causing appropriate muscles to contract thus bringing the head back to its normal position. Besides responding to the posture of the head and body *(static equilibrium)*, this apparatus also responds to *linear acceleration*, that is, straight line rapid forward or backward movements of the head, which are non-rotational.

The *cristae* are sensory organs in the ampullae of semicircular canals. They are similar to maculae but lack the otoliths. They respond only to the changes in the direction or rotational movements of the head. When the head is turned in a particular direction, the endolymph because of its inertia does not move as fast as the head thus bending the hairs in opposite direction, so that the brain is informed about the particular rotational movement.

A person may twirl, that is rapidly turn around and around and then suddenly stop. But the endolymph continues to turn in the semicircular canals for some time more stimulating hair cells and sending false information to the brain. As a result, the person who has actually stopped turning, but feels so. This confusion results in the dizziness or vertigo which is experienced in such cases.

Reproductive System

In rabbit the sexes are separate and *sexual dimorphism* is well marked.

[I] Male reproductive system

The male reproductive organs include a pair of *testes*, a pair of *epididymes*, a pair of *vasa deferentia*, *urethra*, *penis* and some *accessory glands*.

1. Testes. The paired testes are small, ovoid bodies of light pink colour. Each testis lies in a special thin-walled sac of hairy skin outside the abdominal cavity, called the *scrotum*, which is located ventrally in the pubic region. In the foetus and new born rabbit, the testes lie within the abdominal cavity, near kidneys where they were developed. But at puberty, they descend through *inguinal canals* into scrotal sacs. In most species of mammals the testes remain within scrotal sacs throughout life. But in rabbit, rat and other rodents, they are migratory. They descend into the scrotum during the breeding season, but withdraw into the abdominal cavity during non-breeding periods through inguinal canals which remain open throughout life. The reason for this is a curious one. In mammals, spermatozoa can develop only within a limited temperature range. They cannot develop inside the abdomen because of the normally high temperature, but develop within the scrotal sacs having a somewhat lower temperature.

Histologically, the mammalian testis is composed of a number of wedge-shaped or cone-shaped compartments or *lobules*. The outer protective covering of testis, the *tunica albuginea*, is a tough capsule made of white fibrous connective tissue, which projects inwards forming interlobular septa. Each lobule contains long, slender, much convoluted microscopic *seminiferous tubules*, bound together by connective tissue. The germinal epithelium lining the tubules is made of two kinds of cells. The most numerous are the smaller *spermatogenic cells* which undergo spermatogenesis to produce spermatozoa. A few larger, tall, columnar supporting cells, called

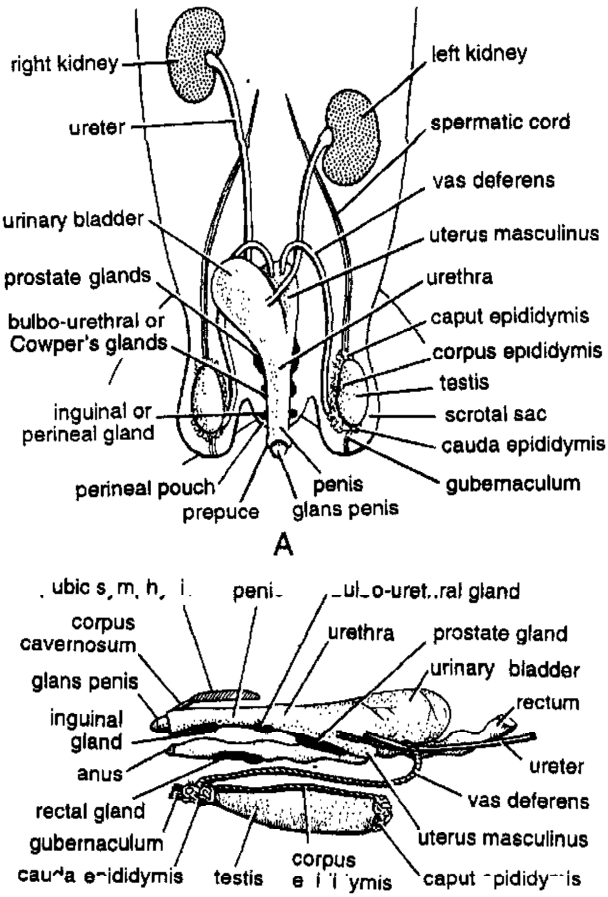

Fig. 50. Rabbit. Male urinogenital system. A—Ventral dissection. B—In side view.

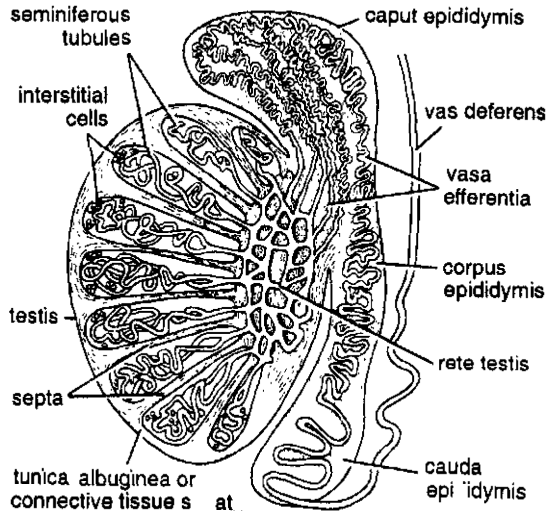

Fig. 51. Rabbit. L.S. of testis and epididymis showing structure and relationship.

Sertoli cells, nourish the sperm cells before they leave the tubule. Each *sperm* consists of a head composed mainly of the nucleus, and a long cytoplasmic tail. In the connective tissue between the seminiferous tubules lie scattered the *interstitial cells* or the *cells of Leydig* which are endocrine in function.

All the seminiferous tubules in each testis open into a network called *rete testis.* It opens by several fine ductules lined by cilia, called *vasa efferentia,* into the *epididymis..* The spermatozoa produced by testis are transferred through vasa efferentia into the epididymis.

2. Epididymes. The epididymis is an irregular, narrow and highly convoluted tubule of great length. It forms a compact ridge-like mass all along the inner surface of the testis. The epididymi_ ha_ _hree di__inct parts :

(a) Caput epididymis. It is the head or a_t____ pa__ which _s c___nected with the anterior end of the testis through vasa efferentia. It lies buri__ in t__ fat b__y. It is also conn_cted with the dorsal abdominal wall by a *spermatic cord* _onsis_ing of _onn___iv_ tissue, spermatic artery, spermatic vein and a nerve. The vein forms an extensive capillary network round the artery called the *pampiniform plexus.*

(b) Cauda epididymis. It is the tail or posterior part which connects the posterior end of the testis to the scrotal sac by a thick elastic cord of connective tissue, called the *gubernaculum.* When it shortens, it draw the testis into the scrotal sac.

(c) Corpus epididymis. It is the narrow body or middle part connecting the caput and the cauda epididymes.

The two epididymes serve to store and nourish the spermatozoa.

3. Vasa deferentia. The basal end of each epididymis (cauda epididymis) leads into a yellowish-white, straight somewhat heavier, and muscular tube, the *sperm duct* or *vas deferens.* It runs forward along the inner side of the scrotal sac, traverses the inguinal canal to enter the

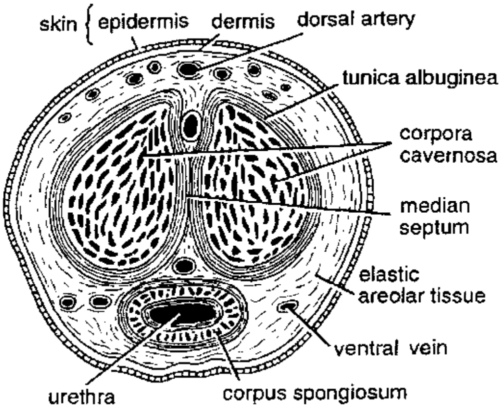

Fig. 52. Rabbit. T.S. of penis.

abdominal cavity, loops ventrally under the ureter and opens dorsally into urethra immediately in front of the opening of the ureter, A small, slightly bifurcated blind sac, the *uterus masculinus* or *seminal vesicle,* opens dorsally into urethra just dorsal to the openings of vasa deferentia.

4. Urethra. The neck of the urinary bladder and the vasa deferentia open into a thick-walled muscular duct, the urethra. It is the common passage for both urine and semen and called the *urinogenital duct* which traverses and opens at the tip of the penis as the *male urinogenital aperture.*

5. Penis. The copulatory organ or penis is a small, cylindrical and erectile organ in front of the anus. It is composed of three longitudinal columns of spongy erectile tissue, which becomes filled with blood during sexual exitement to produce an erection of penis. Surrounding the urethra is *corpus spongiosum* above which lie the two *corpora cavernosa.* The penis is enclosed in a sheath of skin which hangs loosely as a fold over its cap-like tip or *glans penis* as *prepuce.* The penis serves to transmit sperms into the vagina of the female during sexual intercourse. The operation of circumcision is the removal of the prepuce.

6. Accessory sex glands. Several accessory sex glands open into urethra of male. Their secretions, together with those of epididymes and uterus masculinus, constitute the *seminal fluid* or *semen.*

(a) Prostate gland. A large prostate gland lies dorsally around the base of uterus masculinus. It opens into urethra by several small ducts. Its whitish alkaline secretion activates the passive spermatozoa.

(b) Cowper's glands. A pair of ***bulbourethral*** or *Cowper's glands* lie posteriorly to the prostate dorsally at the base of penis. Their secretion neutralizes acidity for the protection of spermatozoa.

(c) Perineal glands. These are a pair of dark elon ated scent lands lying behind the Cowper's glands. As mentioned earlier, they open into the hairless perineal depress ons one on e t er s de of anus. Their odorous secretion gives the rabbit its characteristic smell.

(d) Rectal glands. A pair of rectal glands of unknown function is situated dorsally on the rectum.

[II] Female reproductive system

The female reproductive organs include a pair of *ovaries,* a pair of *oviducts,* a pair of *uteri, vagina, vestibule, clitoris* and some *accessory glands.*

1. Ovaries. The two ovaries are small, whitish, oval bodies, about 2 cm long. They are found behind the kidneys, each ovary attached to the dorsal abdominal wall by a double fold of peritoneum called *mesovarium.* From the surface of ovaries project several blister-like, small, rounded, semitransparent projections, called *ovarian* or *Graafian follicles,* each containing a developing ovum.

Histologically, the section of a mammalian ovary shows a peripheral layer of *germinal epithelial cells* surrounding a dense mass of connective tissue fibres, called *stroma,* containing blood and lymph vessels and nerves. Stroma contains groups of actively dividing germinal cells, called *follicles,* in various stages of development. In each follicle, a single cell, destined to become *oocyte* or *ovum,* enlarges while other cells surround and nourish it forming a protective mass called *discus proligerous* which is attached to one side of the follicle. When ripe, the follicles are known as *Graafian follicles,* which project from the surface of ovary as minute bumps. Each contains a large fluid-filled *follicular cavity.* The cells lining the cavity are termed *membrana granulosa.* The fully mature oocyte is surrounded by a thick transparent membrane called *zona pellucida* containing yolk and fat droplets. It is covered by another striated layer of columnar cells, called *corona radiata* : In the stroma there are also groups of *interstitial cells* which produce sex hormones *(oestrogen).*

Eventually, each mature follicle bursts to liberate the oocyte into body cavity, a process known as *ovulation.* The follicular cells remaining behind divide rapidly to form a yellowish solid moss of cells called *corpus luteum.* During pregnancy it serves as a temporary endocrine gland secreting a hormone (*progesterone*) which causes uterus to enlarge to receive the growing foetus and stimulates lactation. It ovum is not fertilized, corpus luteum gradually disappears leaving a scar called *corpus albicans.*

2. Oviducts. Each oviduct opens anteriorly, close to the outer border of the ovary of its side, by a wide funnel called *fallopian* or *oviducal funnel.* The opening of funnel, or *ostium,* is fimbriated, that is, beset with many cilia to receive the minute ova released from the ovary. Funnel leads into the upper part of oviduct. It is a short, narrow, coiled and internally ciliated duct called *fallopian tube.* Ova pass through this tube by ciliary action and fertilization also occurs here. The fallopian tube is followed by a much wider, longer convoluted, thick walled muscular tube the *uterus.* It is richly vascular and highly distensible and attached to the dorsal abdominal wall by a *mesentery.* Fertilized ova or zygotes get implanted on the uterine wall to develop into embryos or foetuses, each attached to the placenta by an umbilical cord.

3. Vagina and vestibule. The uteri of both the sides meet into a long wide, median duct, the *vagina,* lying dorsally upon the urinary bladder. It opens posteriorly into the neck of bladder to join the urethra forming a short narrow common *urinogenital canal* or *vestibule.* It runs backwards ventral to the rectum and opens to the exterior by a slit-like aperture, the *vulva.* The vagina serves to receive the penis of the male during copulation.

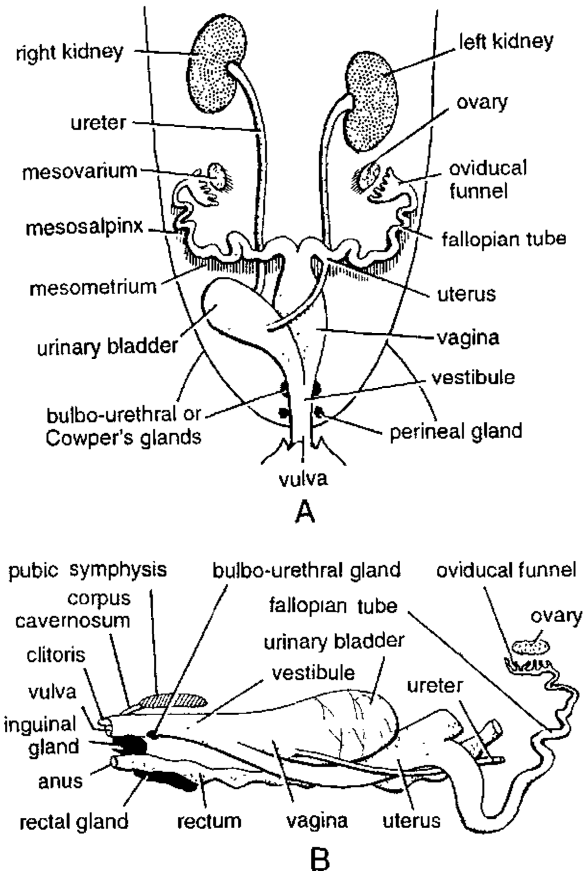

Fig. 53. Rabbit. Female urinogenital system. A—Ventral dissection. B—In side view.

4. Clitoris. From the anterior wall of vulva projects a small erectile knob-like *clitoris.* It is regarded homologous with the male penis since it contains a pair of erectile tissue, the corpora cavernosa. But the urethra does not pass through the clitoris.

5. Accessory sex glands. In the female rabbit, there is no *prostate gland.* A pair of small *Bartholin's* glands or *Cowper's glands* lie embedded in the dorsal wall of vestibule. Their viscid secretion lubricates the vaginal passage. They are reduced in size or even absent. The *perineal* and *rectal glands* are also found as in the male.

Endocrine System

All the vertebrates have two types of glands in their body—*exocrine* and *endocrine.*

1. Exocr'ne glands. An exocrine gland ' as a duct to liberate its secretion to the exterior of the body or into an internal organ. Examples are salivary glands, liver and pancreas.

2. Endocrine glands. The term '*endocrine*' means 'internally secreting. The endocrine glands are located in various regions of the body. They do not have any duct, hence the name '*ductless glands*' originally applied to them. Their secretions are called *hormones,* a term coined by the British physiologist E.H. Starling in 1905. These diffuse directly into the blood stream and transported to other parts of the body where they regulate some metabolic activity. The hormones are definite chemical compounds each having a rather specific effect upon some particular organ or tissue, called the *target organ* or *tissue.* They serve as *chemical messengers* and bring about *chemical coordination* of various parts in the body, as distinguished from t..e *nervous coordination* which is produced by t... nervous system. Whereas the effect of nervous system is quick and of shorter duration only, the action of endocrine system is slow and of longer duration.

The study of the endocrine glands is done under the branch of zoology called *Endocrinology.*

The relative positions of the endocrine glands in the body and the hormones secreted by them are much the same in all the vertebrates. A summary of the main hormones of vertebrates and their physiological effects (functions) is given in the Table 3. The chief endocrine glands of vertebrates are :

(i) The pineal body, (ii) pituitary, (iii) carotid bodies, (iv) thyroid, (v) parathyroid, (vi) thymus, (vii) islets of Langerhans in pancreas, (viii) adrenals, (ix) gonads (testes and ovaries) and (x) the epithelial lining of alimentary canal.

Of these, the *pineal body* and *thymus glands,* previously considered to be endocrine, are no longer considered so because of their doubtful function in vertebrates. The same is the case with the *carotid bodies* in rat and rabbit. The pancreas and gonads do have ducts, but their endocrine secretions enter the blood stream directly by diffusion.

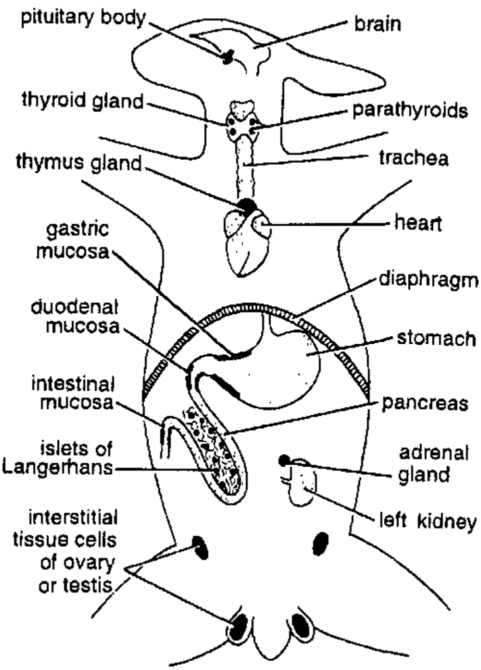

Fig. 54. Rabbit. Position of main endocrine glands.

1. Pineal body. This is a small rounded body lying on a slender pineal stalk in the roof of the diencephalon of brain. It can be seen by spreading apart the two lobes of cerebral hemispheres. It may be said to have pseudo-alveolar structure with the cells arranged in masses and lobules surrounded by highly vascular connective tissue. The modern concept is that the pineal gland connects neural information to endocrine information. Extracts of pineal gland show the presence of following hormones :

(i) Noradrenaline, (ii) serotonine, (iii) melatonine and (iv) aldosterone. Melatonine regulates the contraction of melanophores and is said to induce sleep. Darkness increases melatonine secretion. Serotonine is a vasoconstrictor substance. It effects mental processes and helps in keeping them sound.

2. Pituitary or hypophysis. The pituitary is a rounded structure located just below the diencephalon of brain attached to the hypothalamus by a stalk (the infundibulum). It is made of three main lobes. The *anterior* and *intermediate lobes* arise embryonically from the

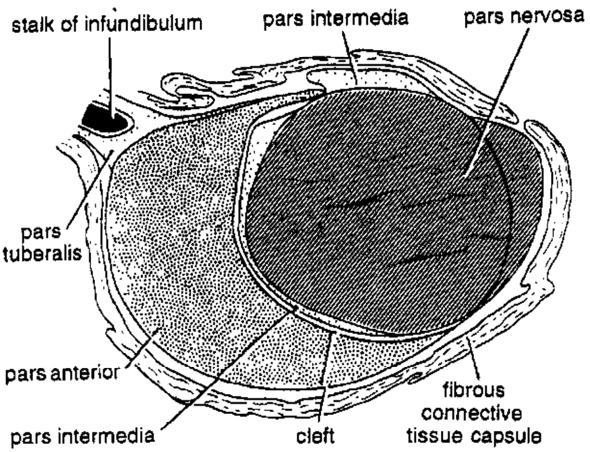

Fig. 55. Rabbit. V.S. of mammalian pituitary.

roof of the mouth and collectively known as *adenohypophysis.* The *posterior lobe* arises from the hypothalamus of diencephalon and is known as *neurohypophysis.* The female rabbit has somewhat heavier pituitary than that of the male. Pituitary is perhaps the most complex endocrine gland secreting about a dozen hormones some of which directly affect several body functions while others influence other endocrine glands. Therefore, it has often been ranked as the *master endocrine gland.* But, it is now understood that all the glands affect one another and bring about coordination of the body by their integrated actions. Several well known hormones are produced by the *anterior lobe* or *adenohypophysis.* They are named with the addition of the suffix '*trophic*' or '*tropic*' or '*in*' to the name of the body part affected by them. For example the *growth hormone* (GH) is named *somatotrophic* or *somatotropic hormone* (STH) or *somatotropin.*

(a) Somatotropin. It regulates protein synthesis and growth of skeleton. Insufficient secretion of this hormone in childhood results in a *dwarf* or *midget,* whereas too much of this hormone during development produces a *giant.* Its hypersecretion after maturity results in a condition known as *acromegaly* with barrel-chest, huge head, hands and feet, long jaws and rough skin.

(b) Thyrotropin. It is the *thyroid stimulating* hormone (TSH) affecting growth of thyroid and production of thyroxine.

(c) Adrenocorticotropin. The adrenocorticotropic hormone (ACTH) stimulates the growth of adrenal cortex and production of its hormones.

(d) Pancreatotropin. The pancreatotropic or diabetogenic hormone affects the metabolism of carbohydrates. It converts glycogen reserves into glucose, an effect opposite to that of insulin.

(e) Gonadotropins. At least two *gonadstimulating* or *gonadotropic hormones* (GTH) are known. One is the *follicle-stimulating hormone* (FSH). In its absence, the Graafian follicles in female and the seminiferous tubules in male fail to form and function. The other is the *luteinizing hormone* (LH) without which the gonads do not produce hormones.

(f) Prolactin. *Prolactin* or *lctogenic hormone* (LTH) promotes growth of mammary glands and secretion of milk during pregnancy.

The *intermediate lobe* of adenohypophysis secretes a hormone, *intermedin*, which controls the distribution of melanin pigment in the chromatophores of the skin. It is also known as the *chromatotropic hormone* (CTH) or *melanocyte-stimulating hormone* (MSH).

The posterior *lobe* of pituitary or *neurohypophysis* is associated with following two hormones in mammals :

(a) Oxytocin. It stimulates the contraction of the uterine muscles at the time of childbirth. It also stimulates milk secretion by the mammary glands.

(b) Vasopressin. It raises blood pressure and stimulates intestinal peristalsis. It is also called *antidiuretic hormone* (ADH) as it promotes reabsorption of water by kidney tubules. Its deficiency causes a disease known as *diabetes insipidus* in which the patient passes excessive urine, feels very thirsty and drinks copiously.

3. Carotid bodies. In rabbit, one carotid body or gland is situated in the bifurcation of common carotid artery between external and internal carotid arteries. They are of doubtful nature.

4. Thyroid. In mammals (rabbit), it is a bilobed gland in the neck. The two lobes are located on either side of the larynx and connected by a narrow transverse *isthmus* of tissue across the

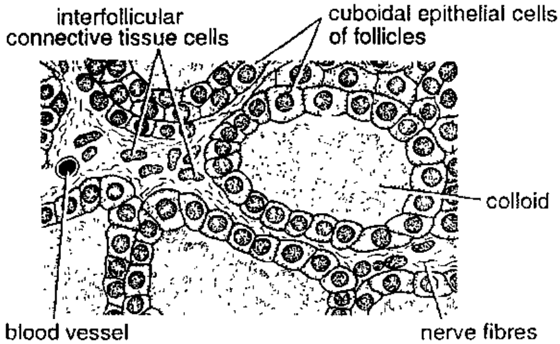

Fig. 56 Section of thyroid gland.

ventral surface of the trachea, just below the larynx.

The thyroid has an exceptionally rich blood supply. Histologically, it is made of small hollow spheres or *follicles* with walls composed of one cell thick cuboidal epithelium, and embedded in connective tissue containing blood and lymph vessels. The cuboidal cells secrete into the cavities of the follicles a yellow colloid containing the thyroid hormones one of which is *thyroxine.*

Thyroxine contains iodine and has two main functions : it stimulates O_2 consumption or increased metabolic rate and also controls the rate of growth thus affecting development.

Deficiency of thyroxine during infancy leads to *cretinism.* A cretin is stunted in growth, remains sexually immature or infantile and mentally retarded. Deficiency of hormone in adult *(hypothyroidism)* leads to *myxoedema* and the person remains fat, slow-witted and sluggish oweing to poor rate of tissue oxidation. The thyroid gland responds to a shortage of iodine in diet by pathologically enlarging and producing what is known as a *goiter* in the neck. This can be avoided by the people living in the goitre-belt by taking iodized salt or by eating sea foods which usually contain iodine.

An opposite condition is *hyper-thyroidism* or over-activity of the thyroid which means increased oxidation. The person becomes over-active, nervous and thin. Sometimes the eyes bulge out abnormally out of their sockets, a condition known as *exophthalmia.* Hyperthyroidism is also

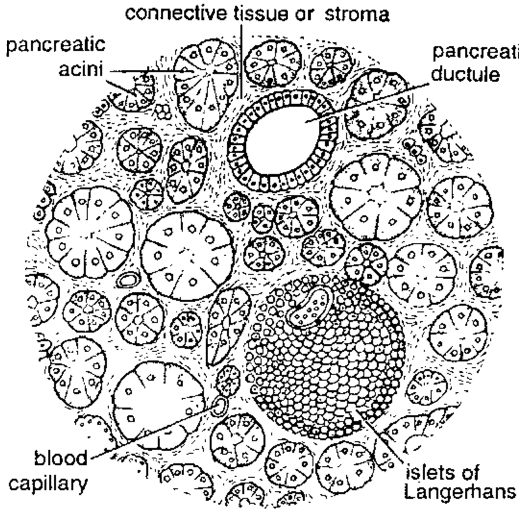

Fig. 57. Section of pancreas through Islets of Langerhans.

accompanied by the swelling of the gland leading to goiter formation in the neck.

5. Parathyroids. In rabbit, there are normally found two small, oval parathyroid glands, one attached antero-laterally to each lobe of thyroid gland. The usual number of parathyroids in other mammals is four. Their hormone, called *parathormone,* regulates the concentration of calcium and phosphorus in the blood and body fluids. The glands are essential for life and necessary for growth of bones, muscle tone and nervous activity. Their removal from body leads to muscular tremors, cramps and finally convulsions, a condition known as *tetany* which results in death.

6. Thymus. It is located in the upper chest region just in front of the heart and ventral to the base of trachea. It has maximum development during infancy but gradually degenerates or disappears altogether on reaching maturity. It is a soft, bilobed gland fully developed in a 90-day old rat. Little is known about its real function. It has been postulated that it is concerned with growth, attainment of sexual maturity and immunity.

7. Islets of Langerhans. Lying scattered in the connective tissue, which binds together the acini of the pancreas, are groups of endocrine cells called the *islets of Langerhans,* described by Paul

Langerhans in 1869. In the islets there are two types of cells, *alpha cells* that produce the hormone *glucagon,* and *beta cells* that secrete *insulin.* Both of these hormones function in controlling sugar metabolism.

Insulin stimulates the burning of glucose in cells into carbon dioxide and water and also its conversion and storage as glycogen in the liver and muscles. In case of deficiency of insulin, glucose is not utilized in the normal way, so its level rises in blood to such an extent that the kidneys excrete it in urine. It can be diagnosed by testing the urine for sugar with Benedict's solution. This disorder is known as *diabetes mellitus* which can be cured with an injection of insulin at frequent intervals.

Glucagon has the opposite effect of insulin. If the glucose concentration in blood goes down, glucagon converts glycogen of liver into glucose so that its concentration remains normal in blood.

8. Adrenal glands. The *adrenal* or suprarenal *glands* in rabbit are a pair of flat, oval, white bodies lying one in front of each kidney. They are relatively larger in female rabbit. Each gland consists of two distinct parts, an outer covering called the *cortex* derived from the mesoderm, and an inner or central part called *medulla* derived from the nervous tissue. The tissues of both the parts are distinct, their hormones different and their blood and nerve supplies individual.

(a) Cortex. The adrenal *cortex* secretes several hormones, all steroids synthesized from cholesterol, and the functions of all not clear. The best known are :

(i) Cortisone. It functions in the conversion of proteins into glucose and decreases inflammatory reactions of many kinds. Cortisone is used clinically for supressing allergies, tissue inflammation and rheumatoid arthritis.

(ii) Aldosterone. It controls salt (sodium and potassium) and water metabolism in the kidney tubules and is widely used clinically.

(iii) Adrenosterone. It is an androgen (male sex harmone) which stimulates the development of male characteristics.

Underactivity or failure of adrenal cortex in human beings results in *Addisons' disease.* It is characterized by muscular weakness and nervous depression due to decline in blood sugar. Blood pressure becomes low due to increased excretion of salts in urine. Appetite for food and water decreases and weight is lost. The sexual function fails and the skin becomes bronze in patches due to deposition of melanin. Death ensues within a few days.

Overactivity of adrenal cortex enhances maleness in males with excessive hair growth. In a male child, sex organs becomes mature, and the hair, musculature and voice resemble those of an adult man. In an adult woman, a beard grows, body becomes muscular, voice deepens and the ovaries become nonfunctional.

(b) Medulla. The adrenal medulla produces two closely related hormones *epinephrine,* sometimes called *adrenaline and norepinephrine.*

(i) Epinephrine or adrenaline. Normally small amounts of this hormone are continuously secreted into the blood and maintain the muscle tone. But its secretion is greatly enhanced during emergencies and emotional stresses such as fear, anger, fighting, nervousness, worries, cold, pain, etc. All these situations require a sudden burst of energy for which a chain of events taks place. The heart beats faster, blood pressure rises, breathing rate increases, more glycogen of liver is broken down raising sugar level of blood thus releasing more energy. In a sense, adrenaline enhances and prolongs the action of the sympathetic nervous system controlling involuntary activities of the body. Fortunately, the effects of excessive hormone are quickly destroyed after the emergency.

Adrenaline is widely used clinically in treating *asthma* where it dilates the respiratory passages, in increasing blood pressure under *shock* following an accident or an operation, and in *starting a heart* that has suddenly stopped beating.

(ii) Norepinephrine. It constricts blood vessels and resgulates the blood pressure under normal conditions.

***Table 3.* Summary of Vertebrate Hormones.**

Source (Endocrine gland)	Hormone	Physiologic effects (Functions)
1. Pineal body		
2. Pituitary		
(a) Anterior lobe	1. *Somatotropin*	Controls growth and metabolism of protein. Deficiency causes dwarfism, excess causes gigantism and acromegaly
	2. *Thyrotropin* (TSH)	Stimulates thyroid
	3. *Adrenocorticotropin* (ACTH)	Stimulates adrenal cortex
	4. *Pancreatotropin* (PTH)	Suppresses secretion of insulin
	5. *Follicle-stimulating hormone* (FSH)	Affects growth of Graafian follicles in ovary and seminiferous tubules in testis
	6. *Luteinizing hormone* (LH)	Affects production and release of gonadal hormones
	7. *Prolactin* (LTH)	Affects mammary glands and milk production
(b) Intermediate lobe	*Intermedin*	Affects pigments in skin chromatophores
(c) Posterior lobe	1. *Oxytocin*	Stimulates contraction of uterine muscles and secretion of milk
	2. *Vasopressin*	Regulates blood pressure and water loss by kidneys
3. Carotid bodies	?	
4. Thyroid	*Thyroxine*	Increases O_2 consumption or basal metabolic rate. Deficiency leads to cretinism in children and myxoedema in adults. Hyperthyroidism causes goiter formation and exoptholmia.
5. Parathyroids	*Parathormone*	Regulates calcium and phosphorus metabolism
6. Thymus	?	Regulates growth, sexual maturity and immunity
7. Islets of Langerhans		
(a) Beta cells	1. *Insulin*	Oxidation of glucose and its conversion into glycogen. Deficiency causes diabetes mellitus
(b) Alpha cells	2. *Glucagon*	Conversion of liver glycogen into blood
8. Adrenal		
(a) Cortex	1. *Cortisone*	Conversion of proteins to carbohydrates
	2. *Aldosterone*	Metabolism of sodium and potassium
	3. *Adrenosterone*	Stimulates male characteristics
(b) Medulla	1. *Epinephrine or adrenaline*	Supplements action of sympathetic nervous system during emergencies
	2. *Nonepinephrima*	Norepinephrine Regulates normal blood pressure
9. Gonads		
(a) Testes	*Testosterone*	Development and maintenance of male sex characters
(b) Ovaries	1. *Estrogen*	Development and maintenance of female characteristics
	2. *Progesterone*	Changes associated with pregnancy
(c) Placenta	1. *Chorionic gonadotropin*	Acts with other hormones to maintain pregnancy
	2. *Relaxin*	Relaxes pelvic ligaments at child birth
10. Alimentary canal		
(a) Stomach	*Gastrin*	Induces gastric secretion
(b) Duodenum	1. *Enterogastrone*	Slows down gastric secretion
	2. *Secretin*	Stimulates pancreatic secretion
	3. *Cholecystokinin*	Stimulates bile secretion

9. Gonads. The ovaries and testes not only produce gametes (ova and sperms), but they also act as ductless glands and secrete sex hormones.

(a) Testis. The connective tissue in between the seminiferous tubules of the testis contains special *interstitial cells* or *cells of Leydig*. They secrete the male sex hormones (androgens) such as *testosterone*. It stimulates secondary sexual characteristics of the male such as the enlargement of the external genitals and accessory glands, growth of beard and body hairs, deepening of voice, coloration and aggressive behaviour.

(b) Ovary. The main hormones produced by the vertebrate ovaries are :

(i) Oestrogen or estradiol. It is the counterpart of the male testosterone and is produced by the cells surrounding the Graafian follicles. It brings about the development of the female secondary sexual characteristics such as enlargement of breasts and genital organs, fat deposition under skin, changes in body contours, broadening of pelvis and the onset of menstrual cycle.

(ii) Progesterone. It is secreted by the corpus luteum of the ovary. It suspends ovulation during pregnancy and prepares the uterine wall for the fixation of the embryo and its development.

(c) Placenta. The placenta secretes *chorionic gonadotropin* produced by the cells of the chorionic villi which acts with other hormones to maintain pregnancy. It also secretes *estrogens* and *progesterone* which supplement those produced by the ovary for the maintenance of pregnancy. In some mammals (e.g. rabbit), the ovary as well as the placenta secrete the hormone *relaxin* which relaxes pelvic ligaments to facilitate the easy birth of the young one.

10. Epethelial lining of alimentary canal. The mucous lining of pyloric stomach produces a hormone *gastrin* which stimulates the gastric glands to produce more gastric juice. The wall of duodenum secretes some hormones. Of these, the *enterogastrone* inhibits gastric secretion, *secretin* stimulates pancreas to pour the pancreatic juice into duodenum, and *cholecystokinin* causes gall bladder to contract forcing bile through bile duct into duodenum.

Gametogenesis

Before fertilization the gametes are formed though meiotic cell divisions to produce haploid cells. This process is known as gametogenesis. In male the spermatozoa are produced through spermatogenesis and in female the ova are produced through oogenesis.

Spermatogenesis

Spermatogenesis takes about 64 days. It begins in spermatogonia which contain deploid chromosome number. These cells develop from the primordial germ cells which arise from the yolk sac endoderm and enter the testes early in development. In the embryonic testes the primordial germ cells differentiate as spermatogonia but remain dormant until they begin to undergo mitotic proliferation at puberty.

Spermatogonia are known as the stem cells because when they undergo mitosis, some of the daughter cells remain near the basement membrane in an undifferentiated state and serve as the reservoir cells for future mitosis. The rest of the daughter cells loose contact with the basement membrane of the seminiferous tubule and are differentiated as primary spermatocytes. These cells are also deploid cells.

Reduction division (Mitosis I)

In this phase the primary spermatocytes enlarge. Then two nuclear divisions take place as part of meiosis. In the first division the DNA replicates and the chromosomes made of a pair of chromatids move towards the equatorial plane of the cell. There they line up in homologous pairs of duplicated chromosomes in the centre of the cell. At this point crossing over takes place which permits the exchange of genes between the chromatids. The meiotic spindles are then formed which pull the duplicated chromosomes toward opposite poles. The cells thus formed are termed as secondary spermatocytes which are haploid. Each chromosome within a secondary spermatocyte is made up of two chromatids still attached by a centromere.

Equatorial division (Meiosis II)

In this phase there is no replication of DNA. The chromosomes come to be along the equatorial plane and their chromatids get separated from each other and finally form daughter cells which are known as spermatids, each having half number of chromosomes (haploid). In this way each primary spermatocyte produces four spermatids by meiosis through two rounds of cell division. The s~ermatids so prouuceu f~il t~ ---pl-t- cytokinesis. The four daughter cells remain in contact via cytoplasmic brid~es.

Spermiogenesis

In this phase maturation of spermatids into sperm takes place. Each spermatid develops a head with an acrosome and a flagellum and in this way is differentiated into a sperm cell (spermatozoan) which later attaches to the sustentacular cells for som~tim~ and ar~ th~n r~l~as~d from them. This hase f release is kn wn as spermiati n.

Hormonal control of spermatogenesis

Spermatogenesis is initiated by the increase in secretion of t e gonadotropic ormones (i) leutilizing hormone (LH) and follicle stimulating hormone (FSH). Release of these hormones is regulated by the gonadotropin releasing hormone (GnRH) released from the hypothalamus. FSH helps in d~v~lopm~nt of follicl~s. LH stimulates the Leyding cells which secrete testosterone (male hormone). An enzyme called 5 alpha-reductase converts testostero..e to a more pote..t a..droge.. called dihydrotestosterone (DHT). FSH anu LH act together on sustentacular cells (Sertoli cells) which produce a protein, the androgen binding protein (ABP) which binds to testosterone which keeps the concentration of testosterone high near the tubules. Testosterone stimulates the final steps of s~~rmatog~n~sis. Figure ~xplains th~ various events more elaborately.

Oo~enesis

It is the process through which the haploid (h) secondary oocytes are formed in the ovaries. It includes several phases including meiosis.

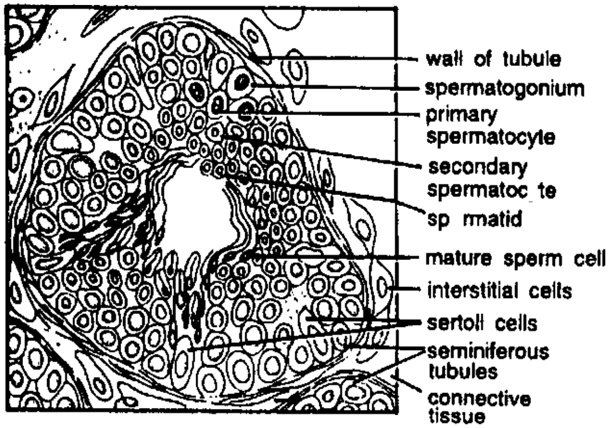

Fig. 58. Cross section of seminiferous tubule of man showing spermatogenesis.

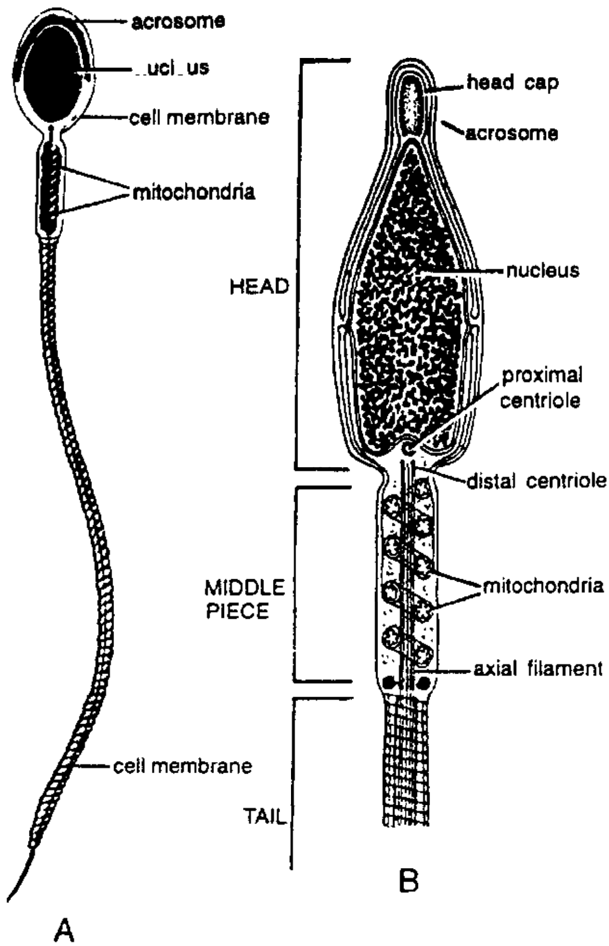

Fig. 59. Structure of mammalian sperm under electron microscope. A—Complete sperm, B—A part magnified.

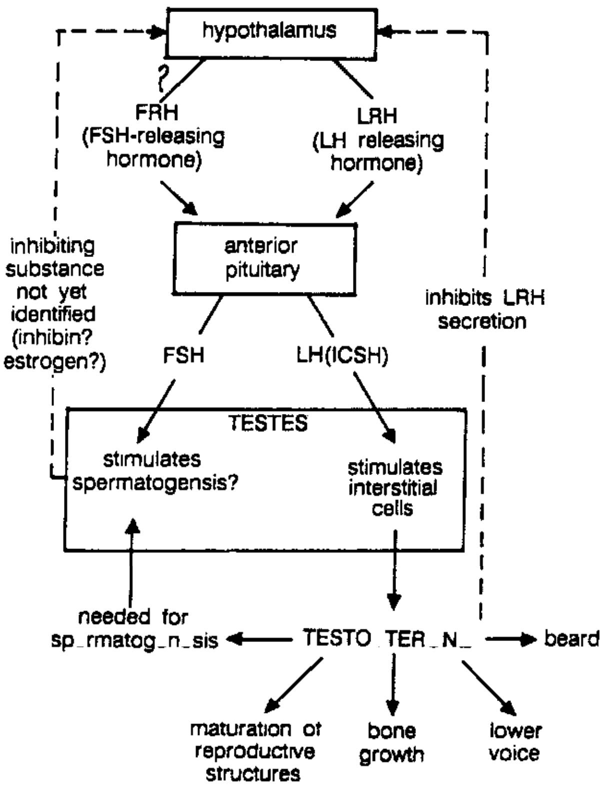

Fig. 60. Reproductive hormone relationship in the male, dotted line shows inhibition.

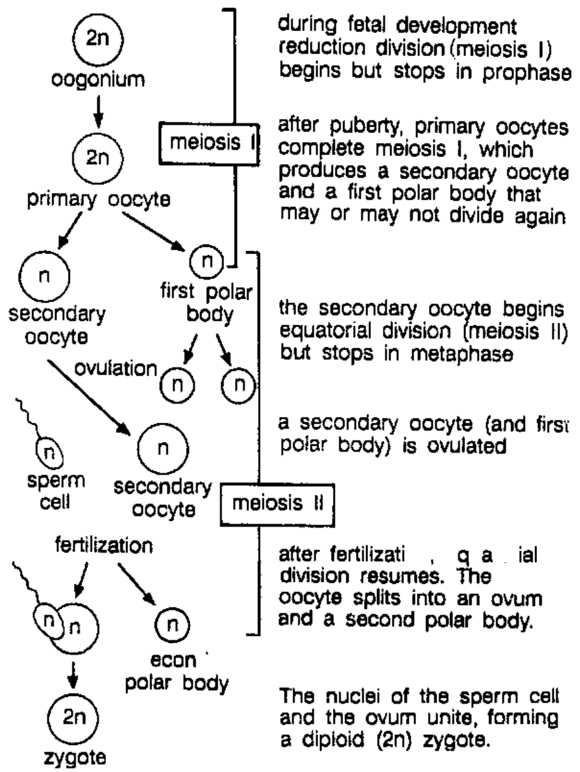

Fig. 61. Summary of events associated with fertilization and implantation.

Reduction division (Meiosis I)

During early development of the foetus the primordial germ cells migrate from the endoderm of yolk sac to lie in the ovaries and differentiate into deploid (2n) oogonia. The oogonia divide mitotically to give rise to a large number of germ cells. Many of these germ cells undergo degeneration and a few develop into primary oocytes which enter into prophase of reduction division (meiosis I) during fetal development but do not complete it till puberty.

Each primary oocyte is surrounded by a single layer of follicular cells, and the entire structure is called the primordial follicle. The primary follicles are surrounded by a single layer of cuboidal cells. Later on more layers are added to it (6-7) called the granulosa cells. A glycoprotein layer zona pellucida develops between the primary oocyte and the granulosa cells. The innermost layer of the cells becomes firmly attached to the zona pellucida and is called the corona radiata. The outermost granulosa cells form theca folliculi which consists of the theca interna and theca externa. The granulosa cells secrete a fluid which accumulates in the cavity of the follicle called antrum. The follicle is now called the secondary follicle. After puberty, under the influence of the gonadotropin hormones secreted by the anterior pituitary gland meiosis starts in some of the follicles. The diploid primary oocytes complete reduction division and two haploid cells of unequal size are formed both with half number of chromosomes. The smaller cell so produced is called the first polar body. The polar body contains mostly the discarded nuclear material and very little cytoplasm. The larger cell known as the secondary oocyte proceeds to the metaphase of the equatorial division (meiosis II) and then stops at this stage. The follicle containing such oocytes are

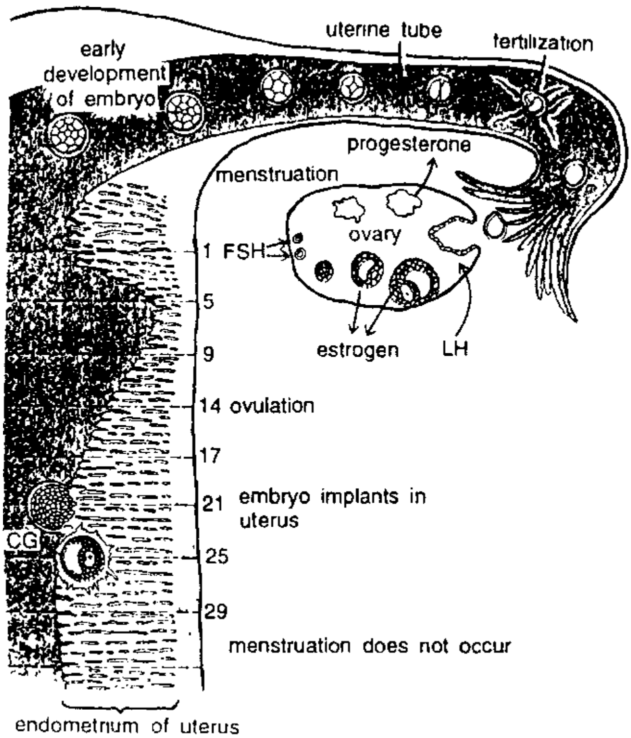

Fig. 62. Interruption of menstrual cycle after pregnancy in human.

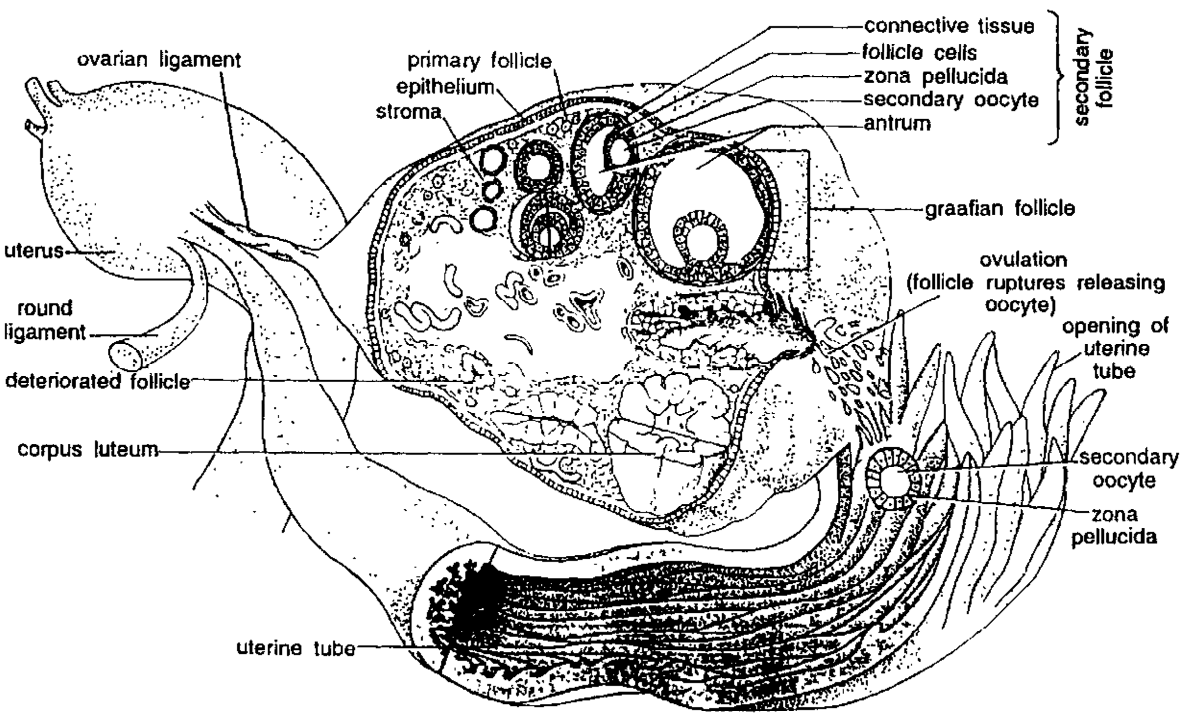

Fig. 63. Section of ovary and other associated organs of human female showing follicles in various stages of development.

called the mature follicles or Graafian follicles which rupture and release the secondary oocyte (ovulation).

Equatorial division (Meiosis II)

At ovulation the secondary oocyte is expelled into the pelvic cavity but soon is taken into the fallopian tubes. If fertilization does not take place the secondary oocyte degenerates. If fertilization takes place the equatorial division (meiosis II) takes place. The secondary oocyte divides into two unequal haploid cells. The larger cell is the ovum (mature egg) and the smaller one is the second polar body. The nuclei of the sperm and the ovum unite to form the diploid (2n) zygote. The second polar body is degenerated. In this way one oogonium gives rise to a single gamete (ovum) whereas one spermatogonium produces four gametes (sperm).

Sexual Cycles

All vertebrates bread by sexual reproduction. These animals show tremendous changes in reproductive organs and general behaviour prior to reproduction. Since reproductive phase is regularly repeated, it is known as sexual cycle. In mammals the female exhibits rhythmic changes related to reproductive phase which can be easily recorded. There are types of sexual cycles in mammals : (i) Oestrous cycle, (ii) Menstrual cycle.

Oestrous cycle

The changes in reproductive organs during reproductive phase are inter-related. All these inter-related changes constitute the oestrous cycle. In non-primates the events oestrous cycle are more or less similar, although there are slight variations from species to species.

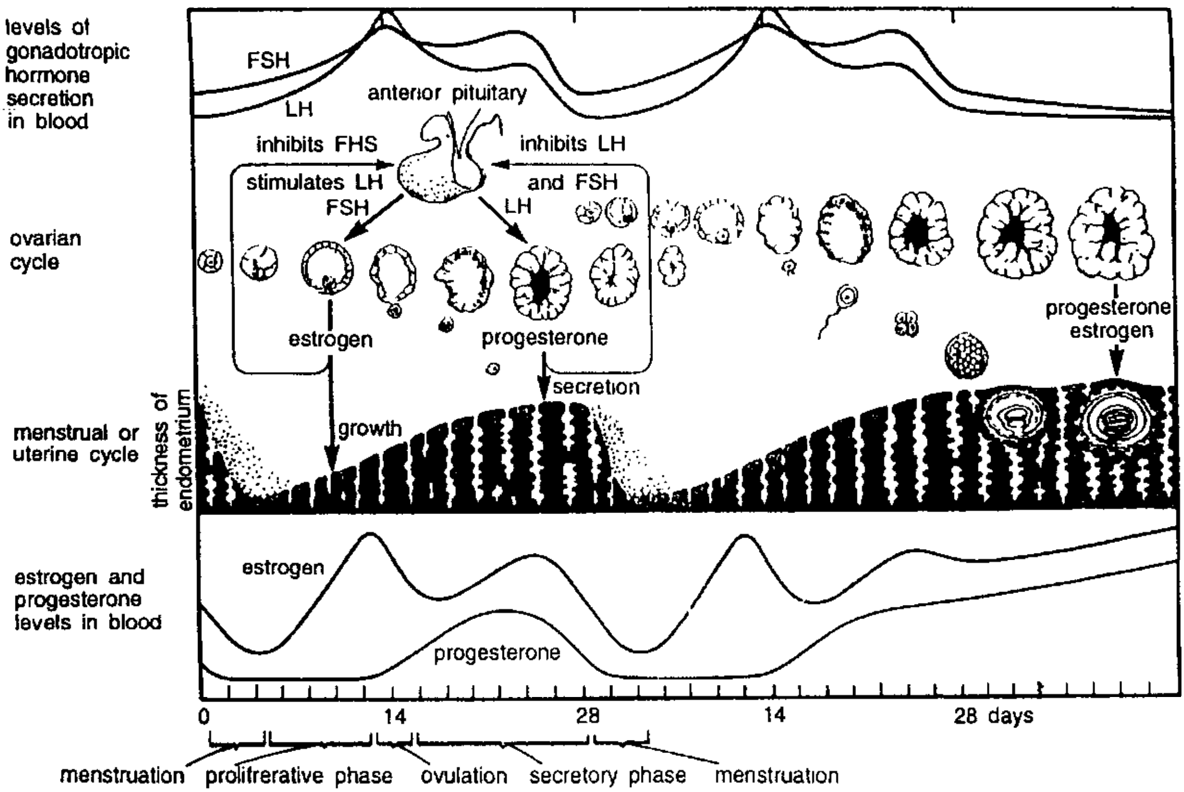

Fig. 64 Events in menstrual cycle and their hormonal regulation in human.

Types of oestrous cycle. ***(a) Polyoestrous.*** When many oestrous cycles occur in a year, the animal is called polyoestrous e.g., cow, pig, rabbit etc.

(b) Monoestrous. When only one oestrous cycle occurs in a year, the animal is called monoestrous e.g. wolf, fox, dear etc.

Duration of oestrous cycle. Length of oestrous cycle varies in different groups. It is 21 days in pig, 5 days in rat and mouse. There may be slight variations also due to various factors.

During oestrous cycle changes occur most predominantly in ovary, uterus, mammary glands and vagina.

Changes in oestrous cycle. During oestrous cycle, changes occur mainly in four different organs namely ovary, uterus, mammary glands and vagina. Four different patterns of changes occur which are described as follows ·

(a) Ovarian cycle. Changes occurring in the ovary are called ovarian changes.

(b) Uterine cycle. The changes occurring in the uterus are called uterine cycle.

(c) Mammary cycle. The changes occurring in the mammary glands are called mammary cycle.

(d) Vaginal cycle. The changes occurring in the vagina are called vaginal cycle.

Oestrous cycle in pig. In pig each oestrous cycle has a duration of 21 days. According to the activity of the ovary and the uterus and according to the behaviour of the animal, the oestrous cycle is divided into three cycles.

(1) Pro-oestrous.
(2) Oestrous.
(3) Dioestrous.

(a) Pro-oestrous. This period lasts for one day. Female shows no interest in the opposite sex. The uterus shows increased uterine glands and blood supply. The Graafian follicle in the ovary shows rapid growth.

(b) Oestrous. It takes three days. The female becomes restless and accepts mating. The vascular and glandular activities of uterine epithelium continue. Ovulation occurs the middle of this period.

(c) Dioestrous. The period lasts 17 days. The female shows no interest in the opposite sex. The ruptured follicle becomes filled with luteal cells reforms the corpus luteum which grows and persists for about first fourteen days and then starts to regress. The uterine epithelium becomes thick and secrete a viscous fluid the uterine milk.

In animals like cats, dog, etc. there are only two or three cycles a year with a long inactive interval between each period of heat. This inactive period is called anoestrous phase. During this phase the uterine epithelium is low.

Menstrual Cycle

This cycle is homologous to oestrous cycle and is a characteristic of primates (man and monkey). In this cycle there is periodic discharge of blood, mucus and cellular debris from the uterus through vagina called as menstruation and therefore, the cycle is known as menstrual cycle. Menstrual cycle in woman lasts for 28 days which may vary to some extent and sometimes it may extend to five weeks.

Phases of menstrual cycle

Menstrual cycle can be divided into three phases, namely —

(1) Proliferative phase
(2) Premenstrual phase or secretory phase, and
(3) Destrictive phase or menses

1. Proliferative phase. This period begins from the sixth day of menstruation and lasts for 9 days after the repair of the damage caused to the uterus during previous mensus. The uterine epithelium is low in the beginning but it then receives more blood supply and it increases in thickness. In the ovary the Graafian follicle grows and matures. On the 14th day ovulation occurs. The Graafian follicle ruptures and the egg is released.

2. Secretory phase or premenstrual phase. It lasts from 15th day to 28th day of the menstrual cycle (14 days). The uterine epithelium progressively increases in thickness and the uterus becomes highly vascular. The uterine glands become elongated and much coiled and secrete more mucus. The ruptured follicle is soon filled with blood and is now called corpus haemorrhagicum. The follicle cells multiply rapidly and they are deposited with a yellow carotenoid substance. These yellow cells replace the clotted blood of corpus haemorrhagicum and is converted to corpus luteum. If pregnancy occurs corpus luteum persist, otherwise it degenerates four days before menstruation. The degenerated corpus luteum then remains in the form of a connective tissue scar and is called corpus albicans.

3. Destructive phase or menses. This phase lasts for first four or five days of menstrual cycle. It occurs in the absence of pregnancy. Menstrual discharge takes place which contains mucus, cellular debris and the blood shed from the endothelium of the uterus.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the structure of mammalian skin and enumerate its functions.
2. Describe the food, feeding habits, digestive organs and process of digestion in rabbits.
3. Give an account of mammalian respiratory system.
4. What do you understand by tissue respiration. Describe the physiology of respiration in rabbit.
5. Describe the structure and working of a mammalian heart, with a note on its automacity.
6. Give an account of arterial or venous system of rabbit.
7. Describe the structure of blood of rabbit.
8. Describe fully the brain of rabbit.
9. Describe fully the internal ear of a mammal and discuss its advancement over an amphibian ear.
10. Describe the mechanism of hearing in rabbit. Draw a well labelled diagram of T.S. of ear of rabbit.
11. Describe the structure and working of mammalian eye. Also give the structure of retina of eye.
12. Describe the structure and physiology of mammalian kidney.
13. Describe the male and female urino-genital organs of rabbit.
14. Write an essay on endocrine system of rabbit.
15. Describe sexual cycles in detail.
16. Describe the hormonal regulation of the process of spermatogenesis.

» *Short Answer Type Questions*

1. Describe the structure of hair of rabbit.
2. Describe in tabular form the origin, distribution and nature of cranial nerves of rabbit.
3. Make well labelled diagrams of the following organs of mammals—(i) Ventral and dorsal view of brain, (ii) T.S. cochlea, (iii) T.S. ear region of rabbit, (iv) Male or female urinogenital system, (v) T.S. ovary, (vi) V.S. skin, (vii) T.S. tongue, (viii) T.S. through the region of thorax.
4. Write short notes on—(i) Corpus callosum, (ii) Differences between hare and rabbit, (iii) Graffian follicle, (iv) Sylvian fissure.
5. What is gametogenesis ? Describe the process of spermatogenesis.
6. Describe the process of oogenesis.

» *Multiple Choice Questions*

1. The burrow of rabbit is called :
(a) Warren (b) Form
(c) Barren (d) Barrel
2. The burrow of hare is called :
(a) Warren (b) Form
(c) Barren (d) Barrel
3. The external nares in rabbit are surrounded by :
(a) Hare lip (b) Vibrissae
(c) Rhinarium (d) Nictitating membrane
4. The perineal pouch bears :
(a) Anus (b) Cloaca
(c) Vulva (d) Perenial scent glands

5. The tail in rabbit serves as :
(a) Balancing organ (b) Sensory organ
(c) Decorative structure (d) Hearing aid
6. The glands and keratin structures in rabbit are derived from :
(a) Stratum lucidum (b) Stratum germinativum
(c) Stratum spinosum (d) Stratum granulosum
7. The secretion of sebaceous glands is :
(a) Sweat (b) Tears (c) Sebum (d) Ear wax
8. Sweat glands are absent in the skin of :
(a) Rabbit (b) Cat (c) Man (d) Rat
9. Mammary glands are modified :
(a) Sebaceous glands (b) Sweat glands
(c) Tear glands (d) Meibomian glands
10. Buccal cavity is divided into nasal and food passage by :
(a) Tongue (b) Palate
(c) Teeth (d) Vestibule
11. Dental formula of rabbit is :
(a) $\frac{2123}{2033}$ (b) $\frac{2103}{2103}$ (c) $\frac{2033}{1033}$ (d) $\frac{2234}{2033}$
12. The wide toothless gap due to the absence of canines is :
(a) Glottis (b) Epiglottis
(c) Cheek (d) Diastema
13. Mucin is a mixture of :
(a) Proteins (b) Fatty acids
(c) Lipids (d) Carbohydrates
14. The duct of infra-orbital salivary glands opens near :
(a) Upper incisors (b) Upper molars
(c) Angles of mandibles (d) Tongue
15. Hormone insulin is secreted by :
(a) Pancreatic acini (b) Cystic lobe of liver
(c) Islets of langerhans (d) Gastric glands
16. Ptyalin is present in :
(a) Gastric juice (b) Saccus entricus
(c) Bile juice (d) Saliva
17. Bilirubin and biliverdin are derived by the disintegration of :
(a) Haemoglobin (b) Globulin
(c) DNA (d) Myosin
18. Rabbits re-eat the faeces produced during :
(a) Evening (b) Night
(c) Morning (d) Noon
19. Adam's apple in human neck is :
(a) Glottis (b) Pharynx
(c) Larynx (d) Trachea
20. True vocal cords are absent in :
(a) Man (b) Lion (c) Dog (d) Hippopotamus
21. Fossa ovalis represents :
(a) Foramen ovale (b) Musculi pectinati
(c) Sinus venosus (d) Auricular appendix
22. The left auriculo-ventricular valve is known as :
(a) Tricuspid valve (b) Mitral valve
(c) Semilunar valve (d) Eustachian valve
23. Veins carrying oxygenated blood :
(a) Aorta (b) Coronary veins
(c) Pulmonary veins (d) Caval veins
24. Funnel shaped space towards the concavity of the kidney :
(a) Capsule (b) Cortex
(c) Medulla (d) Pelvis
25. Renal columns of Bertini are formed by :
(a) Cortex (b) Medulla
(c) Pelvis (d) Capsule
26. The volume of urine is controlled by :
(a) Thyroxine (b) ADH
(c) Insulin (d) Adrenalin
27. Involuntary activities of body are controlled by :
(a) Cerebrum (b) Cerebellum
(c) Pons and Medulla oblongata
(d) Spinal cord
28. Contraction of melanophores is regulated by :
(a) Noradrenalin (b) Serotonine
(c) Aldosterone (d) Melatonine
29. Hormone controlling the contraction of uterine muscles at the time of child birth :
(a) Oxytocin (b) Vasopressin
(c) Prolactin (d) Gonadotropin
30. Removal of parathyroid glands leads to :
(a) Diabetes melitus (b) Tetany
(c) Diabetes insipidus (d) Myxoedema
31. Cells of islets of Langerhans responsible for the secretion of glucagon :
(a) Gamma cells (b) T cells
(c) Alpha cells (d) Beta cells
32. Addison's disease results from the under activity of :
(a) Thymus (b) Parathyroid
(c) Adrenal medulla (d) Adrenal cortex

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d) 13. (a) 14. (b) 15. (c) 16. (d) 17. (a) 18. (b) 19. (c) 20. (d) 21. (a) 22. (b) 23. (c) 24. (d) 25. (a) 26. (b) 27. (c) 28. (d) 29. (a) 30. (b) 31. (c) 32. (d).

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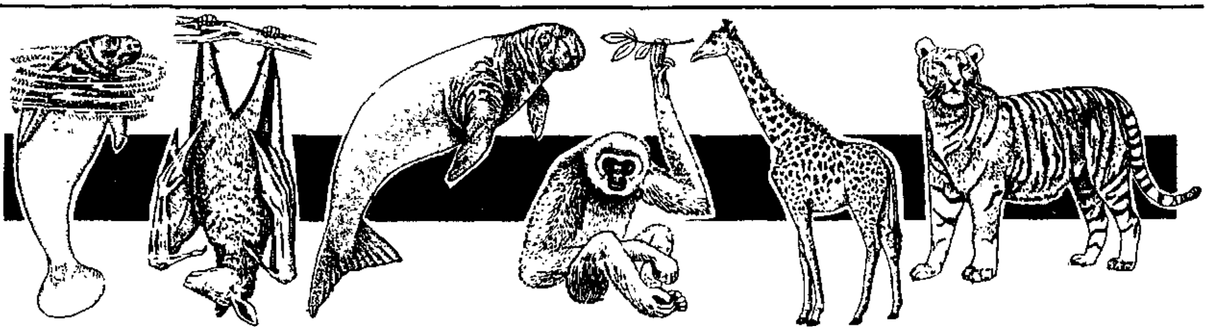

Class 9. Mammalia

General Characters

1. Hair-clad, mostly terrestrial, air-breathing, warm-blooded, viviparous, tetrapod vertebrates.
2. Body distinctly divisible into head, neck, trunk and tail.
3. Limbs 2 pairs, pentadactyle, each with 5 or fewer digits and variously adapted for walking, running, climbing, burrowing, swimming or flying. Hind limbs absent in cetaceans and sirenians.
4. Exoskeleton includes lifeless, horny, epidermal hairs, spines, scales, claws, nails, hoofs, horns, bony dermal plates, etc.
5. Skin richly glandular containing sweat, sebaceous (oil) and sometimes scent glands in both the sexes. Females also have mammary glands with teats producing milk for suckling the young.
6. A muscular partition, called diaphragm, separates the anterior thoracic cavity from the posterior abdominal cavity.
7. Endoskeleton thoroughly ossified. Skull dicondylic, having 2 occipital condyles formed exclusively by the exoccipitals. Cranium large. A single zygomatic arch present. Pterygoids small, scale-like. Otic bones fused into periotic which forms tympanic bulla with tympanic. Absent bones of skull are prefrontal, postfrontal, quadratojugal, supraorbital and basipterygoids. Each half of lower jaw made of a single bone, the dentary, articulating with squamosal of skull. Vertebrae with terminal epiphyses and flat centre (acoelous). Cervical vertebrae usually 7. Ribs bicephalous. Coracoid vestigial.
8. Alimentary canal terminates by anus, there being no cloaca. Buccal cavity separated from

nasal passage by a hard palate, formed by premaxillae, maxillae and palatines. Teeth are of several types (heterodont), borne in sockets (thecodont) and represented by two sets (diphyodont).

9. Respiration always by lungs (pulmonary). Glottis protected by a fleshy and cartilaginous epiglottis. Larynx contains vocal cords.
10. Heart, 4-chambered with double circulation. Only the left aortic arch present. Renal portal system absent. R.B.C. small, circular and non-nucleated. Body temperature regulated (homoiothermous).
11. Kidneys metanephric. Ureters open into a muscular urinary bladder. Excretion is ureotelic. Excretory fluid is urine.
12. Brain highly evolved. Both cerebrum and cerebellum large and convoluted. Optic lobes small and 4 in number called corpora quadrigemina. Corpus callosum present connecting both cerebral hemispheres. Cranial nerves 12 pairs.
13. Senses well developed. Eyes protected by lids, the upper of which is movable. External ear opening protected by a large fleshy and cartilaginous flap called pinna. Middle ear cavity with 3 ear ossicles—malleus, incus and stapes. Cochlea of internal ear spirally coiled.
14. Sexes separate. Sexual dimorphism generally well marked. Male has an erectile copulatory organ or penis. Testes commonly placed in a bag or scrotum outside abdomen. Eggs are small, with little yolk and no shells.
15. Fertilization internal, preceded by copulation.
16. Except egg-laying monotremes, mammals are viviparous, giving birth to living young ones.
17. Development uterine. Developing foetus attached to uterine wall of mother by a placenta for nutrition and respiration. Embryonic membranes (amnion, chorion and allantois) present.
18. After birth, young nourished by milk secreted from mammary glands of mother.
19. Parental care well developed reaching its climax in humans.
20. Mammals show greatest intelligence among all animals.

Classification

Mammals have been thoroughly described and adequately classified. They include approximately 5,000 living species (15,000 subspecies) and numerous fossil forms. Their classification differs with different authorities. The main characters forming the basis of their classification into orders include : (i) mode of caring for their young, (ii) nature of dentition, (iii) foot posture, (iv) nails, claws and hoofs, (v) complexity of nervous system, and (vi) systematics. G. G. Simpson provided a complete review of the group in a publication entitled. "The Principles of Classification and a Classification of Mammals" (Bull. Am. Mus. Nat. Hist., 1945, Vol. 85). He recognized 18 living and 14 extinct orders of mammals. For the purpose of this text, we shall refer to only 18 living orders of mammals which are first divided into 2 subclasses : *Prototheria* and *Theria*.

Subclass I. Prototheria
(Gr., *protos*, first + *therios*, beast)

Primitive, reptile-like, oviparous or egg-laying mammals.

Order 1. Monotremata. (Gr., *monos*, single + *trema*, opening). Cloacal opening present. Confined to Australian region.

Examples : Monotremes. Platypus or duckbill (*Ornithorhynchus)* Spiny anteater *(Tachyglossus = Echidna).*

Subclass II. Theria
(Gr., *ther*, animal)

Modern or typical viviparous mammals that give birth to living young. Theria are subdivided into 2 living infraclasses :

Infraclass 1. Metatheria
(Gr., *meta*, between or after)

Pouched and viviparous mammals without or with a rudimentary yolksac placenta. Confined mostly to Australian region.

Order 2. Marsupialia. (Gr., *marsypion*, pouch). Born in a very immature state, and complete their development attached to teats or nipples in the abdominal pouc or marsup um. Usually 3 premolars and 4 molars in each jaw on either side. Vagina double.

Examples. Marsupials. Opossum *(Didelphis),* k g (*Macropus*), ala (P. ascolarctos).

Infraclass 2. Eutheria

(Gr., eu, true + *therios* + beast)

Higher viviparous, placental mammals without arsupium. You g bor i a relatively advanced stag. D ntition never exceeds $\frac{3.1.4.3}{3.1.4.3} = 44$. Eutherians constitute the vast majority of living mammals arranged in 16 orders. (N.B. The general characters of class Mammalia, infact, represent the characters typically of the infraclass Eutheria).

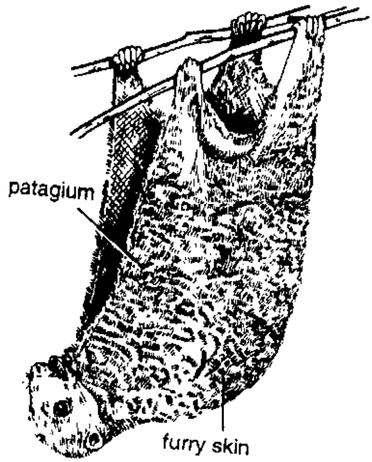

Fig. 1. Flying lemur *Cynocephalus*.

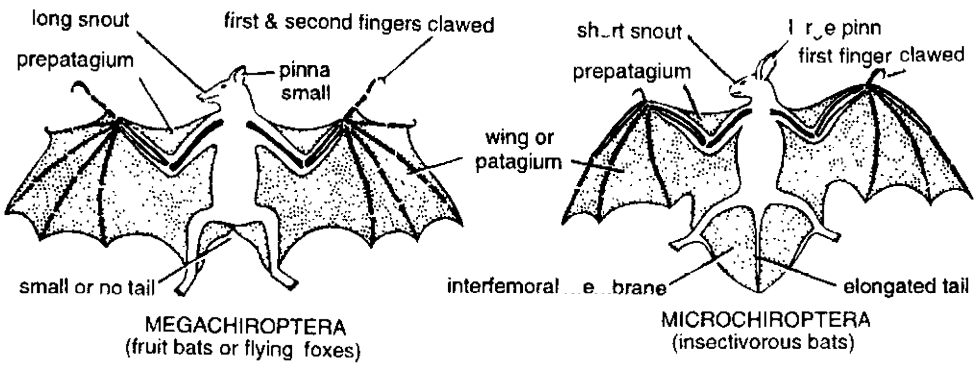

Table 1. **Comparison between Megachiroptera and Microchiroptera,**

	Characters	Suborder 1 Megachiroptera	Suborder 2 Microchiroptera
1.	Habitat	During day sleep on trees in deserted area in Old World tropics, hanging upside down by hind claws with wings folded.	Sleep during day in rock crevices, hollow trees and abandoned buildings in both the hemispheres, hanging head downward
2	Habits	Nocturnal, frugivorous, often found in great flocks.	Nocturnal, mainly insectivorous, gregarious or solitary.
3.	Size	Larger bats.	Smaller bats.
4.	Head	Head fox-like. Eyes large. Snout elongated without nose-leaf.	Eyes small. Snout short and blunt with nose-leaves.
5.	Pinna	Small, simple, devoid of appendages.	Usually large bearing leaf-like appendages called *tragus*.
6.	Clawed fingers	First and second fingers clawed.	Only first finger (thumb) clawed
7.	Tail	Absent or small. Free from narrow interfemoral membrane.	Large. Enclosed in a large interfemoral membrane.
8	Molars	Crowns devoid of sharp cusps. Longitudinal grooves present.	Crowns have sharp cusps Transverse grooves present.
9.	Examples	Fruit bats or flying foxes *Pteropus, Cynopterus*	Little brown bat *(Myotis), Rhinolophus, Vespertilio,* vampire bat *(Desmodus).*

Order 3. Insectivora. (L., *insectum,* insect + *vorare,* to eat). Small primitive mammals with long pointed snout. Feet plantigrade, usually 5-toed, with claws. Molars with pointed, peg-like cusps for insect feeding. Placenta discoidal. Nocturnal and terrestrial.

Examples : Mole *(Talpa),* common shrew *(Sorex),* Solenodon *(Solenodon),* hedgehogs *(Erinaceus, Paraechinus).*

Order 4. Chiroptera. (Gr., *Cheiros,* hand + *pteron,* wing). Flying mammals or bats in which forelimbs are modified into wings (patagium). Hindlegs short and included in wing membrane. Teeth small, sharp, peg-like. Sternum provided with keel. Clavicles are stout and fused with scapula and sternum. Eyes are small with weak vision. Ear have large pinnae. Nocturnal, capable of true flight. Two suborders : *Megachiroptera* and *Microchiroptera* (Table 1).

Order 5. Dermoptera. (Gr., *derm,* skin + *pteron,* wing). Four equal-sized limbs and tail included in a lateral furry skin fold, the *patagium.* Incisor teeth 2/3. Nocturnal in trees. A gliding mammal called flying lemur, resembling a flying squirrel.

Examples : One living genus *Cynocephalus* (= *Galaeopithecus)* with 2 species from Southeastern Asia (Fig. 1).

Order 6. Edentata. (L., *edentatus,* toothless), Teeth absent or reduced to molars, without enamel. Toes with large, strong, curved claws. Testes are abdominal. Some times they are armoured.

Examples : Giant anteater *(Mryrmecophaga),* armadillo *(Dasypus),* 3-toed sloth *(Bradypus).*

Order 7. Pholidota. (Gr., *pholis,* a horny scale). Body covered with large overlapping horny scales with sparse hair in between. No teeth. Tongue long and protrusible, used to capture insects.

Examples : Single genus of scaly anteaters or pangolins *(Manis).*

Order 8. Tubulidentata. (L., *tubulus* tube-like + *dens,* tooth). Tongue slender, protrusible. No incisors or canines. Each jaw with 4 to 5 teeth, lacking enamlel and perforated by numerus fine tubules of pulp. Skin thick covered with hair. Ear are long, erect and pointed. Placenta is zonary.

Examples : Single genus of pig-like aardvark or Cape anteater *(Orycteropus)* of South Africa.

Order 9. Primates. (L., *primus,* of the first rank). Generalized or primitive mammals except for the great development of brain. Flat nails on fingers and toes. First digit usually opposable, an adaptation for grasping. Eyes typically large and turned forward. Mostly arboreal. The Order Primates is divided into 3 suborders : *Lemuroidea, Tarsioidea,* and *Anthropoidea.* The suborder Anthropoidea is further subdivided into two divisions or infraorders : *Platyrrhina* and *Catarrhina.* The main differences between the 3 suborders and between the 2 infraorders have been shown in the Tables 2 and 3, respectively (Figs. 2 & 3).

Order 10. Rodentia. (L., *rodo,* gnaw). Largest order including usually small gnawing mammals. Each jaw with one pair of long, rootless, chisel-like incisors growing throughout life. No canines. Digits provided with claws. Testes abdominal. Space between molars and canine present called diastema.

Examples : Rat *(Rattus),* mouse *(Mus),* squirrel *(Funambulus),* guinea pig *(Cavia),* beaver *(Castor),* porcupine *(Hystrix),* prairie dog *(Cynomys).*

Order 11. Lagomorpha. (Gr., *logos,* hare + *morphe,* form). With a second pair of small upper incisors behind first pair of large chisel-like incisors. No canines.

Examples : Rabbit *(Oryctolagus),* hare *(Lepus),* pika *(Ochotona).*

Order 12. Cetacea. (Gr., *ketos* or L., *cetus,* a whale). Large, marine, fish-like mammals, well adapted for aquatic life. Hair on skin are reduced to a few bristles on the muzzle. Pectoral limbs modified into broad paddle-like flippers. Tail divided in two broad horizontal fleshy flukes with a notch, used in propulsion. No claws, no hind limbs and no external ears. Skull bones are spongy and contain oils. The living Cetacea are divided into two suborders : *Odontoceti* (toothed whales) and *Mysticeti* or *Mystacoceti* (whalebone whales).

Lemur *Lemur*
Tarsier *Tarsius*
New world monkey *Cebus*
Old world monkey *Macaca*
Ape (chimpanzee) *Anthropithecus*

Fig. 2. Some modern Primates. Only heads.

Table 2. **Comparison between Lemuroidea, Tarsioidea and Anthropoidea.**

	Characters	Suborder 1 Lemuroidea (L., *lemures,* ghost)	Suborder 2 Tarsioidea (Gr., *tarsus,* first foot)	Suborder 3 Arthropoidea (Gr., *anthropos* man)
1.	Status	Primitive or lowest.	Slightly advanced.	Most advanced.
2.	Distribution	Madagascar, Africa, Southeastern Asia.	Philippines and adjacent islands.	World wide
3.	Habits and habitat	Arboreal, mostly nocturnal, omnivorous, solitary	Arboreal, nocturnal, solitary, mainly insectivorous.	Arboreal or terrestrial, diurnal, gregarious, mainly frugivorous.
4.	Snout	Usually elongated	Shortened.	Short-faced.
5.	Eyes and vision	Usually lateral. Vision poor.	Large protruding forward eyes. Vision good.	Forward with greater clarity of vision (stereoscopic).
6.	Tail	Long, nonprehensile, sometimes lacking	Long, tufted, non-prehensile.	Usually prehensile when present.
7.	Digits	Second toe with claw, others with flat nails.	2 toes with claws, 3 with nails. Tips of all digits bear rounded pads.	All digits with flat nails.
8.	Dental formula	$\frac{2.1.3.3}{2.1.3.3.} = 36$	$\frac{2.1.3.3}{1.1.3.3} = 34$	$\frac{2.1.2.3}{2.1.2.3} = 32$
9.	Orbit	Confluent with temporal fossa.	Communicates by a wide fissure with temporal fossa.	Separated from temporal fossa by a bony partition.
10.	Cerebellum	Not covered by cerebrum.	Not covered.	Covered by highly developed cerebrum.
11.	Uterus	Duplex.	Bicoinuate	Simplex.
12.	Clitoris	Traversed by urethra.	Traversed by urethra.	Not traversed by urethra.
13.	Placenta	Diffused and non-deciduate.	Metadiscoidal and deciduate.	Metadiscoidal and haemochorial.
14.	Examples	Tree shrew *(Tupaia)*, Aye-Aye *(Cheiromys = Daubentonia)*, lemurs *(Lemur)*, loris *(Loris)*	Only single genus with 3 species. Spectral tarsier *(Tarsius spectrum)*.	New World and Old World Monkeys, apes and man.

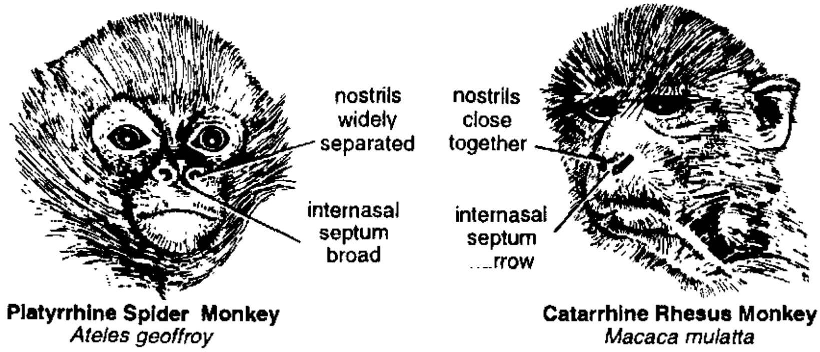

Fig. 3. Comparison between New World Monkeys (Platyrhina) and Old World Monkeys (Catarrhina).

***Table 3.* Comparison between Platyrrhina and Catarrhina.**

	Characters	Infraorder Platyrrhina (New world monkeys)	Infraorder Catarrhina (Old World monkeys, apes, man)
1.	Distribution	Central and South America.	Africa and Asia.
2.	Habitat	Mainly arboreal.	Arboreal or terrestrial.
3.	Size	Relatively small.	Relatively large.
4.	Nose	Nose flat. Internasal septum broad. Nostrils widely separated and directed variously.	Nose raised, Internasal septum narrow. Nostrils close together and face downwards.
5.	Cheek pouches	Absent.	Present except in apes.
6.	Tail	Long, usually prehensile.	When present, not prehensile.
7.	Ischial callosities	Ischial callosities on buttocks absent.	Coloured callosities on buttocks present.
8.	Bony auditory meatus	Poorly developed.	Well developed.
9.	Tympanic bulla	Well developed.	Poorly developed.
10.	Dental formula	$\frac{2.1.3.3.}{2.1.3.3.}$ Premolars 3.	$\frac{2.1.2.3}{2.1.2.3}$. Premolars 2.
11.	Sigmoid flexure	Poorly developed.	Well developed.
12.	Placenta	Not secondary discoidal.	Secondary discoidal.
13.	Offsprings	Usually more than one.	Usually one.
14.	Examples	Spider monkey *(Ateles)*, howling monkey *(Aloutta)*, capuchin *(Cebus)*, marmoset *(Callithrix)*	Rhesus monkey *(Macaca)*, langur *(Presbytis = Semnopithecus)*, gibbon *(Hylobates)*, baboon *(Papio)*, orange-utan *(Pango = Simia)*, chimpanzee *(Pan = Anthropithecus)*, gorilla *(Gorilla)*, man *(Homo sapiens)*.

A comparison of the two suborders has been given in the Table 4.

Order 13. Sirenia. (Gr., *siren*, sea nymph). Large, clumsy, herbivorous, aquatic mammals with paddle-like forelimbs, no hind limbs and a flattened tail with horizontal lateral fleshy flukes with or without a notch. No external ears. Muzzle blunt. Hairs few. Stomach complex having several chambers. Clavicles absent. Testes are abdominal. Inhabit estuaries and coastal sea (Fig. 4).

Examples : Manatee *(Trichechus)*, dugong *(Dugong = Halicore)*, recently extinct Steller's sea-cow *(Rhytina)*.

Order 14. Carnivora. (L., *caro*, flesh + *vorare*, to eat). Small to large predatory, flesh-eating mammals. Claws well developed. Incisors small, canines large, fang-like and molars of cutting type. Temporal fossa are open behind. Tympanic bulla are large and rounded. Clavicles are incomplete or reduced. Scaphoid and lunar

***Table 4.* Comparison between Odontoceti and Mysticeti.**

	Characters	Suborder Odontoceti (Toothed whales) (G., *odontos*, tooth + *cetos*, whale)	Suborder Mysticeti (Whalebone whales) (G., *mustax*,mustache + *cetos*, whale)
1.	Size	Relatively smaller.	Relatively much larger.
2.	Nostrils	Fused into a single blow hole on top of head.	Two separate external nostrils present.
3.	Teeth and baleen plates	Numerous conical or pointed teeth present in lower of both jaws. Baleen plates absent.	Teeth absent. Instead V-shaped upper jaw bears a series of horny plates of whalebone or baleen.
4.	Lower jaw	Narrow. Two halves not bowed outwards. Mandibular symphysis present.	Two halves arched outwards to cover baleen plates. No true mandibular symphysis.
5.	Food	Feed mainly on fish	Baleen plates serve to sieve or strain plankton on which they feed.
6.	Olfactory organ	Rudimentary or absent.	Well developed.
7.	Caecum	Absent.	Short.
8.	Skull	Upper surface asymmetrical. Nasal passages directed up and posteriorly. Maxilla mostly overlaps the orbital process of frontal Lacrimal fused with jugal. Tympanic not ankylosed to pterotic.	Upper surface symmetrical. Nasal passages directed up and anteriorly. Maxilla does not cover orbital process. Lacrimal distinct but small. Tympanic ankylosed to pterotic.
9.	Sternum and ribs	Ossified sternal ribs articulate with many jointed sternum.	One pair of not ossified ribs articulate with sternum made of a single segment.
10.	Hyperdactyly and hyperphalangy	Absent.	Present.
11.	Body oil	Not edible but used in cosmetics, candles, lubricants, etc.	Edible and used in many food products.
12.	Examples	Sperm whale *(Physeter catodon)*, killer whale *(Orcinus)*, common porpoise *(Phocaena)*, Ganges dolphin *(Platanista gangetica)*, common dolphin *(Delphinus delphis)* Narwhal *(Monodon)*, porpoise *(Phocaena)*.	Blue whale *(Balaenoptera musculus)*, common rorqual or fin whale *(Balaenoptera physalus)*, right whale *(Balaena)*.

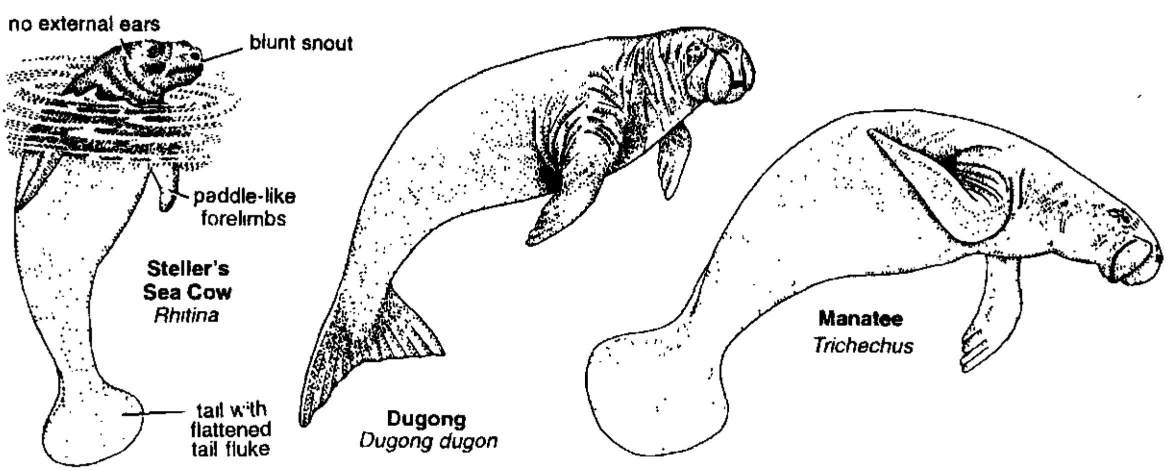

Fig. 4. Examples of Sirenia.

bones of an are a ways fuse . v ng carn vores are divided into 2 suborders : *Fissipedia* and *Pinnipedia.*

Suborder Fissipedia. Modern terrestrial carnivores whose feet contain separate toes. Feebly developed incisors and are always 6 in each jaw. Canines are strong and large. Last premolar in the lower jaw is called *carnassial* or *sctorial teeth.*

Examples : Dog *(Canis familiaris),* wolf *(C. lupus),* jackal *(C. aureus),* red fox *(Vulpes),* otter *(Lutra),* badger *(Meles),* cheetah *(Acinonyx),* lion *(Panthera leo),* tiger *(Panthera tigris),* domestic cat *(Felis domesticus),* hyaena *(Hyaena),* mongoose *(Herpestes),* bear *(Ursus),* racoon *(Procyon),* mink *(Mustela),* skunk *(Mephites),* panda *(Ailuropoda).*

Suborder Pinnipedia. Marine carnivores with streamlined, torpedo-shaped body, reduced tail, and limbs modified into flippers or paddles.

Examples : Walrus *(Odobenus),* fur seal *(Callorhinus),* common seal *(Phoca).*

Order 15. Hyracoidea. (Gr., *hyrax,* shrew + *eidos,* form). Small, guinea-pig like mammals, distantly related to elephants. Snout, ears and legs short. 4 toes on front foot, 3 on hindfoot, each with a flattened hoof-like nail. Incisors 1/2. No canines. Cheek teeth lophodont. Clavicles are absent. Dorsal gland is present. Testes abdominal. Mammae are six pairs, four pairs inguinal and two pairs axillary.

Examples : Conies (*Hyrax = Procavia*) from S. Africa, Syria and Arabia (Fig. 5).

Order 16. Proboscidea. (Gr., *pro,* in front + *boskein,* to eat). Largest living land animals having large heads, massive ears, thick practically hairless skins (pachyderm), bulky straight legs and 3 to 5 toes with small, nail-like hoofs. Conspicuous feature is the nose and upper lip modified as an elongated flexible proboscis or trunk. 2 upper incisors elongated as ivory tusks. Cheek teeth lophodont.

Examples : Indian or Asiatic elephant *(Elephas maximus),* African elephant *(Loxodonta africana),* pigmy african elephant *(Elephas cyclotis).* Extinct mammoths and mastodons. Some interesting features of differences between Indian and African elephants have been listed in Table 5.

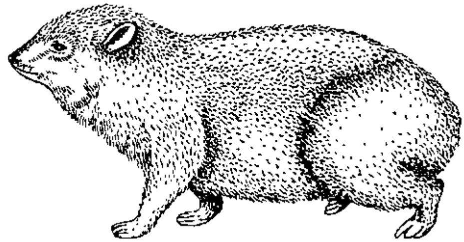

Fig. 5 Hyrax, *Procavia syriacus.*

Order 17. Perissodactyla. (Gr., *perissos,* odd + *dactylos,* toes). The odd-toed hoofed mammals or ungulates have an odd number of toes (1 to 3). Functional axis of foot passes through the middle or third digit. Incisors present in both jaws. Stomach simple.

Examples : Horse *(Equus cabalus),* wild ass *(Equus asinus),* zebra *(Equus zebra),* tapir *(Tapirus),* rhino *(Rhinoceros = Diceros).*

Order 18. Artiodactyla. (Gr., *artios,* even + *dactylos,* digit). The even-toed hoofed mammals having an even number of toes (2 or 4). Axis of support passes between third and fourth toes. All except pigs and peccaries ruminate or chew their cud. Incisors and canines in upper jaw usually lacking. Stomach 4-chambered. Many with antlers or horns.

Examples : Pig *(Sus),* common hippopotamus *(Hippopotamus amphibius),* camel *(Camelus),* deer *(Carvus),* musk deer *(Moschus),* sheep *(Ovis),* goat *(Capra),* giraffe *(Giraffa),* blackbuck *(Antilope),* Ox *(Bos indicus),* water buffalo *(Bubalus bubalis),* yak *(Bos grunniens),* bison *(Bison).*

Other Mammalia

Many and wonderful are differences we find among mammals living today. Their diversity seems almost infinite. They differ widely from one another in their mode of life and in their adaptations to evironment, showing great *adaptive radiation.* Only some of the more interesting groups are being presented here.

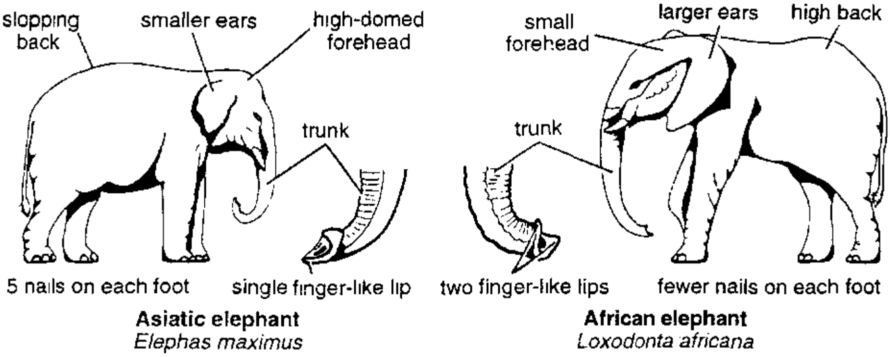

Fig. 6. Comparison between Indian and African elephants.

Table 5. **Comparison between Indian and African Elephants.**

Indian Elephant (*Elephas maximus*)	African Elephant (*Loxodonta africana*)
1. Found in tropical forests of Southern Asia (India, Burma, Thailand, Sri Lanka, etc.).	1. Found throughout Africa South of Sahara, in Savanna (grasslands).
2. Relatively smaller, 3 metres tall at the shoulder and weigh over 6 tons.	2. Relatively larger, about 3.45 metres high, and weigh over 7 tons.
3. External ears are smaller.	3. External ears are much larger covering shoulders.
4. Forehead is high, domed, with a cleft.	4. Forehead is low, flat, without a cleft.
5. Back is slopping.	5. Back is arched.
6. Tip of trunk has only one lip.	6. Tip of trunk bears two finger-like lips.
7. Only the male has tusks which may grow 2 metres or more.	7. Tusks larger in both the sexes, grow 3.5 metres long in males.
8. 5 nails on each foot.	8. Generally fewer nails on each foot.
9. Has long been domesticated and trained to do heavy work.	9. Not easily domesticated and trained.

[I] Egg laying (oviparous) mammals or Monotremes

Most primitive living mammals are monotremes belonging to subclass Prototheria. They are represented by two types, spiny anteaters (*Tachyglossus* and *Zaglossus*) and duckbills (*Ornithorhynchus*), confined to the Australian region (Fig. 7). Besides egg-laying habit, they retain several reptilian characteristics including a cloaca. However, they are not regarded as ancestral types.

1. *Tachyglossus* (Spiny anteater). The Australian spiny anteater or echidna is *Tachyglossus (= Echidna) aculeatus.* It is found throughout Australia and Tasmania. It is terrestrial and burrowing about 45 cm long. Body is covered with coarse hair and small spines, except on the belly. The short limbs have broad feet bearing strong claws for fast digging. The long tubular snout forms a slender beak with terminal rounded mouth. Tongue is long, protrusible and sticky, and used to sweep insects. Teeth are absent. Upper surface of tongue has horny serrations which grind against ridges on palate. Eyes are small, without nictitating membrane, external ears are inconspicuous, and tail is absent. During breeding season, the female develops a temporary abdominal pouch into which she puts her single egg (sometimes 2 or 3) for incubation. Egg-shell is leathery. The young hatches in an immature condition. It is carried for some time in pouch and nourished on milk from mammary glands without teats. Male echidna also possesses mammary

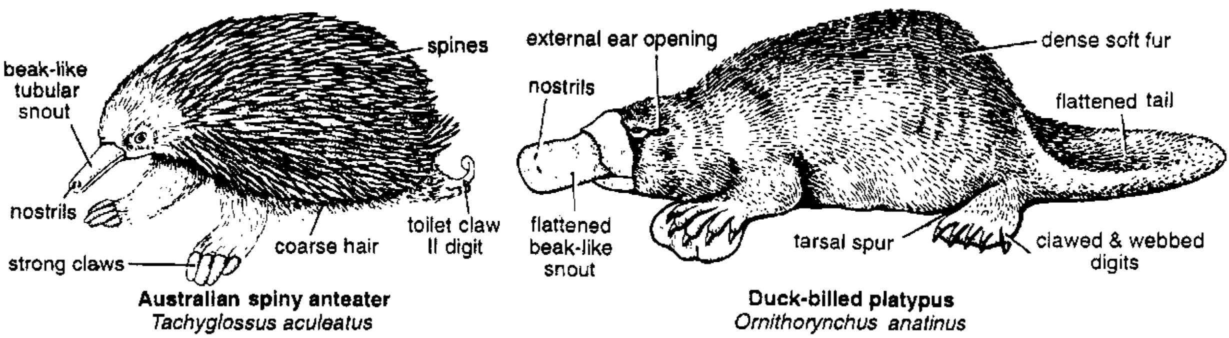

Fig. 7. Egg-laying mammals (monotremes).

glands secreting milk to feed the young. This condition is known as *gynaecomastism.* Male echidna also has a hollow tarsal *spur* on each hindleg connected to a *poison gland* in the thigh. Second claw of each hindleg forms a long and curved *toilet claw* to clean spines. Sweat glands absent. Cervical vertebrae bear separate ribs.

2. ***Zaglossus.*** (Spiny ant eater). *Zaglossus (= Proechidna)* is solely confined to New Guinea. It differs from *Tachyglossus* in several ways. (i) It is larger in size. (ii) It has short spines all over the body, almost concealed by the long underfur. (iii) Instead of 5, each foot carries only 3 clawed toes. (iv) Head is larger and beak twice as long as the head. (v) It stands up on its comparatively longer legs, rather than shuffling about on its belly like *Tachyglossus.*

3. ***Ornithorhynchus*** (Duckbill). Duck-billed platypus, *Ornithorhynchus anatinus,* is found in the rivers in eastern Australia and Tasmania. It is a beaver-like monotreme about 50-60 cm long and well adapted to life in water. It has a thick covering of soft, waterproof fur and a flattened tail. Eyes are small, bead-like, with nictitating membrane, and there are no external ears. Toes are clawed as well as webbed, the webs extending beyond the tips of claws. Upper jaw forms a broad sensitive bill, like that of a duck, covered with soft hairless rubbery skin. With its bill, the animal probes in the bottom mud of streams for worms, crustaceans, insect larvae, molluscs, etc. Teeth are replaced in the adult by horny epidermal plates meant for crushing hard food. Each hindleg of male carries a sharp, stout, movable, hollow tarsal *spur* on its heel, connected with a *poison gland* higher in the leg. These spurs mark sexual dimorphism, serve to hold the female in sexual embrace and are used in combat. Pectoral girdle reptile like, partly changed to a mammal. It has separate clavicle and a median T-shaped interclavicles. On each side, there is a coracoid, pre-coracoid and scapula without spine. Vertebrae have no epiphysis except tail. The female burrows in the bank of a river and constructs a nest of grass at the end of a subterranean tunnel. Usually 2 eggs are laid at a time. The female curls around them for incubation and remains inactive for about 2 weeks. Newly hatched young are exceedingly immature, naked, blind and each 2.5 cm long. Female holds the young to the abdomen with the help of her tail. As the mammary glands are modified sudorific glands have no teats, the young feed by lapping milk from the two milk grooves on the abdomen of the female.

[II] Pouched mammals or marsupials

Pouched mammals or marsupials belong to the infraclass Metatheria. They are also primitive mammals next to only monotremes. They are the dominant group of mammals in Australia and neighbouring islands. Only the opossum is found in the America. They are viviparous. They are characterized by an abdominal pouch, the *marsupium,* but not all have this pouch. Due to short period of uterine development (gestation), 7 to 13 young are born in an exceedingly immature condition, naked and blind. They crawl into the brood pouch or marsupium, where each

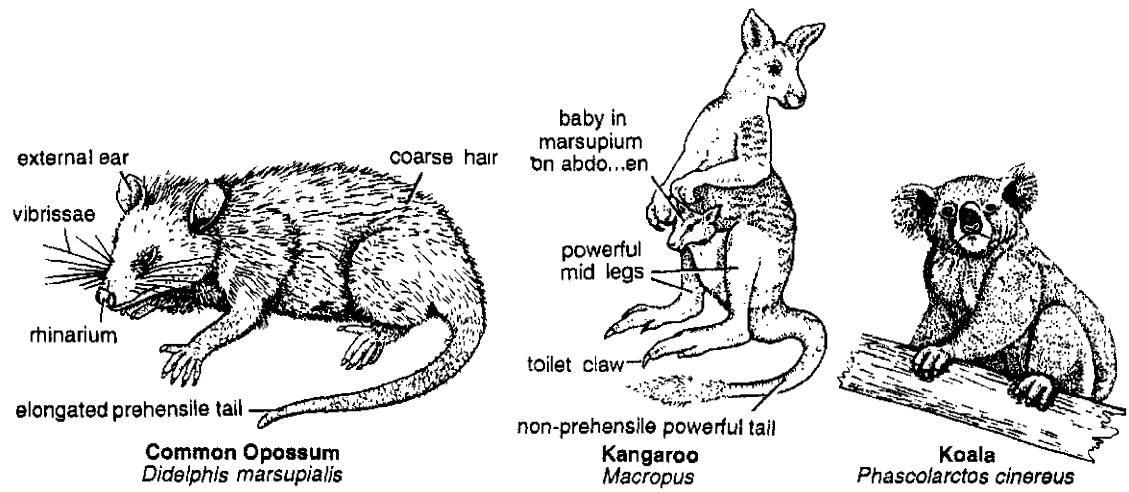

Fig. 8. Pouched mammals (marsupials).

becomes attached to a nipple and feeds on milk until sufficiently developed to move about. Familiar marsupials are opossums, *(Didelphis)*, kangaroos *(Macropus)* and koalas *(Phascolarctos)*.

1. *Didelphis* (Opossum). Opossums are largely tree-dwelling marsupials confined to America. The common opossum, *Didelphis marsupialis,* found in eastern U.S.A. to South America, measures about 50 cm and covered with a coarse fur. Legs are much shorter, snout is elongated and large black eyes which shine in its white face. Tail is long, scaly and prehensile. First digit on both limbs is opposable to grasp objects firmly. There are 5 pairs of incisors in the upper jaw and 4 pairs in the lower jaw. It is nocturnal, arboreal, omnivorous and very destructive, feeding upon grain, fruit, carrion, birds, eggs, etc. When suddenly disturbed, it may froth at the mouth and fein death, often called 'playing possum'. Their gestation period is the shortest for any mammal, 12 to 14 days only. Newly born young (7-13) are about 1 cm long and embryo like. They grow closely attached to the nipples for 50 to 60 days before leaving. It is a common sight to see a mother opossum carrying her little ones riding on her back. Hunting the opossums is a popular sport, its roasted flesh is considered a delicacy and the fur has considerable commercial value.

2. *Macropus* (Kangaroo). Even a small child knows what animal mother carries her babies about with her in a pouch. Without question, the kangaroo is the best known of pouched mammals. About 52 species are spread over Australia, Tasmania and New Guinea. The largest is the Great Grey Kangaroo, belonging to the genus *Macropus* which means 'large foot'. The male may stand 2 metres high. Head is small, ears large, and the hind legs and feet very long, powerful and used in leaping. Hallux is absent, 2nd and 3rd toes united (syndactylus) and the middle or 4th toe enormously enlarged and armed with a powerful claw used in combats. The large tail, usually thick at the base, is used as a balancer during leaping. The animal literally sits on its tail during rest. Dental formula is 3.1.2.4. / 1.0.2.4 = 34. Gestation period is 35 to 45 days. Vertebrae have prominent metapophysis and anapophysis. Cervical ribs are absent, sacrum is made of single vertebra. Pectoral girdle has large scapula with a spine, coracoid is reduced, clavicles are large and interclavicles are absent. Usually a single offspring, immature, naked, about 3 cm long, is born. It is fed on milk inside the marsupium, enclosing teats of mammary glands, to complete development in about 4-6 months. Kangaroos are mostly terrestrial, gregarious and herbivorous animals causing great harm to the growing crops. They are also hunted for flesh, fur and sport.

3. *Phascolarctos* (Koala). *Phascolarctos cinereus* is the koala or Australian teddy bear. It is an arboreal marsupial, living and feeding on the

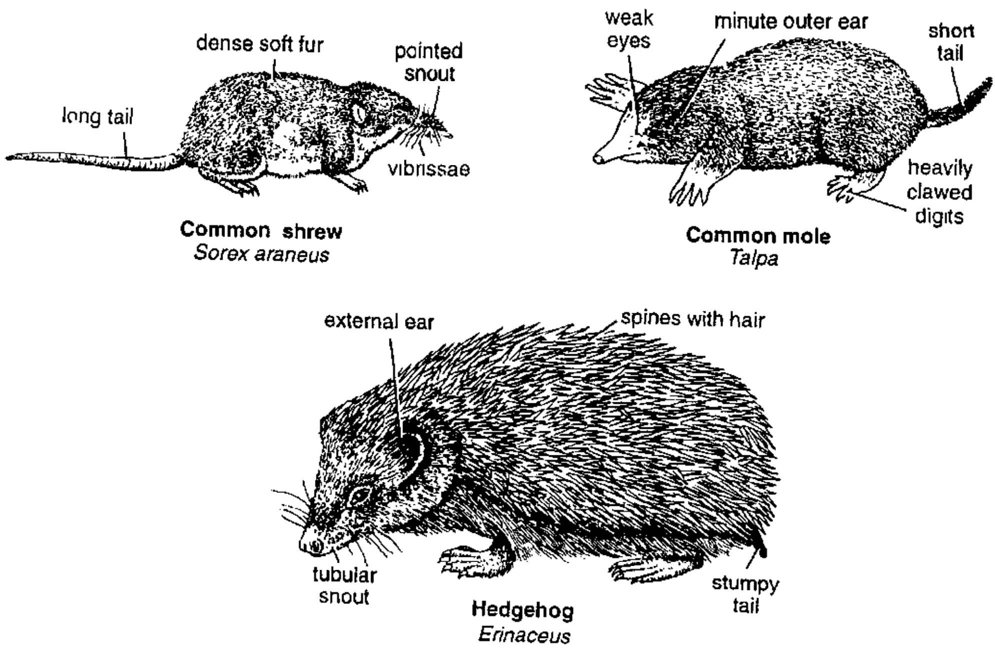

Fig. 9. Insect-eating mammals (Insectivora).

eucalyptus forests of eastern Australia. Adults are nearly 75 cm long. They have woolly fur, large ears, a soft pad on nose, rudimentary tail, cheek pouches and enlarged caecum. The female first carries young in a posteriorly opening abdominal pouch, and later on her back.

[III] Insect eating mammals (Insectivora)

Insectivora are probably the most primitive of placental animals. They are found everywhere except Australia and some parts of South America. They are small, nocturnal mammals and feed principally on insects. Their cheek teeth have sharp conical cusps for crushing insects. They have long sensitive snout, 5 clawed toes and flat feet termed *plantigrade*. They include shrews, moles and hedgehogs (Fig. 9).

1. *Sorex* (Shrew). Shrews superficially resemble mice. The smallest mammal known is the pigmy shrew *(Sorex)*, which is 4-5 cm long and weighs about 3 grams. The common long-tailed shrew, *Sorex araneus*, ranges through moist areas of Europe and Asia. Body is slender, about 7.5 cm long, with a short, dense fur, short legs, sharply pointed sensitive, bewhiskered muzzle or snout and small weak eyes. First pair of incisors are very long, lower canines are absent all teeth are red and dentition is 3/2, 1/0, 3/1, 3/3 = 32. Limbs have 5 clawed digits. They live in burrows but come out on surface at night. Cats avoid eating them because of their rancid odour. They have high metabolic rate and enormous appetite. The Indian genus is *Soriculus* commonly known as 'chuchunder'. *Suncus murinus* is the common short-tailed shrew.

2. *Talpa* (Mole). Moles *(Talpa)* are also known as 'chuchunder'. They differ from shrews in being larger and in having enormous shoulder girdle and muscles so that head and trunk seem to merge. They are also efficient burrowers. Body is thick, cylindrical and covered by a soft velvety fur. Ears are minute and tiny eyes practically useless, but the elongated snout is highly sensitive. Snout has a pre-nasal bone. Tail is short and without hair. The front limbs are enlarged, heavily clawed, flattened and turned permanently outwards, an adaptation for digging. There is an extra sickle shaped bone of the carpus called

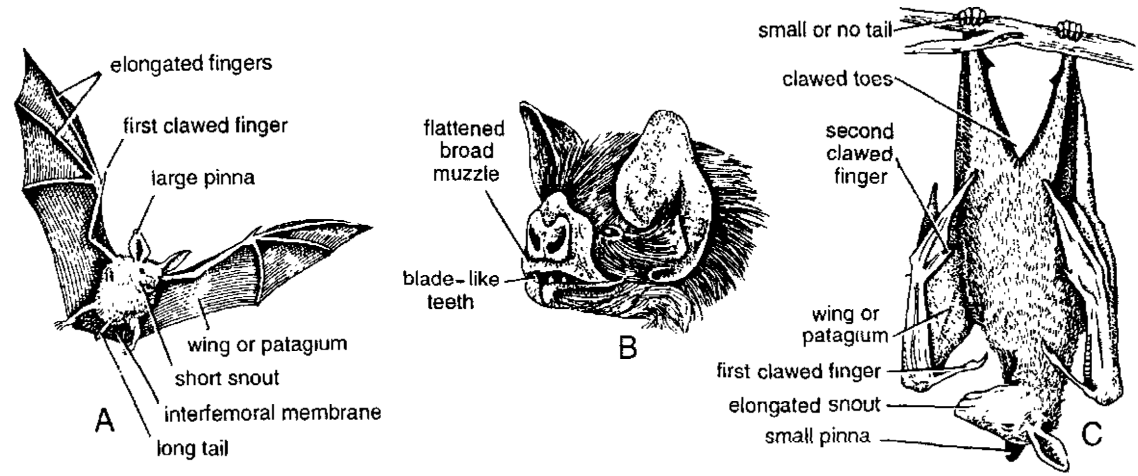

Fig. 10. Flying mammals or bats. A—An insect-eating bat (Microchiroptera). B—Head of a vampire bat, *Desmodus*. C—A fruit-eating bat (Megachiroptera).

radial sesmoid or *falciform* bone. Moles are of some commercial value because of their fur and because of the insects they destroy.

3. ***Erinaceus*** (Hedgehog). Hedgehogs range throughout Europe, Africa and Asia. They have a small globular body, pointed snout, stumpy tail and short legs. Skin is covered with short barbless spines, intermingled with hair, except on the belly. When disturbed, they roll up into a ball for protection, so that the spines project outward like pins in a pincushion. They are omnivorous creatures, feeding on insects, snails, young birds and snakes. It lives under bushes or in subterranean channels. Common Indian name is 'Jhau Chuha'. Common Indian genera are *Erinaceus, Hemiechinus* (Rajasthan) and *Paraechinus* (South India).

[IV] Flying mammals

Order Chiroptera includes bats which are the only true flying mammals that compete very well with the birds. Their forelimbs are modified into wings or *patagia*. These are the membranous leathery extensions of skin along the two sides of body, limbs and tail. The wings are supported by greatly elongated forearms and four fingers (2nd to 5th). The hindlegs are small and have clawed digits by which they hang upside down to a tree branch or perch, while sleeping during day. All are nocturnal with remarkable power to avoid obstacles while in flight at night. They have a highly developed sonar or echoapparatus, a kind of radar. Their vocal cords produce ultrasonic sounds, inaudible to human ears. When striking objects, their reflected echos are caught by the highly sensitive ears, and utilized to avoid objects during flight. Bats may be frugivorous, insectivorous or sanguinivorous (Table 1, Fig. 10).

1. ***Pteropus* or *Cynopterus*** (Frugivorous bats). These are the fruit-eating bats found in the Old World tropics and sub-tropics, including India. They belong so the suborder Megachicroptera. They are called the *flying foxes* because of fox-like head, long snout and large eyes. Some of them are the largest of bats with a body 30 cm in length and a wingspread of 1.5 metres. Body is covered with brown fur. Molars are marked with a longitudinal groove and are not tubercular. They have short rudimentary tails and a claw on the second as well as first finger which is free from patagium.

2. ***Rhinolophus*** (Insectivorous bats). Insectivorous bats belong to the suborder Microchiroptera. They are small to medium in size, with small eyes, comparatively short snout and without claw on second finger. Most have nose leaves and special flaps in front of their large ears, used for navigation or echo-location,

Common examples are horseshoe bat *(Rhinolophus)*, mousetailed bat *(Rhinopoma)*, etc.

3. *Desmodus* (Vampire bat). Tree vampire bats occur in tropics and are famous because of their sanguinivorous habit. They often feed on fresh blood of sleeping domestic animals, even human beings. Their incisors are razor-sharp with which they slit the skin of the prey, where hairs and feathers are scanty, and the oozing blood is lapped up. The vampires are very sly so that the sleeping victim often remains unaware. They transmit paralytic rabies in their victims. Associated with the blood-sucking habit is the very small lumen of their oesophagus through which solid food cannot pass. The first digit of the forelimb bears claw. Tail is present. Pinna are large with a lobe called *tragus*. Molars bear transverse groove. Vampires do not have a nose-leaf. Instead, they have a naked pad wearing U-shaped grooves. Common genera are *Desmodus* and *Megaderma*.

[V] Toothless mammals

Toothless mammals (Order Edentata) are highly specialized and rather primitive New World mammals. They are either toothless or else have degenerated teeth, without enamel. Ants form a large part of their diet. They include sloths, anteaters and armadillos (Fig. 11).

1. *Bradypus* (Sloths). Sloths of tropical America are distinctly arboreal and slow-moving creatures. They have short rounded heads, inconspicuous ears, forward-looking eyes and no tails. The hands and feet bear 2 or 3 long and curved claws by which the animal hangs upside down from tree branches, eating, sleeping and moving in that position. There are no incisors, but molars are present. In the neck there are 9 cervical vertebrae and excessive number of trunk vertebrae. Algae often grow on their straw-like hairs providing a green protective colouration among the leaves. They feed mainly on fruits and leaves. The 3-toed sloth is *Bradypus tridactylus*, while the 2-toed slots is *Choloepus didactylus*.

2. *Myrmecophaga* (Great anteater). Anteaters are characterized by long tapering snouts, tubular mouths, without teeth and long sticky protrusible tongues for capturing ants and termites which are swallowed whole. Their forefeet have long, sharp claws for digging open the anthills. Hind limbs have 4 digits with normal claws. While walking

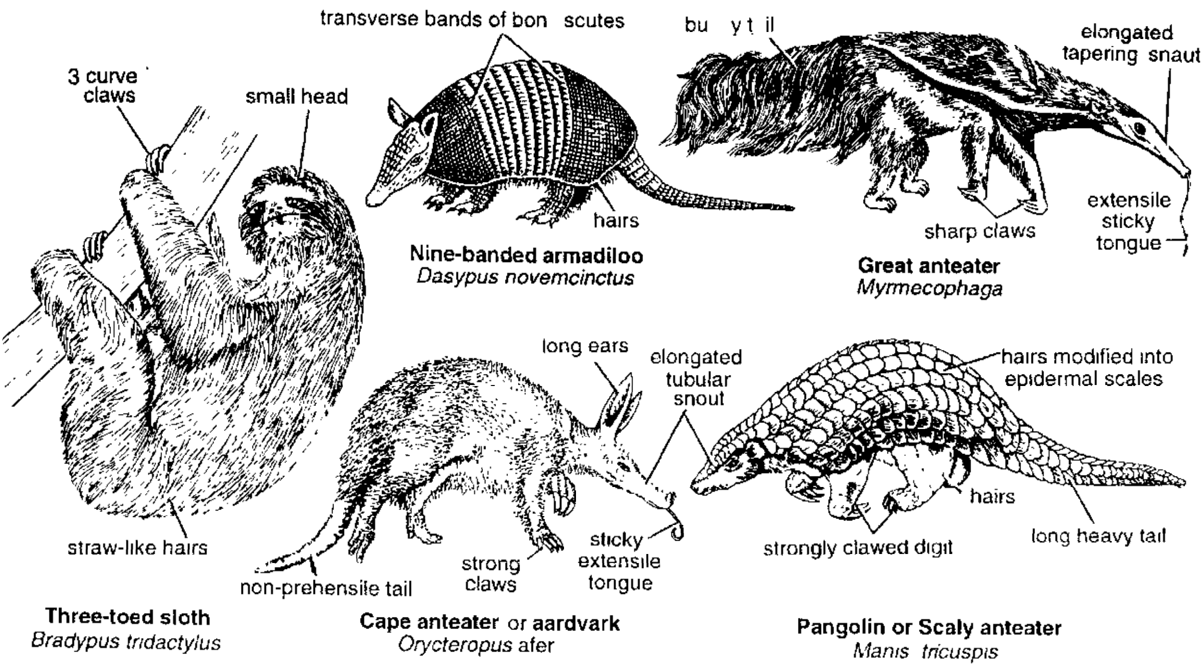

Fig 11. Toothless mammals and anteaters.

digits of manus are bent and their dorsal surface is placed on the ground. There are three living anteaters—(i) giant *(Myrmecophaga tridactyla)*, about 2 metres long, with a bushy tail, (ii) lesser *(Tamandua tetradactyla)* about 60 cm long, with a nonbushy prehensile tail, and (iii) pigmy anteater.

3. *Dasypus* (Armadillo). The nine-banded armadillo *(Dasypus novemcinctus)* found in South and Central America, is about 75 cm long. It has a well-developed dermal skeleton of transverse bony scutes. These are covered with horny plates or scales with hairs embedded and connected by flexible skin. In adults incisors and canines are absent but there are numerous continuously growing molars with no enamel. When threatened, it rolls up into a ball for protection. Strong claws on front feet are used for burrowing. The animal shows an interesting case of *polyembryony* in which a single fertilized egg produces 4 to 8 young ones of the same sex.

[VI] Other anteaters

The Old World counterparts of the New World edentates are the scaly anteaters or the pangolins (order Pholidota) and the cape anteater or aardvaek (Order Tubulidentata). Their superficial resemblance with edentates is probably due to similar mode of life (convergent evolution).

1. *Manis* (Pangolin). Scaly anteaters or pangolins have their home in tropical Asia and Africa and belong to the single genus *Manis*. They live on ground, in burrows or in trees and range from 30 cm to 1.5 metres in length. Their long tapering body is covered with large overlapping epidermal scales, except on snout, sides of face and undersurface. They have a long, sticky, extensile tongue with muscular roots, used for feeding on termites or white ants. Stomach is reduced and linked with as thick keratinous layer for grinding insects. The 5 strong front claws are used to tear open termite's nests and for burrowing. When attacked, they roll themselves into a ball for defence, like armadillos. Common Indian species are *Manis crassicaudata* (South India), *M. pentadactyla* (India to Sri Lanka) and *M. aurita* (Nepal to China).

2. *Orycteropus* (Cape anteater). Order Tubulidentata is represented by a single genus *(Orycteropus)* with 3 or 4 species of aardvarks or cape anteaters widespread in African grass lands. Aardvark is the Dutch name meaning earth-pig. These peculiar animals have a 75 cm long pig-like body, long donkey-like ears, an elongated snout with a tubular mouth and wide nostrils, and a long heavy tail. Tongue is long, sticky and extensile for collecting ants and termites which form their principal diet. With strong claws they are expert diggers.

[VII] Gnawing mammals

Gnawing mammals are mostly small in size and characterized by the absence of canine teeth, and great development of incisors which continue to grow throughout life and used in gnawing. They belong to two orders : *Rodentia* (rats, mice, squirrels, chipmunks, gophers, porcupines, beavers, woodchucks, guinea pigs, hamsters, chinchillas, etc.) and *Lagomorpha* (pikas, rabbits, hares). True rodents have only 1 pair of chisel-shaped incisors in each jaw, whereas lagomorphs have a reduced second pair besides the functional pair of upper incisors. The two orders seem to resemble due to parallel evolution. Gnawing has been a very successful mode of life since rodents are found all over and exceed in number of species and individuals than all other mammals combined (Fig. 12).

1. *Rattus* (Rat). Rats are the most harmful and well-known rodent pests, living in holes and burrows in the houses and in cultivated fields all over the world. They have naked, scaly tails and long snouts. They are very cunning, gregarious, nocturnal and prolific breeders. They are host to ratfleas which carry the bacillus *Pasteurella pestis* causing bubonic plague in man. Common black house rat is *Rattus rattus*, and the grey rat, *R. norvegicus*. White laboratory rat is an albino mutant of wild grey form.

2. *Mus* (House mouse). Common house mouse *(Mus musculus)* is a miniature replica of the house

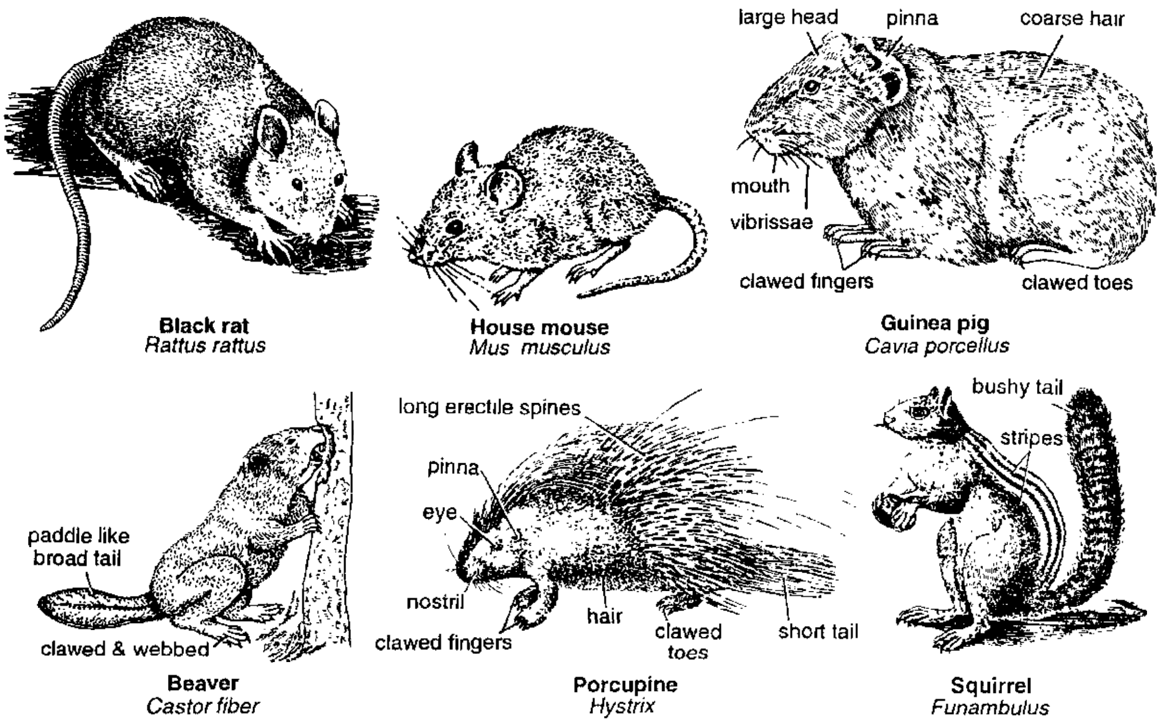

Fig. 12. Gnawing mammals.

rat is general built and appearance. It is also common throughout the world in association with man, and is active mainly at night.

3. *Funambulus* (Squirrel). Squirrels are found all over the world except Australia, and noted for their soft fur. They are active diurnal and arboreal rodents with large eyes, mustachioed snout and bushy tails. *Funambulus* species with 3 to 5 black and white longitudinal stripes on the back, and sharp claws for climbing trees are common in India. They feed on seeds, nuts and fruits.

4. *Porcupine (Hystrix)*. Old World porcupines from Africa and Asia are large, thick-set and short-legged rodents having a short, non-prehensile tail. Body and tail are covered dorsally with long, sharp, erectile black and white spines or quills for defence, in addition to coarse hairs. Porcupines do not attack by throwing their spines as generally believed. The Indian crested porcupine, *Hystrix indica,* inhabits forests, rocky hills and ravines. It spends most of the day time in its burrow, but emerges at night to feed on crops, vegetables and plant roots. It produces grunting sounds like that of a pig.

5. *Cavia* (Guinea pig). Like white rats, guinea pigs *(Cavia)* are also used extensively for research. In the wild, they occur in rocky or swampy areas near forests or grasslands. Body is about 20 cm long, with fairly coarse hairy coat, large head, long thin limbs and rudimentary tail. It digs its own burrow or occupies deserted burrows of other animals. Like rabbit, it is crepuscular, vegetarian, coprophagus and easily domesticated.

6. *Castor* (Beaver). Beaver, *Castor fibre,* is a large semi-aquatic water-dwelling rodent found in the rivers and lakes in Europe, Asia and North America. Body is about a meter long and covered with dense under fur, overlaid with coarse guard hairs. Hindfeet are webbed. Tail is broad, paddle-like and scaly. Ears and eyes can be closed under water. Their food consists of roots of aquatic plants, grasses, bark and leaves. They are noted for felling trees into streams to build dams showing great ingenuity and strength. Inside the dams they make their homes comprising chambers and galleries. Their social life is interesting. They are of considerable value for their fur.

[VIII] Carnivorous mammals

The members of the order Carnivora are the swiftest, keenest and strongest of animals. They have large size and predatory habits. They are well equipped for flesh-eating with powerful jaws, large canine teeth for killing and tearing prey, cheek teeth for cutting, and strong claws for gripping. Suborder *Fissipedia* comprises terrestrial carnivores whose feet contain toes armed with well-developed curved claws. The well-known examples are cats, hyaenas, dogs, wolves, foxes, racoons, badgers, weasels, minks, snunks, otters and bears. Suborder *Pinnipedia* includes aquatic carnivores in which limbs are in the form of flippers with webbed digits for swimming, such as sea lions, seals and walruses (Fig. 13).

1. *Panthera leo* (Asiatic lion). The most notable in the cat family is the Asiatic lion. It lives in the grasslands of Africa and South-Western Asia. It is now very rare. In India, it is preserved in a sanctuary in Gir forests in Gujarat. Body is about 2 metres long and uniform tawny yellow in colour. Tail is tufted. The male is easily distinguished having a ruff of long hairs called *mane* round the neck and shoulders. It hunts large grazing animals (antelope, zebra, etc.) and lives in a group called *pride*. It is famous for its great strength, courage and roar.

2. *Felis tigris* (Tigers). Tiger, *Panthera tigris* or *Felis tigris*, is a large and much dreaded carnivore living in forests of Asia including India. Its coat is orange-yellow, striped with black. Tiger is solitory and male has no mane. It can kill the largest herbivorous animals and attacks even man. Since 1972, the tiger has become the national animal of India. Under save tiger project, it is protected in several sanctuaries such as at Sariska, Ranthambore, Simlipal, Corbett, etc.

3. *Acinonyx* (Cheetah). Cheetah or hunting leopard, *Acinonyx jubatus*, inhabits grasslands and semideserts of Africa and S.W. Asia. It is 1.5 metres long, leanly built and with non-retractile claws. It is the fastest running land animal reaching a top speed of 70 miles per hour. It hunts in groups. Easily tamed they make docile pets. Cheetah became extinct in India early in the present century.

4. *Hyaena* (Hyaena). *Hyaena* is a scavenger feeding chiefly on carrion. It often robs graves in regions where it is found. It looks like a dog, but its hind quarters are low, while front quarters are heavy with massive jaws and neck and large ears. Cheek teeth are well developed for crushing. Limbs have 4 digits, with non-retractile claws. Spotted or laughing hyaena *(Crocuta)* of African plains produces a characteristic laughing cry when excited. The striped Indian hyaena *(Hyaena striata)*, commonly called 'Lakad baggha', is nocturnal, lives in burrows, and also produces sound similar to crackling human laugh.

5. *Canis lupus* (Wolf). Wolves are restricted to the relatively uninhabited areas of N. hemisphere. They have slender limbs and are generally good runners, moving on the tips of their toes (digitigrade). They hunt in packs of about 30 and prey on small mammals. *Canis lupus* has coarse brown or grey fur, bushy tail and pointed ears. It is a great menace to stock raisers, killing calves and other young domestic animals.

6. *Herpestes* (Mongoose). Mongooses are abundant in Asian and African countries. They are small (60 cm), burrowing and nocturnal carnivores with slender low bodies, short legs, long bushy tails and pointed snouts. Body has a coat of yellowish grey fur. Front feet have 5 toes with sharp, non-retractile, fossorial claws. They feed on rodents, reptiles, birds and their eggs and are noted for snake-killing powers. It also takes vegetable foods. Common Indian mongoose is *Herpestes edwardsi*.

7. *Melursus* (Sloth bear). Bears are the largest carnivores, heavily built, with short powerful legs, plantigrade feet, short tails, and elongated snouts. The polar bear *(Thalarctos maritimus)* of the Arctic region is the biggest and strongest predator which feeds mainly on fishes and seals. It has a dense white pelage and fully furred feet. The sloth bear *(Melursus ursinus)* found in India has body

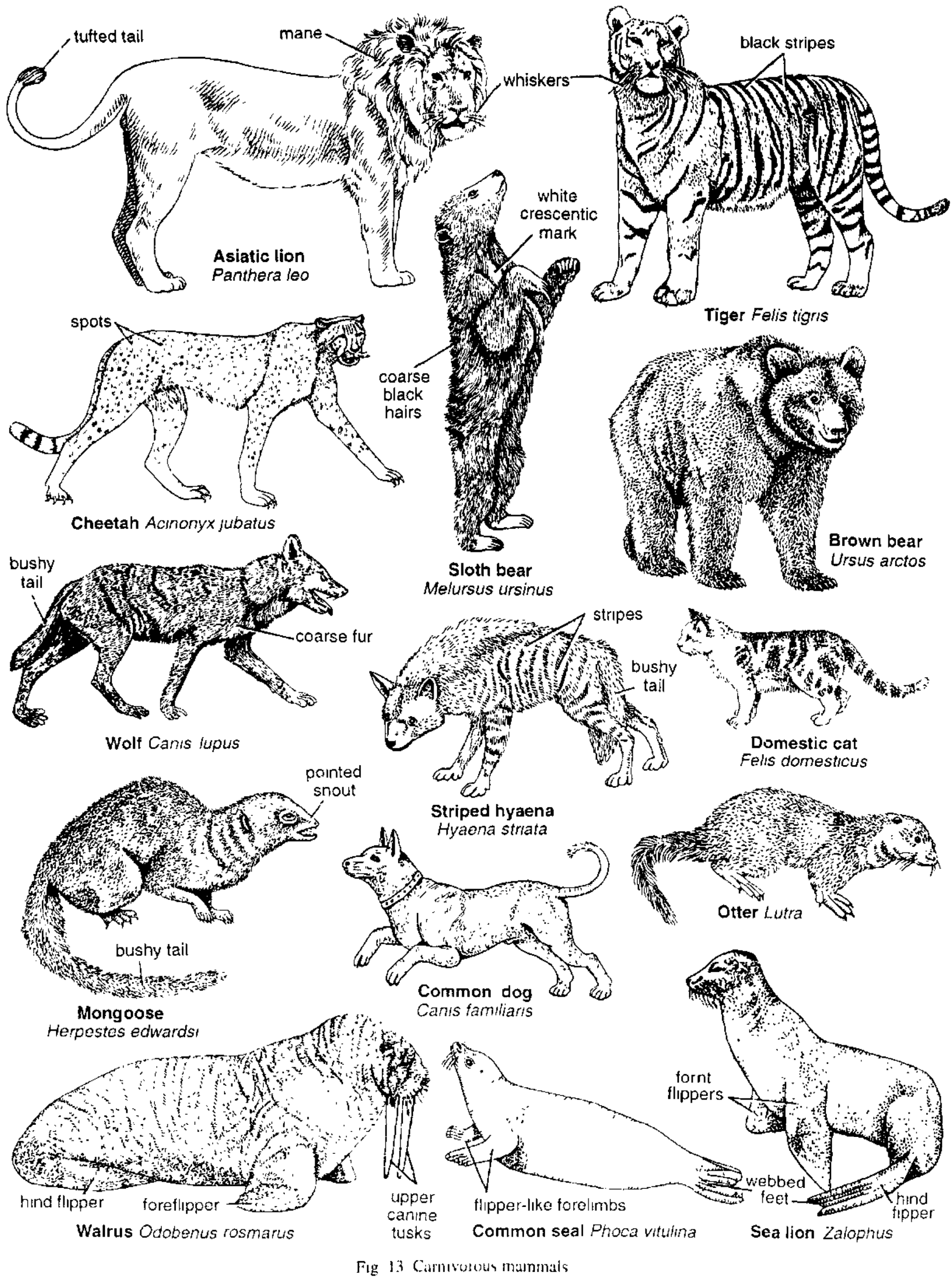

Fig 13 Carnivorous mammals

covered with long and coarse black hairs with a white crescentic mark on chest. Lower lip is elongated, tongue extensile and some of the teeth rudimentary. They feed on fruits, honey and insects, and can climb trees. The grizzly *(Ursus horribilis)* or brown bear *(Ursus arctos)* is found in Europe, Asia and N. America. The Himalayan black bear is *Sclenarctos thibetanus* with a white V-shaped mark on chest.

8. *Odobenus* (Walrus). The walrus *(Odobenus rosmarus)* found in Arctic waters, is the largest of aquatic carnivores. The spindle-shaped body, sparsely haired, is upto 3.5 meters long, and may, weigh well over one ton. The upper canines grow downwards, forming elongated *tusks,* used for digging up molluscs and crustaceans from muddy bottoms, and for climbing onto the ice from water. Upper lip is thick, fleshy and bearing sensory bristles. A thick layer of fat or blubber under skin insulates against the cold. External ears are absent. Hind flippers can be turned forwards for locomotion on land. They breed once in three years for which they come on land.

9. *Phoca* (Seal). Like walrus, seals also possess streamlined, fish-like form, flipper-like limbs and strongly webbed feet adapted for swimming. They are hunted for oil-yielding blubber and skins. They are usually gregarious and each adult male or 'bull' lords over a harem of 50 to 60 females or 'cows'. Seals are of several kinds. The true, common or harbour seal *(Phoca vitulina)* is without external ears and its hind flippers can not be turned forwards. Fur seal *(Callorhinus)* and sea lion *(Zalophus)* have conspicuous external ears and use all the four limbs for moving on land.

[IX] Cetacean mammals

Whales, dolphins and porpoises of the order Cetacea are large marine animals, well adapted for aquatic life. Their cylindrical streamlined body tapers towards long fish-like tail, ending in 2

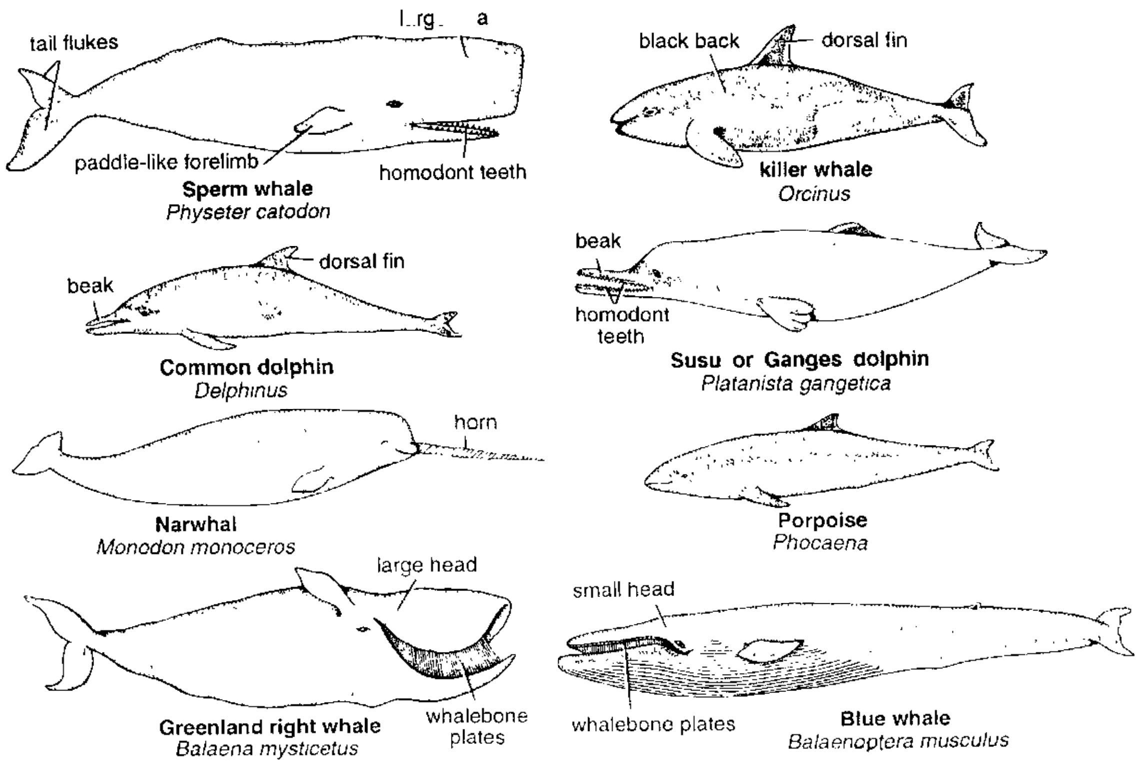

Fig 14 Cetacean mammals

fleshy horizontal lobes or flukes. Forelimbs are modified into broad paddle-like flippers while posterior limbs are absent. Nostrils open far back on top of head. Eyes are small, external ears absent and mammary glands well-developed. Skin is smooth with hairs except for few whiskers on muzzle. A thick layer of fat or blubber under skin compensates for lack of hairs and insulates body. There are two distinct suborders : Odontoceti and Mystacoceti (Table 4, Fig. 14).

1. *Physeter* (Sperm Whale). *Physeter catodon* is common in warmer seas. It is the largest toothed whale with male upto 25 metres long while female only half in size. There is no dorsal fin. The enormous, barrel-shaped head or rostrum measures a third of total body length and filled with about one ton of *spermaceti oil.* It is non-edible but used in industry as a lubricant, in making candles and as a base of cosmetics. A peculiar stone-like substance, *ambergris,* is formed in its stomach and is used in perfumes. Upper jaw has vestigial teeth. Lower jaw is much shorter than the upper and bears numerous functional homodont conical teeth. It feeds mostly on squids. When it comes to surface, it expires forcibly through the single nostril. The moist warm exhaled air condenses in cold atmosphere forming a spout of water. This act is called *blowing.*

2. *Orcinus* (Killer whale). *Orcinus orca* is found in oceans throughout the world but is most common in Arctic and Antaractic waters. The male grows to 9 metres long, while the female is 4.5 metres long. Body is black-backed, with a white undersurface and a tall, narrow, triangular dorsal fin. It is the most savage cetacean and the tiger of the sea. It normally feeds on fishes, birds, seals and porpoises, but does not hesitate to attack larger whales and tear huge mouthfulls from their bodies. It has teeth in both jaws.

3. *Platanista* (Ganges dolphin). All freshwater dolphins have long, almost bird-like, beaks containing upto 200 teeth in both the jaws. 'Susu' or Ganges dolphin, *Platanista gangetica,* lives in the Ganges, Brahmputra and perhaps in the Indus rivers and their tributaries. Body is 2 to 3 metres long, dark grey in colour, with a small head with a well developed maxillary crest, long beak and sharp teeth in both the jaws. It probes in the mud for shellfish.

4. *Delphinus* (Common dolphin). It is the common marine dolphin having a large number of teeth. It differs from *Platanista* in having a neck, well-developed eyes and a dorsal fin in the centre of back.

5. *Phocaena* (Porpoise). It is a small marine whale about 2 metres long. It is more common in Atlantic and Pacific oceans and often swims up rivers. It has no beak but a large dorsal fin with tubercles. It feeds mainly on gregarious fish. It often follows the ships, is intelligent and even tamed.

6. *Monodon* (Narwhal). *Monodon monoceros* lives in Arctic waters and grows to 5 metres in length. In male, one of the two upper incisors grows into a spirally twisted tusk or horn, upto 2.5 metres long, and of unknown function. The female retains undeveloped incisors, buried in premaxillae.

7. *Balaenoptera* (Blue Whale). The blue whale, *Balaenoptera musculus,* is a whalebone whale. It may grow upto 35 metres and weigh 150 tons. It is the longest whale and the largest animal that has ever lived. It feeds in Arctic and Antarctic waters but migrates to temperate waters to breed. Body is blue above and yellow below. Also called the rorqual or fin whale, it is distinguished from sperm whale in having a small dorsal fin, smaller head, narrow ridges on throat and slightly curved jaws. Instead of teeth mouth cavity is provided with a series of numerous parallel horny plates of *whalebone* or *baleen* hanging down from the palate. These act as sieves or strainers for microscopic animals or plankton on which they live. Thus the largest animals in the world live upon the smallest.

[X] Primates

The order Primates is interesting because it includes man, besides lemurs, tarsiers, monkeys and apes. They inhabit chiefly the warmer parts of the world. They stand first in the animal kingdom in brain development. However, they are relatively

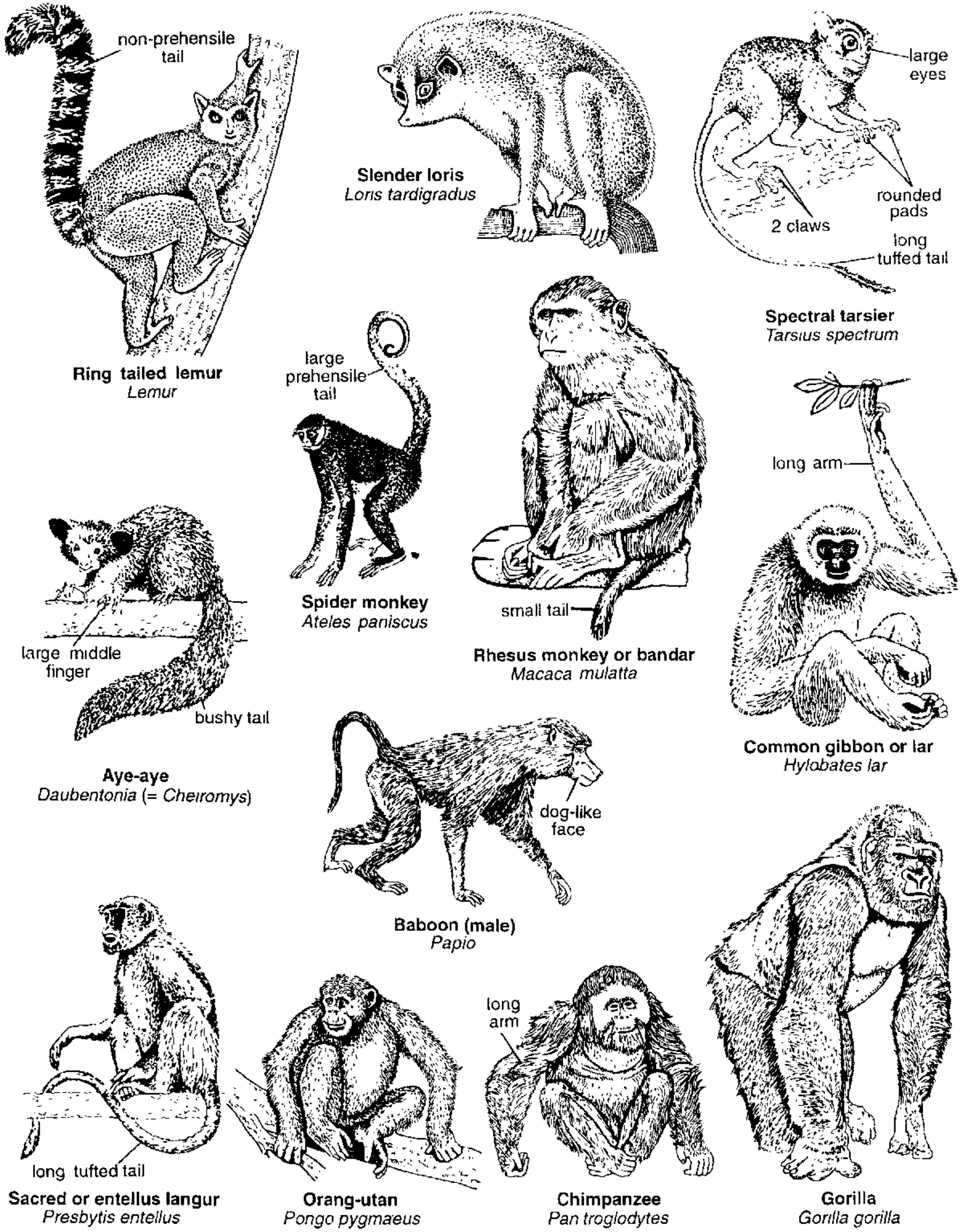

Fig. 15. Modern Primate mammals.

unspecialized and mostly tree-dwelling (arboreal). Limbs have 5 digits and generally bear nails instead of claws. Great toe and thumb are opposable to other digits for grasping. Their eyes are in front of head and meant for stereoscopic vision. Some primates are as follows (Fig. 15) :

1. *Lemur* (Lemur). The name 'lemur' means 'ghost'. They are most abundant in Madagascar and neighbouring islands and are regarded to be the lowest primates. Thumb and big toe are opposable. Digits bear nails but each second toe carries a long grooming claw. Tail is long and nonprehensile. Head is fox-like. Vision is poor. Lower incisors are modified to form a fur-grooming comb. They are arboreal and mostly nocturnal although genus *Lemur* is diurnal. If feeds mostly on plants and small animals.

2. *Loris* (Loris). Lorises are found outside Madagascar. Slender loris, *Loris tardigradus,* is known from southern India and Sri Lanka, while *Nycticebus bengalensis* from northern India. Like lemurs, they are arboreal, nocturnal and have a tooth comb. They also eat fruits and small animals. However, they are tailless, move slowly and often hang upside down.

3. *Tarsiers* (Tarsier). Tarsiers are small solitary primates, about the size of rats, living in Philippines and adjacent islands. They are slightly advanced over lemurs. They have flat face, very large eyes for binocular vision, round skull and no tooth comb. Tarsal region of foot is long, 2 toes on each foot provided with claws. and tips of all digits, bear rounded pads. Scaly underside of long narrow tufted tail provides support. Spectral tarsier, *Tarsius spectrum,* found in forests in Celebes, is arboreal, nocturnal, very agile and feeds on insects, small amphibians and reptiles.

4. *Daubentonia* (Aye-aye). Aye-aye or *Daubentonia (= Cheiromys) madagascariensis* of Madagascar is about the size of a cat. It is like lemurs in many ways. There is one incisor on each side in each jaw continually growing as in rodents and used for gnawing. It has a very long and wiry middle finger for impaling insect grubs.

5. *Ateles* (Spider monkey). The most dexterous prehensile tail of all the New World Monkeys belongs to the spider monkey, *Ateles paniscus,* found in tropical jungles from Mexico to Brazil. The tail can be used as an extra limb, to hang from trees, as a sensitive probe, or to pick up an object as small as a peanut.

6. *Alouatta* (Howler monkey). Howler monkeys are the largest of the New World monkeys with prehensile tail and loud voice. They have special laryngeal sacs and their loud voice is used in the assertion of territorial rights by the clan. They have a language, of at least a dozen distinct sounds with separate meaning·.

7. *Papio* (Baboon). The large baboons are the Old World monkeys from Africa. They have a doglike face with a long muzzle and large canine teeth. They are the most ferocious and perhaps the most despised. They are not arboreal but live in open country in family groups with hierarchial organization.

8. *Macaca* (Rhesus monkey). One of the best known Old World monkeys is the rhesus monkey or 'bandar', *Macaca mulatta.* It is common in northern India, southern China and Indochina (Vietnam). It is widely used in biological investigations. The Rh blood factor was first discovered in these monkeys. It has simple stomach and large cheek pouches for storing food.

9. *Presbytis* (Langur). The sacred or entellus langur, *Presbytis (= Semnopithecus) entellus,* lives in the forests of India and Pakistan. Colour is silvery grey with a black face. It has no cheek pouches but stomach is complex for feeding on leaves. Unlike other langurs, it lives mainly on the ground.

10. *Hylobates* (Gibbon). Gibbon is the smallest, cleanest and genttest anthropoid ape found in the rain forests of Assam, S.E. Asia and Indonesia. It has slender body and limbs and about one meter tall. Male is black in colour but female is yellowish. Unlike apes, it has ischial callosities. It lives almost entirely in trees swinging rapidly from branch to branch by its long arms and famous for its acrobatics. It has a bipedal gaite on ground moving upright with arms held high for balance. It is frugivorous. Gibbons live in pairs and make loud territorial calls.

11. *Pongo* (Orangutan). *Pongo (= Simia) pygmaeus* is confined to the low-lying forests of Sumatra and Borneo. Orangutan means 'man of the woods'. Body is 1.5 metres high with long arms, short legs and long shaggy red hairs. Male has a big goitre-like throat sac and two fatty swellings in the cheeks. It is mainly arboreal, feeding on buds and fruits. It constructs a sort of nest on tree top for living. On ground, it walks on its feet and knuckles.

12. *Pan* (Chimpanzee). Chimpanzee, *Pan (= Anthropuhecus) troglodytes*, lives in the rain forests of tropical West Africa. Chimpanzee is most intelligent of all apes and possesses high level of curiosity. It is more nearly like man than any other living mammal. It is easily tamed when young and trained to perform simple acts. Body is upto 1.2 metres in height, with smooth rounded skull, prominent bow ridges, large ears, relatively short arms and long scant black hair. It lives on trees and on ground and is frugivorous. Communities are loose and without leaders. The pygmy chimp or bonobo, *P. paniscus*, is found South of Congo river.

13. *Gorilla* (Gorilla). Gorilla is the most powerful ape and the largest living primate, nomadic in the deep equatorial African forests of Cameron, Gabon and Congo. Massive and strongly built body is 1.8 metres tall, 250 kg in weight, with large canines, arms longer than legs and big toe larger than the rest. *Gorilla gorilla* is almost entirely terrestrial, ferocious and untamable, but more quiet and retiring than the chimpanzee. It walks semi-erect on plantigrade feet, using knuckles of hands for support and subsists on plant materials. Gorillas live in family groups of upto 30 headed by an adult male. Mountain gorillas have dense black hairs, while lowland gorillas are blackish-brown in colour.

[XI] Hoofed mammals (Ungulates)

Ungulates or hoofed mammals are divided into two distinct orders. Those with an odd number of toes (horse, ass, zebra, tapir, rhino) are placed in the order Perissodactyla. Those with an even number of toes (rest of ungulates) are placed in the order Artiodactyla, which also includes the majority of the big game animals (Figs. 16 & 17).

1. *Equus* (Horse, Ass, Zebra). The horse family Equidae, which also includes asses and zebras, are large, fast running animals having only one functional toe with a large hoof on each foot. They live in herds. Their molars are specially well-developed for grinding plant food. *Equus caballus przewalskii* or Mongolia is the only surviving wild horse from which all the 50 to 60 domesticated races have descended.

African wild ass is *Equus asinus*, while Asiatic wild ass is *Equus hemionus*. They are on the verge of extinction. Their domesticated variety is known as donkey. The main differences in the external features of an ass or donkey and a horse have been given in the Table 6. *Mule* is the hybrid between male ass (jack) and female horse (mare). It has the stamina of ass and size of horse, but is sterile. Similarly, the cross between male horse (stallion) and female ass is called *hinny*. Zebras *(Equus zebra)* are found in open grassy lands of Africa. They resemble an ass except that their white or buff coloured body is fully striped with black or brown, and they are seldom domesticated.

2. *Tapirus* (Tapir). Tapirs are nocturnal herbivorous and heavy-bodied mammals, native to C. and S. America and S.E. Asia. They have short legs with 4 hoofed toes on the forefeet and 3 on the hind feet. The upper lip and nose form a short flexible proboscis. Largest is the Malayan tapir, *Tapirus indicus*. It lives near water in forests from Thailand to Sumatra. Its coat is strikingly black and white, probably for camouflage.

3. *Rhinoceros* (Rhino). Rhinoceroses are massive, thick-skinned and herbivorous mammals with 3 hoofed toes on all feet. They live in African grasslands and forests of southern Asia. The most striking feature is the fibrous horn (1 or 2) composed of matted hair, on the top of snout having a prehensile upper lip. The Indian rhinoceros *(Rhinoceros unicornis)*, living in N. Bengal, Assam and Nepal, bears a single

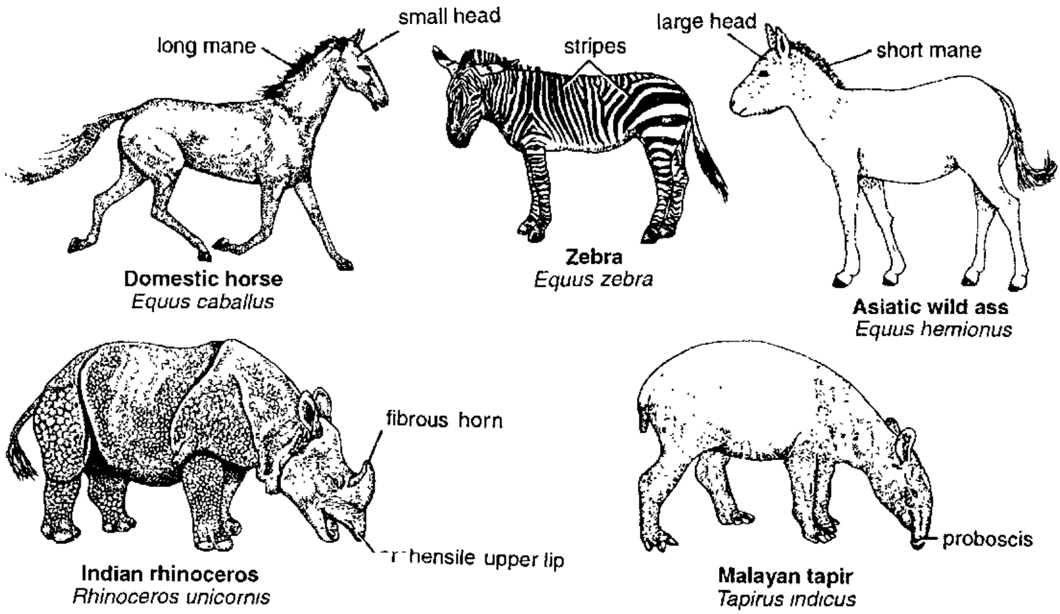

Fig. 16. Odd-toed hoofed mammals.

Table 6. **Differences between a Horse and an Ass.**

Characters	Horse	Ass or Donkey
1. Distribution	Cosmopolitan.	Africa and Asia.
2. Size	Relatively larger.	Relatively smaller.
3. Head	Smaller.	Larger.
4. Ears	Shorter.	Longer.
5. Mane	Longer, pendant.	Shorter, erect.
6. Hooves	Broader. A horny callosity (vestigial hoof) on each foot.	Narrower. A bare callosity only on forefeet.
7. Tail	Completely covered with long hairs.	Only lower part of tail covered with hair.
8. Hardy & sure footed	Less.	More.

horn. The African black rhinoceros *(Diceros bicornis)* has two horns. Largest is African white rhino, *R. simus.*

4. *Sus* (Pig). The wild boar or pig, *Sus scrofa,* found in the woodlands of Europe, N. Africa and almost whole of Asia, is the ancestor of all domesticated pigs used for meat (pork) and fat (lard). Its stocky body is covered with short stiff hair. They have a long head, mobile snout and canines of both jaws curved upwards for rooting. There are 4 toes on each foot, but only the 3rd and 4th reach the ground. Stomach is simple, food is both plant and animal, but they do not ruminate.

5. *Hippopotamus* (Hippopotamus). The common hippopotamus, *Hippopotamus amphibius,* found in most rivers of tropical Africa, is a large, heavy and short-legged, nocturnal, herbivorous ungulate, 4 metres in length and weighing upto 4 tons. It lives in small groups remaining in water in daytime but coming out at night for feeding. Muzzle is very broad and nostrils, eyes and short ears placed dorsally upon head as an adaptation for submerged life in water. Slightly webbed feet

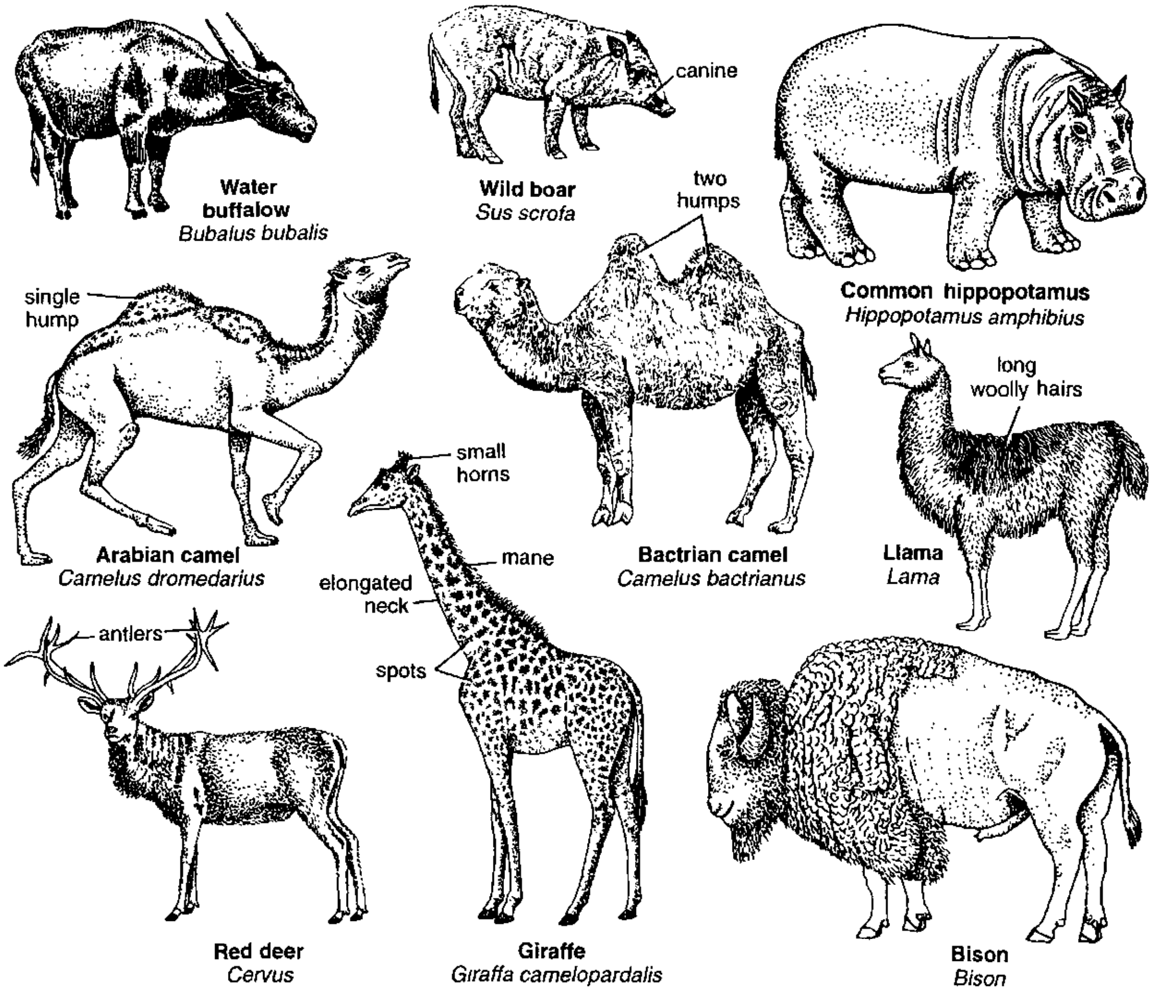

Fig. 17. Even-toed ungulate mammals.

have 4 hoofed toes each. Skin is 5 cm thick with few hairs and a thick layer of fat underneath. Sweat is red in colour. Bulls fight using their tusk-like lower canines as weapons. They are good swimmers and divers. Pigmy hippopotamus, *Choeropsis liberiensis,* is only 60 cm high at the shoulders.

6. *Camelus* (Camel). Camels are so well adapted for desert life that they are known as the 'ships of the desert'. Each foot has only 2 toes without hoofs, supported by pads below which spread the load on sand. Slender snout bears a cleft upper lip. Long eyelashes and muscular nostrils can be closed for protection from blown sand. They chew cud and have a complex 4-chambered stomach to carry a reserve water supply. They can survive for 2 weeks without water. Their characteristic fatty hump on the back is used as a source of reserve food when they are forced to fast during scarcity of food. Two species of camels are known. The one-humped Arabian camel or dromedary, *Camelus dromedarius* of N. Africa and S.W. Asia, is somewhat taller, lighter and faster and used for racing or riding. The bactrian camel, *Camelus bactrianus,* of cold rocky deserts of Central Asia (Gobi desert) has two humps, shaggy hairs and is sturdy and weight carrier. Camels provide transport, flesh, hide and wool.

7. *Lama* (Llama). Lama is mainly a mountain dweller of South America. It resembles camel is

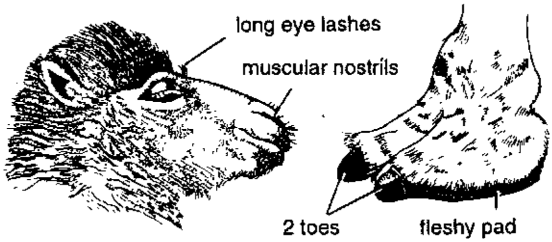

Fig. 18. Camel. Head and foot showing adaptations to sand.

basic structure. However, it is smaller in size, without hump and covered with long woolly hairs. As a protective device, it spits the contents of stomach on the attacker. Lama is valued as a pack animal and for providing fur, flesh and tallow (fat).

8. *Giraffa* (Giraffe). Giraffe, *Giraffa camelopardalis*, inhabits tree-studded grasslands of E. Africa. It is the tallest living animal reaching a height of 6 meters above ground. Body shows brownish spots all over on a yellow background. Forelimbs are longer than hind limbs. Enormously elongated neck bears a sh~rt ~~ct ~~~~ ~~d contains only seven cervical vertebrae. Head in both sexes carries 3 to 5 small bony horns covered by velvety skin. Its prehensile tongue can extend upto 50 cm to eat leaves of trees. Giraffe is fast enough to outrun most of its enemies. It cannot make sound.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give an account of distinguishing characters and outline classification of mammals.
2. Give a brief classification of mammals stating important characters and examples of each order.

» *Short Answer Type Questions*

1. Distinguish between the following in a tabular form—(i) Horse and ass, (ii) Indian and African elephants, (iii) Lemuroidea, Tarsioidea and Anthropoidea, (iv) Lion, Tiger and Leopard, (v) Megachiroptera and Microchiroptera, (vi) New world and old world monkeys, (vii) Odontoceti and Mysticeti (viii) Platyrrhina and Catarrhina, (ix) Spiny and scaly anteaters.
2. Write short notes on — (i) Anteaters, (ii) Bats, (iii) Cetacea, (iv) Duckbilled Platypus, (v) Echidna, (vi) Kangaroo, (vii) Pangolin, (viii) Primates.

» *Multiple Choice Questions*

1. In mammals hind limbs are absent in .
   (a) Cetaceans (b) Rodents
   (c) Marsupials (d) Chiropterans
2. Teeth in mammals are :
   (a) Thecodont, homodont, diphyodont
   (b) Thecodont, heterodont, diphyodont
   (c) Acrodont, homodont, monophyodont
   (d) Acrodont, homodont, polyphyodont
3. Monotremates are confined to :
   (a) Oriental region (b) Ethiopian region
   (c) Australian region (d) Neotropical region
4. Marsupium is present in :
   (a) Monotremes (b) Insectivores
   (c) Chiropterans (d) Marsupialia
5. The dental formula of sub order Lemuroidea is :
   (a) $\frac{2133}{2133}$ (b) $\frac{2133}{1133}$ (c) $\frac{2123}{2123}$ (d) $\frac{2023}{2023}$
6. Largest mammalian suborder :
   (a) Logomorpha (b) Rodentia
   (c) Cetacea (d) Sirenia
7. Largest living land animals are included in the suborder :
   (a) Perissodactyla (b) Artiodactyla
   (c) Probiscidea (d) Hyracoidea

ANSWERS

1 (a) 2 (b) 3 (c) 4 (d) 5 (a) 6 (b) 7 (c).

32

Subclass Prototheria (Order Monotremata)

Class mammalia is divided into 2 subclasses : Prototheria and Theria. The subclass *Prototheria* includes primitive egg-laying mammals belonging to a single order, *Monotremata* or *Ornithodelphia.* They stand at the base of the mammalian stock and present many features in common with the *Sauropsida* (reptiles + birds).

Distinctive Characters

1. Distribution. Restricted wholly to the Australian region including Australia, Tasmania, New Guinea and sundry neighbouring islands.

2. Habits and habitat. Aquatic or terrestrial, burrowing, mainly insectivorous, nocturnal, air-breathing, incompletely warm-blooded, quadrupedal, oviparous or egg-laying mammals.

3. External features. Body small and covered by hairs and spines. Muzzle or snout produced into a beak. External ears inconspicuous or absent. Tail present or absent. Mammary glands are without teats or nipples. Male carries a hollow, horny, tarsal spur on each hindleg, connected internally to a crural poison gland. A temporary mammary pouch, equivalent to teats, develops during breeding season on the abdomen of female.

4. Exoskeleton. Includes epidermal horny hairs, spines, beaks and claws. Skin glandular.

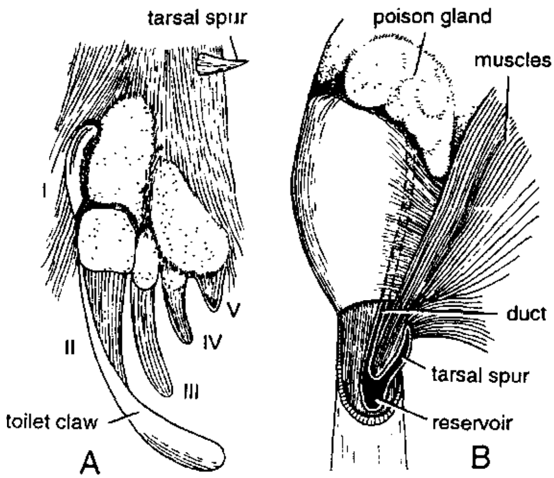

Fig. 1. Tarsal spur. A—Foot of male echidna. B—Poison apparatus of male platypus dissected.

5. Body cavity. Divided by a typical mammalian diaphragm into an anterior thoracic and a posterior abdominal cavity.

6. Endoskeleton. Skull dicondylic. Skull sutures become obliterated. Orbits continuous with temporal fossae. Lacrimals and alisphenoids absent, but distinct pterygoids present. Tympanic ring-like and no tympanic auditory bulla formed. Ear ossicles three. Malleus and incus relatively large. Each half of mandible made by a single bone, the dentary. Mandibular symphysis weak and coronoid

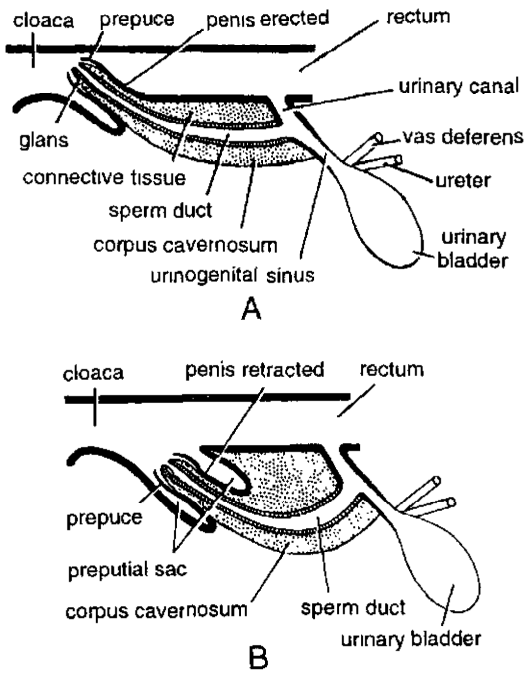

Fig. 2. Diagrammatic L.S. through cloacal region of a male monotreme. A—Penis erect. B—Penis retracted.

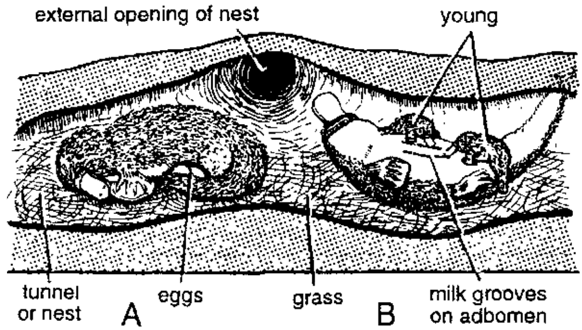

Fig. 3. Female platypus. A—Incubating her two eggs. B—Newly hatched young lapping up milk on the belly of mother.

process small. Vertebral epiphyses indistinct or absent. Cervical vertebrae 7 and without zygapophyses. Ribs unicephalous, with only capitulum. Coracoids well developed. Spine of scapula present at its anterior border. A large T-shaped interclavicle similar to that of reptiles, present. Ischia and pubes fuse at a long ventral symphysis. A pair of small rod-like epipubic or marsupial bones present in ventral abdominal wall.

7. Digestive system. Teeth develop only in embryos, replaced by horny beak in adults. Rectum opens into a cloaca.

8. Respiratory system. Respiration pulmonary, by lungs.

9. Circulatory system. Heart 4-chambered. Right auriculoventricular valve incomplete and fleshy. Right valve tricuspid, not bicuspid as in other mammals. Chordae tendineae absent. Single left aortic arch persists. Ventral abdominal vein or its mesentery present. R.B.C. small, circular and non-nucleated. Body temperature variable (25°-28°C).

10. Excretory system. Kidneys metanephric. Ureters open into urinogenital sinus which terminates into common cloaca.

11. Nervous system. Brain relatively small, simple and without corpus callosum. Optic lobes four (corpora quadrigemina). Cochlea slightly bent and with a lagena.

12. Reproductive system. In male, testes abdominal and penis retractile passing out sperms but not urine. In female, right ovary reduced and oviducts lead separately into cloaca. There are no uterus and vagina (Fig. 2).

13. Development. Females oviparous. Eggs large with much yolk and plastic shells. Cleavage meroblastic. No uterine gestation. Newly hatched young very immature, fed on milk in abdominal pouch till fully developed (Fig. 3).

Classification

Order Monotremata includes only two families :

Family 1. Tachyglossidae. Terrestrial. Limbs strongly clawed for burrowing. Body covered above with short barbless spines and coarse hairs. Tail vestigial. Pinna distinct. Teeth never present. Examples : Spiny anteaters, *Tachyglossus* and *Zaglossus*.

Family 2. Ornithorhynchidae. Semi-aquatic, burrowing. Limbs clawed as well as webbed for swimming. Body covered by soft fur. Tail well-developed and paddle-like. Pinna vestigial. Rudimentary teeth in embryo. Examples : Duck-bill or platypus, *Ornithorhynchus*.

Affinities

In most characters, the Prototheria resemble the Sauropsida (reptiles and birds), though showing a little advance over them, and thus coming nearer to their mammalian relatives.

1. Reptilian affinity. Although there is no definite connecting link known, there is enough evidence to show that mammals had a reptilian ancestry. This view is further supported by the following resemblances between the monotremes and the living reptiles :

(1) Presence of cloaca.
(2) Skull with large pterygoids, epipterygoids, dumb-bell shaped prevomers and ring-like tympanic bones, but without alisphenoids and tympanic bullae.
(3) Vertebrae without epiphyses and with cervical ribs.
(4) Thorcic ribs are single headed.
(5) A median T-shaped interclavicle present.
(6) Large coracoids and plate-like precoracoids.
(7) Both ischia and pubes form ventral symphyses.
(8) Acetabulum in echidna is perforated.
(9) Can withstand starvation for a long period.
(10) Anterior abdominal vein or its mesentery present.
(11) A large anterior commissure but no corpus callosum joining the two cerebral hemispheres.
(12) Body temperature not constant.
(13) Cochlea of internal ear with lagina.
(14) Ureters lead into a urinogenital sinus.
(15) Testes are abdominal.
(16) Penis is a simple retractile groove conducting only sperms.
(17) Oviducts separately open into cloaca and without uterus and vagina.
(18) Females are oviparous. No uterine gestation.
(19) Eggs large, cleidoic, with a leathery shell.
(20) Newly hatched young with a caruncle and an egg-tooth.

2. Avian affinity. The relationship of prototherian with birds does not have solid facts. The similar characters present in theria are chiefly due to the fact that both possess common reptilian ancestry. The important points of resemblance are–

(1) Shape of beak of *Platypus* resembles with birds.
(2) Teeth are absent.
(3) Feet are webbed.
(4) Presence of obliterated sutures of skull.
(5) Tarsal region bear spur.
(6) Oil gland is present.

3. Mammalian affinity. The prototherians are essentially mammals as they possess the following typical mammalian characters :

(1) Body covered by hairs. Pinnae present.
(2) Skin richly glandular, containing sweat and sebaceous glands.
(3) A typical mammalian diaphragm divides body cavity.
(4) Chondrocranium is typically mammalian.
(5) Skull is dicondylic.
(6) Middle ear cavity has 3 ear ossicles.
(7) Each ramus of lower jaw made of a single bone, the dentary.
(8) Cervical vertebrae typically seven.
(9) Sternum is segmented.
(10) A slender caecum demarcates two intestines.
(11) Lobes of liver typically mammalian.
(12) Heart 4-chambered.
(13) Only left aortic arch present.
(14) R.B.C. small, circular and non-nucleated.
(15) Presence of 4 optic lobes (corpora quadrigemina).
(16) Presence of milk glands secreting milk.

4. Peculiar characters. The following characters are peculiar to Prototheria :

(1) Presence of tarsal spurs in males.
(2) Milk glands derived from sweat glands (not sebaceous as in other mammals), and without teats.
(3) Temporary abdominal mammary pouch in female during breeding season.
(4) Teeth replaced in adults by horny plates.
(5) Jaws elongated forming a beak or rostrum.
(6) Ear ossicles relatively large showing transition.

(7) Marsupial or epipubic bones present.
(8) Imperfectly warm blooded with body temperature varying from 25° to 28°C.
(9) Right ovary smaller and usually functionless.

5. **Conclusions.** Peculiar affinities of Prototheria lead us to some definite conclusions :

(1) Peculiar blending of reptilian and mammalian characters suggests an intermediate stage between two groups.
(2) Possession of primitive, degenerate and highly specialized characters indicates that they represent an early separate side line from main mammalian stock. This justifies their placement in a separate subclass Prototheria from the rest of mammals which are placed under the subclass Theria.
(3) Monotremes show that reptiles, birds and mammals together constitute a natural group more homogeneous than the group Ichthyopsida (fishes + amphibians) or even the superclass Pisces.

About the phylogenetic consideration two hypothesis has been held —

(1) It is expressed that monotremes evolved independently from some early mammal like reptiles and continued to survive in isolation.
(2) It is believed that monotremes have been derived from very early marsupials with peculiar characters and divergent specializations.

Among mammals, the position of monotremes is very controversial. They possess primitive, specialized and degenerative features. It is concluded that they originated as a side line from the main line of mammalian evolution and retained those characters through which higher mammals have passed.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give an account of general characters and affinities of Prototheria.
2. What are egg-laying mammals ? Describe their general characters, habitat, habits and distribution. How do monotremes resemble the reptiles ?

» ***Short Answer Type Questions***

1. Amplify the statement that monotremes show a peculiar mixture of mammalian and reptilian characters.
2. Write short notes on— (i) Egg-laying mammals, (ii) Prototheria.

» ***Multiple Choice Questions***

1. Spiny anteaters are included in the family :
   (a) Tachyglossidae (b) Ornithorhynchidae
   (c) Didelphidae (d) Notoryctidae
2. Which of the following is a tilian affinity of monotremes ?
   (a) Body covered with hair (b) T-shaped interclavicle
   (c) Pinnae present (d) Dicondylic skull
3. Typical prototherian character is :
   (a) Presence of cloaca
   (b) 4 chambered heart
   (c) Tarsal spur in males
   (d) Segmented sternum

ANSWERS

1 (a) 2 (b) 3 (c).

33

Infraclass Metatheria (Order Marsupialia)

Subclass Theria includes two infraclasses : Metatheria and Eutheria. Infraclass Metatheria includes pouched mammals without a true placenta. The young are born in an immature condition and placed in a single order Marsupialia or Didelphia.

Distinctive Characters

1. Distribution. Almost entirely confined to the Australian region with the exception of the American opossums.

2. Habits and habitat. Terrestrial, burrowing or arboreal, rarely aquatic, herbivorous, carnivorous or omnivorous, nocturnal or diurnal, air-breathing, warm-blooded, viviparous and pouched mammals.

3. External features. Body furry, that is, covered with soft hairs. External ear lobes or pinnae are well-developed. Tail generally long, often prehensile. Mammary glands are modified sebaceous glands and have teats. Female usually with a ventral abdominal pouch, called *marsupium,* or with marsupial folds enclosing mammary nipples and supported with a pair of *epipubic* or *marsupial* bones.

4. Exoskeleton. Includes epidermal horny hairs and claws. Skin richly glandular.

5. Body cavity. Typical muscular diaphragm present.

6. Endoskeleton. Skull dicondylic. Skull top flat. Cranium small with well developed sagittal and occipital crests, skull sutures present. Paroccipital processes greatly elongated. Orbit and temporal fossa confluent due to absence of postorbital bar. Nasal bones large and expanded posteriorly. Jugal (malar bone) large and reaches up to glenoid articulation. Pterygoid is small. Tympanic bulla absent. In some cases, alisphenoid large, forming the so-called alisphenoid bulla. Palate imperfectly ossified, having large posterior vacuities. Middle ear cavity with 3 small ear ossicles. Angle of dentary inflected or inturned. Vertebrae with epiphyses. Cervical vertebrae seven. Cervical ribs and odontoid process fuse early with their respective vertebrae. Thoracic vertebrae are 13 in number. Lumber vertebrae are seven in number, caudal vertebrae with *Chevron bone* except Koala and Wombat. Atlas is incomplete and provided with cartilage on its ventral incomplete side. Thoracic ribs bicephalous. Interclavicle absent. Large clavicles present. Coracoids reduced. Scapula with an additional anterior spine. A pair of epipubic bones present in front of pubic symphysis for the support of marsupium (Fig. 1).

7. Digestive system. Teeth generally exceed typical eutherian number of 44. Only one set present (monophyodont) except last pre-molar.

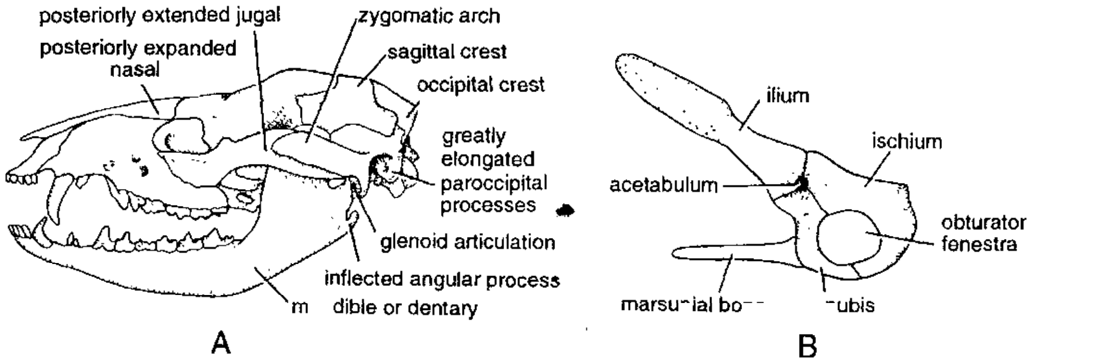

Fig. 1. Opossum. A—Skull and mandible in lateral view. B—Pelvic girdle showing marsupial bone.

Teeth are heterodont and thecodont. Number of premolar 3/4 or 4/4. Anus and urinogenital aperture open into a shallow cloaca surrounded by a common sphincter. Shape and size of stomach is variable. Cardiac gland is present in few forms. Gall bladder is always present.

8. Respiratory. Circulatory and excretory systems typically mammalian.

9. Nervous system. Brain relatively small and less convoluted. Olfactory lobes large. Cerebral hemispheres small. Cerebellum small and exposed. Anterior commissure large. Corpus callosum, feebly developed or absent. Cochlea of internal ear spirally coiled.

10. Reproductive system. In males, penis well-developed, often bifurcated at the tip. Scrotal sacs containing testes lie in front of penis. In females, two oviducts open separately into urinogenital sinus, so that there are two uteri and two vaginae. Clitoris in female may also be double.

11. Development. Females are viviparous. Gestation period for uterine development small, 2 weeks in opossum to 5 weeks in kangaroo. A true allantoic placenta absent except in *Perameles.* Young are born exceedingly small, naked and blind. They are kept in marsupium and nourished on milk until fully formed. Thereafter, small young retreat to marsupium for shelter (Fig. 2).

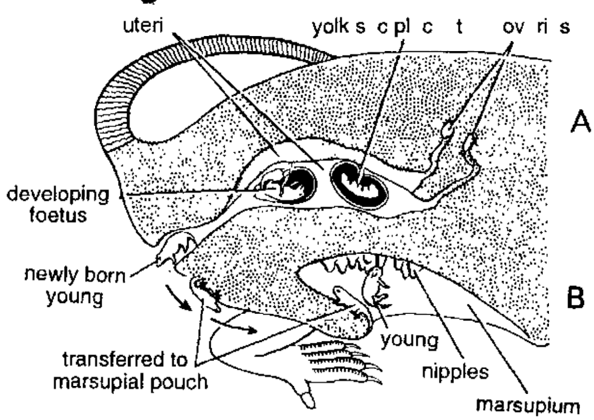

Fig. 2. Female opossum. A—Showing uterine development. B—Showing marsupial development.

Classification

Marsupials are more widespread as fossils. 8-10 families include about 240 living genera. Previously, they were arranged in two groups (or suborders), based on their dentition or foot structure, as follows :

Family 1. Didelphidae. American marsupials. Common or Virginian opossum *(Didelphis marsupialis),* water opossum *(Chironectes).*

Family 2. Dasyuridae. Carnivorous or insectivorous. Native cat *(Dasyurus),* marsupial wolf *(Thylacinus),* banded anteater *(Myrmecobius).*

Family 3. Notoryctidae. Insectivorous. Marsupial moles *(Notoryctes).*

Family 4. Peramelidae. Bandicoots *(Perameles).*

Family 5. Caenolestidae. Shrew-like *(Caenolestes, Rhyncholestes).*

Family 6. Phalangeridae. *Phalanger,* flying phalanger *(Petaurus),* koala *(Phascolarctos).*

Family 7. Phascolomidae. Wombat *(Phascolomys).*

Family 8. Marcopodidae. Herbivorous. Kangaroo *(Macropus).*

Classification of Order Marsupialia.

Scheme 1. On the basis of incisors				Scheme 2. On the basis of toes			
	Groups		***Families***		***Groups***		***Families***
1.	**Polyprotodontia** More than 3 incisors in each half of upper jaw.	1.	Didelphidae	1.	**Didactyla** All the toes separate	1.	Didelphidae
		2.	Dasyuridae			2.	Dasyuridae
		3.	Notoryctidae			3.	Notoryctidae
		4.	Peramelidae			4.	Caenolestidae
2.	**Diprotodontia** Less than 3 incisors in each half of upper jaw.	1.	Caenolestidae	2.	**Syndactyla** 2nd & 3rd toes of hind foot united.	1.	Peramelidae
		2.	Phalangeridae			2.	Phalangeridae
		3.	Phascolomidae			3.	Phascolomidae
		4.	Macropodidae			4.	Macropodidae

Distribution of Metatheria

Not only the marsupials are interesting from the point of view of their structure, their present as well as past distribution is also of equal interest, and leads us to some interesting conclusions :

1. Discontinuous distribution. During Cretaceous period, marsupials were found over much of the earth. Today, they are almost entirely confined to the Australian region. The only exceptions are the opossums *(Didelphis)* and opossum rats *(Caenolestes)* of North and South Americas. Thus they furnish a good example of *discontinuous distribution.*

2. Original home. In Australia, where marsupials dominate at present, no fossil remains occur prior to Pleistocene. However, their earliest known fossils belong to the Jurassic of Europe. This suggests that their earliest home or seat of origin was probably in Europe.

3. Support to land bridge theory. Australia has no native higher mammals or eutherians. With the exception of monotremes, nearly all of the Australian mammals are marsupials. We may assume that at the time the marsupials came into existence, Australia was connected to the main land by a land bridge. It seems that Australia became isolated, from the rest of the world, soon after marsupials entered it but before the higher mammals could arrive.

Similarly, the discovery of strictly dasyurine fossils from South America supports the widely accepted theory that even after separation from the Old World, South America was connected to Australia by an Antarctic land bridge. Some of the Australian marsupials may have wandered into S. America over this land connection.

4. Extinction outside Australia. The cause of total or universal extinction of marsupials outside Australia, except the American opossums, remains a mystery. Probably they disappeared due to stiff competition against the ancestral placental mammals which bear their young alive without need for protection in a pouch.

5. Isolation and adaptive radiation. In Australia, in the absence of competition from higher mammals and isolated and protected by a wall of water (sea) for countless ages from the rest of the world, the marsupials prospered successfully. They developed along several lines of parallel evolution similar to higher mammals in other parts of the world. In addition to opossums and kangaroos, there are marsupial mice, squirrels, rabbits, cats, dogs, wolves and the native bear, the koala. They furnish splendid illustration of the effect of isolation by a natural barrier (sea) on the perpetuation of hereditary variations, an important principle in relation to evolution.

Affinities

Metatherians show a mixture of primitive and advanced characters.

1. Affinity with Prototheria. They have certain primitive characters also found in Prototheria such as :

(1) Presence of cloaca.

(2) Presence of clavicles, epipublic bones and ring like tympanic.

(3) Absence of tympanic bulla.

(4) Brain, relatively simple with large olfactory lobes and anterior commissure, but without corpus callosum.

(5) Absence of true allantoic placenta.

However, metatherians differ from prototherians mainly in being viviparous, having permanent marsupial pouch, teats in mammary glands, well developed external ears, vertebrae with epiphyses, ribs bicephalous, no interclavicle and separate coracoids, teeth in the adult, cochlea spirally coiled, penis bifid, testes in scrotal sacs, uterine gestation and viviparity.

2. Affinity with Eutheria. Metatheria possess many advanced characters similar to eutherians or higher placental mammals :

(1) Presence of hairs and external ears.

(2) Mammary glands sebaceous and with teats.

(3) Brain with 4 optic lobes. Cochlea spirally boiled.

(4) Coracoids reduced. Interclavicle absent. Ribs bicephalous.

(5) Teeth heterodont.

(6) Male with penis. Testes in scrotal sac.

(7) Presence of uterus and vagina.

(8) Female viviparous. Ova small, yolkless. Uterine gestation and placenta.

However, metatherians differ from eutherians mainly in restricted distribution, having shallow cloaca, marsupial pouch, flat small cranium, no tympanic but alisphenoid bulla, epipubic bones, inflected mandibular angle, jugal extending back, palate perforated, more incisors in both jaws, corpus callosum in brain absent, two vaginae and two uteri, bifid penis, scrotal sac in front of penis, gestation period small, no true allantoic placenta, etc.

3. Systematic position. It is obvious that the metatherians are more advanced than the primitive, reptile-like, oviparous Prototheria. They are more closely related with the eutherians, but do not belong to the same grade of evolution. Therefore, they are put under a separate infraclass *Metatheria,* while the rest of the higher and truly placental mammals are placed in the infraclass *Eutheria,* and both combined in the subclass *Theria.*

4. Phylogenetic consideration. Comparative study of organization of marsupial and placental mammals reveals that marsupial are "IInd grade mammals" and often regarded by zoologists as transitional step in the evolution of mammals and coenozoic placentals. But now it is believed that placental mammals and marsupials evolved independently from some common panthotherian ancestor in late Jurassic period side by side (Fig. 3).

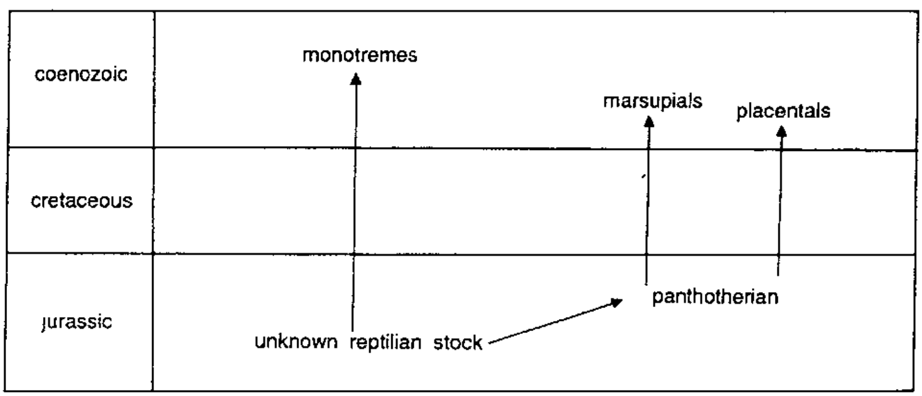

Fig. 3. Showing relationship between three surviving mammalian groups.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give the general characters, affinities and distribution of Metatheria.
2. What are marsupials ? What are their chief differences from Eutheria ? Which of the groups is of higher grade organization and why ?

» *Short Answer Type Questions*

1. Write short notes on — (i) Distribution of metatheria, (ii) Differences between prototheria and metatheria, (iii) Marsupium.

» *Multiple Choice Questions*

1. Metatherian teeth are more than :
   (a) 32 (b) 36 (c) 40 (d) 44
2. Marsupial with true alantoic placenta
   (a) Bandicoots (b) Opossum
   (c) Kangaroo (d) Petaurus
3. Marsupials present in America :
   (a) Kangaroo (b) Bandicoots
   (c) Opossom (d) Wombat

ANSWERS

1 (d) 2 (a) 3 (c).

34

Mammalia : General Account

Dentition in Mammals

Teeth and dentition. The hard and usually pointed structures connected to jaw bones in the buccal cavity of vertebrates are known as *teeth.* The arrangement of teeth in a vertebrate is termed *dentition.* Although teeth are found among fishes, amphibians and reptiles, and are also known to have been present in ancestral birds, but they are most highly specialized in mammals.

Functions of teeth. Teeth play an important role in everyday life of an animal. (i) The primary function of teeth is to *grasp and hold the prey or food* in the mouth cavity. (ii) Teeth are modified to serve as a *grinding mill* for chewing food. (iii) Teeth may serve as *weapons* for offence and defence by working as tearing organs.

Significance of teeth. (i) Teeth are so characteristic of mammals that their classification is based largely on their dentition. Thus study of dentition is important for taxonomic work on mammals. (ii) The number of teeth present gives an idea of the approximate age of the mammal. (iii) Dentition provides clue to the diet of the mammal. (iv) Study of dentition has helped in deciding the pedigree or ancestry of certain mammals.

Toothless mammals. Not all mammals possess teeth. In spiny anteaters *(Tachyglossus)*, no teeth are found at any stage. A secondary toothless condition occurs in some mammals. In platypus *(Ornithorhynchus)*, embryonic teeth are replaced in the adult by horny epidermal plates for crushing molluscs. The true or great anteater *(Myrmecophaga)* also has no teeth. In whalebone whales foetal teeth are replaced before or soon after birth by baleen plates for straining the planktonic food.

[I] Differentiation (shape) of teeth

Morphologically, teeth can be distinguished as homodont or heterodont.

1. Homodont. In vertebrates other than mammals, all the teeth present are similar in shape and size. They are said to be *homodont* or *isodont.* In certain mammals such as toothed whales, dolphins, porpoises and armadillos, teeth become secondarily uniform or homodont.

2. Heterodont. Mammalian teeth are characteristically *heterodont,* that is, dissimilar in shape and size. They are distinguished into several types known as *incisors, canines, premolars* and *molars.* This differentiation depends upon the nature of food eaten and the manner of securing it.

[II] Attachment of teeth

The manner of attachment of teeth at their bases with the jaw bones varies throughout vertebrates.

1. Acrodont. This condition occurs in most vertebrates in which teeth are attached to the free

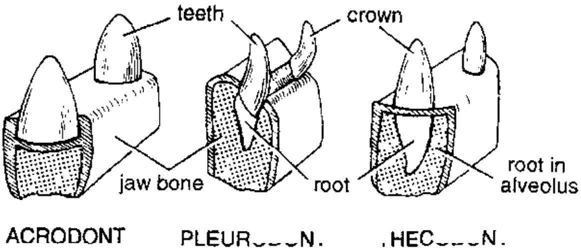

Fig. 1. Three methods of attachment of teeth to jaws.

surface or summit of the jaw bone, as in a shark or frog. Such teeth are apt to break off easily but are replaced.

2. Pleurodont. In this condition, common in urodeles and lizards, teeth are attached to the inner side of jaw bone by their base as well as one side. Acrodont and pleurodont teeth are rootless, so that nerves and blood vessels enter the pulp cavity along lateral side.

3. Thecodont. Such teeth are characteristic of mammals. Teeth have well developed roots implanted in deep individual pits or socketes called *alveoli* or *theca,* in the jaw bone. Thecodont teeth also occur in crocodilans, fossil toothed birds, and some fishes.

[III] Succession of teeth

According to their permanence or replacement (succession), teeth fall into 3 categories : polyphyodont, diphyodont and monophyodont.

1. Polyphyodont. In lower vertebrates, teeth can be replaced an indefinite number of times during life. This is known as *polyphyodont* condition which is not found in mammals.

2. Diphyodont. In most mammals teeth develop during life in two successive sets, a condition known as *diphyodont.* Teeth of the first set are called *deciduous, lacteal* or *milk teeth.* They usually errupt after birth, but in guinea pigs, bats and others, they are formed and shed even before birth. Milk dentition has no molars included. Later, milk teeth are replaced in the adult by the *permanent teeth* which last throughout the life. If lost they are not replaced. In cape anteaters or aardvarks, milk teeth outnumber the permanent teeth.

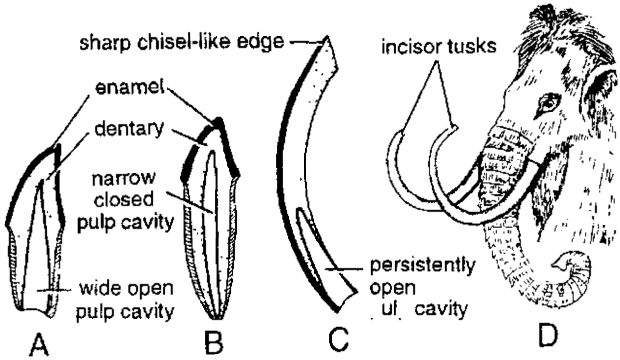

Fig. 2. Various forms of incisor teeth. A—Immature open-rooted. B—Mature close-rooted. C—Open-rooted rodent incisor. D—Open-rooted upper incisors in mastodon.

3. Monophyodont. In some mammals such as platypus, marsupials, moles, sirenians, toothless whales, etc., only one set of teeth develops, known as *monophyodont* condition.

[IV] Kinds of teeth

As already mentioned, 4 types of teeth occur in mammals-incisors, canines, premolars and molars.

1. Incisors. These are the front teeth borne by the premaxillae in upper jaw and tips of dentaries in lower jaw. They are single-rooted, monocuspid and long, curved and sharp-edged. They are adapted for seizing, cutting and biting (Fig. 2).

In rodents and lagomorphs, incisors are open-rooted and continue to grow throughout life. They have enamel on their anterior face only. Since enamel wears down more slowly than dentine, sharp chisel-like edges result which serve for cutting and gnawing. In lemurs, incisors are denticulate like a comb, serving for cleaning fur. Elephant tusks are modified upper incisors with open roots. Incisors may be totally absent (sloths) or lacking on the upper jaw (ox).

2. Canines. A single canine tooth occurs in each half of each jaw, just outside the incisors. Upper canines are the first teeth on maxillae. Canines are generally elongated, single rooted and with a conical sharp monocuspid crown. They are meant for piercing, tearing and offence and defence (Fig. 3).

In carnivores (dog), canines become large, strong and pointed spear-like for tearing flesh.

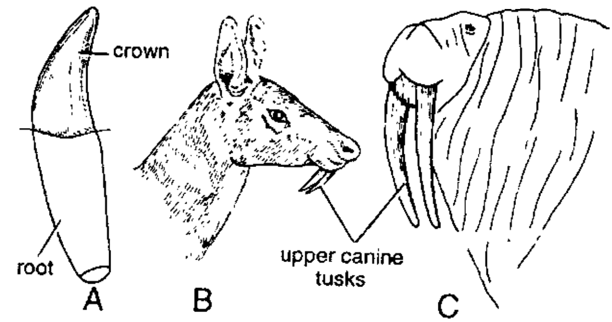

Fig. 3. Canine teeth. A—Of a carnivore (jaguar). B—Of male musk deer. C—Of walrus.

They are often larger in males. They are present only in upper jaw in male musk deer. Upper canines form tusks in walrus for digging molluscs and for locomotion on ice. Canines are absent in some herbivores such as rodents (rats), lagomorphs (rabbits) and some ungulates (ox), leaving a wide toothless space called *diastema*.

3. Cheek teeth. Canines are followed by *premolars* followed by *molars*. Both types are collectively called the *cheek teeth*. Their crowns have broad surfaces with ridges and tubercles meant for crushing, grinding and chewing. Premolars usually have two roots and two cusps and are represented in milk dentition. Molars generally have more than two roots and several cusps and do not have milk predecessors (Fig. 4).

In carnivores, last premolars in upper jaw and first molars in lower jaw may have very sharp cusps for cracking bones and shearing tendons. These are called *carnassial teeth*. In lemurs, first premolars are like canines. In crabeater seal, molars bear denticulate processes to strain plankton. In higher primates (man), last molar is called *wisdom tooth*. Its erruption may be delayed, or it is imperfectly formed or absent in man.

Cheek teeth are of various types depending on the number, shape and arrangement of cusps.

(a) Triconodont. Found in fossil Mesozoic mammals in which 3 cones are arranged in a straight line or linear series.

(b) Trituberculate. Also known in fossil mammals in which 3 cones or tubercles are arranged in the form of a triangle.

(c) Bunodont. These are found in mammals with a mixed diet such as man, monkey, pig, etc. Their crowns bear small, separate blunt and rounded tubercles meant for crushing.

(d) Secodont. This condition is found in carnivores in which teeth have sharp cutt ng edges for tearing and cutting flesh.

(e) Selenodont. This c--diti-- ---u-s f-- grinding in herbivorous grazing mammals in which -rown -ears ve.tical crescentic cusps -f ..a.. enamel enclosing softer areas of dentine. Normal low-crowned selenodont teeth with short roots (ground squirrel) are termed *brachyodont*. In large grazing mammals such as horse and cattle, teeth are elongated, prism-shaped with high crowns and low roots. This is known as *hypsodont condition*.

(f) Lophodont. In lophodont condition, found in elephants, there is an intricate folding of enamel and dentine. Crescentic enamel cusps are connected by several transverse ridges called *lophos*. A single large lophodont molar, 30 cm by 10 cm, is present at one time in each half of each jaw. These are adapted to grind all sorts of plants, including grasses.

The origin of complex cheek teeth in mammals have been a controversial issue. Two different theories were forwarded to explain their origin. Supporters of one theory advocate that cheek teeth originated by fusion of two or more conical teeth. In dugong several *enamel organs* fuse to form molar teeth. But this theory has been discarded on account of absence of any embryological evidence. The other theory holds that the additional conical projections develop on simple conical teeth giving triconodont shape. At the subsequent stage, these cones are shifted to give rise separate tubercles or cusps arranged in a triangle called *tritubercular* position. Later from these tubercles additional cusps or folds develop which finally give rise varied mammalian cheek teeth.

[V] Dental formula

In mammals, number of teeth varies in different species. However, surprisingly enough, number of teeth is constant and characteristic for every

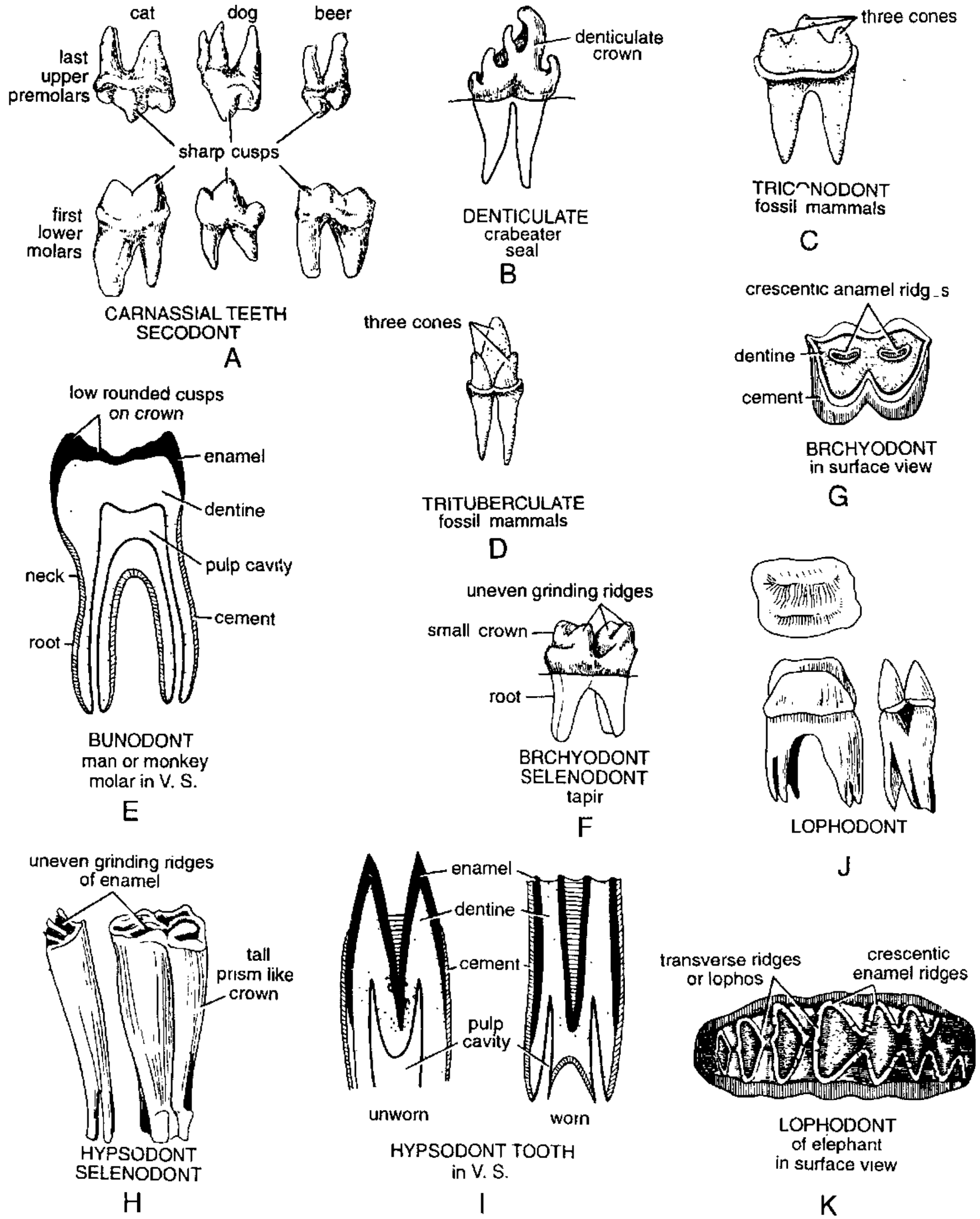

Fig. 4. Modifications of cheek teeth. A—Carnassial teeth (secodont). B—Denticulate molar. C—Triconodont tooth. D—Tritubercular tooth showing arrangement of cusps. E—Bunodont molar in V.S F—Brachyodont selenodont molar. G—Surface view of crown of brachyodont molar H—Hypsodont selenodont molars I—Hypsodont teeth in V.S. J—Lophodont molar, K—Lophodont in surface view

species. Therefore, number and kinds of teeth in a species of mammals can be represented by a sort of equation, which is called *dental formula.* Since two halves of each jaw are identical, only the teeth of one side are recorded. Those of the upper and lower jaws are separated by a horizontal line. Kinds of teeth are denoted by their initial latters *i, c, pm* and *m,* re¬resenting incisors, canines, _remolars and molars, res_ectively. Number of teeth shown in the formula multiplied by 2 gives the total number of teeth in a species. A typical mammalian dentition includes 44 permanent teeth which are shown by the dental formula as follows :

$$i\,\frac{3}{3},\ C\,\frac{1}{1},\ pm\,\frac{4}{4},\ m\,\frac{3}{3}\times 2=44$$

To s mp y urt er, t s customary to om t the initial letters, so that the same formula may be written as $\frac{3.1.4.3}{3.1.4.3}=44$. When a certain type of tooth is lacking, it is indicated by a zero. Dental formul e of some familiar mammals are as follows :

Typical H_rse Pig & Mole	$\frac{3.1.4.3}{3.1.4.3}$	= 44
Opossum	$\frac{5.1.3.4}{4.1.3.4}$	= 50
Dog	$\frac{3.1.4.2}{3.1.4.3}$	= 42
Lemur	$\frac{2.1.3.3}{2.1.3.3}$	= 36
Kangaroo	$\frac{3.1.2.4}{1.0.2.4}$	= 34
Man	$\frac{2.1.2.3}{2.1.2.3}$	= 32
Cow Sheep & Goat	$\frac{0.0.3.3}{3.1.3.3}$	= 32
Cat	$\frac{3.1.3.1}{3.1.2.1}$	= 30
Rabbit	$\frac{2.0.3.3}{1.0.2.3}$	= 28
Squirrel	$\frac{1.0.2.3}{1.0.1.3}$	= 22
Rat	$\frac{1.0.0.3}{1.0.0.3}$	= 16
Elephant	$\frac{1.0.0.3}{0.0.0.3}$	= 14

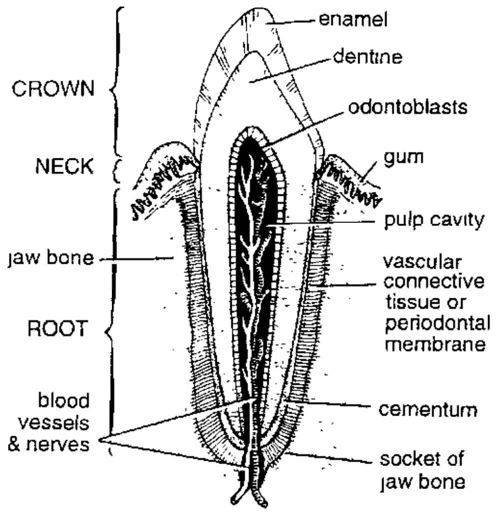

Fig. 5. V.S. of a mammalian canine tooth.

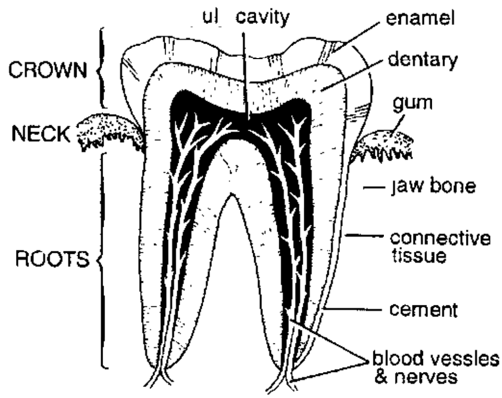

Fig. 6. V.S. of a human molar tooth.

[VI] Structure of teeth

Structure of teeth is similar in all the vertebrates. A typical mammalian tooth is differentiated into 3 parts : crown, neck and root. *Crown* is the exposed glistening part projecting above the gum and out of the jaw bone. *Root* is the basal part, embedded in a socket or alveolus of jaw bone. The junction of crown and root is called the *neck.* A tooth is made largely of a hard dermal bony substance, the *dentine* (ivory). In the crown, it is covered externally by a thin, very hard and shining layer of *enamel.* It is the hardest substance in vertebrates. The root of tooth is surrounded and fixed to jaw bone by a layer of *cement* and a vascular *periodontal membrane* of strong connective tissue fibres (Sharpey's fibres) running from cement to bone. Inside the tooth is a narrow *pulp cavity.* It is filled with a gelatinous connective tissue or *pulp,* containing blood vessels and nerves. Lining the pulp cavity is a layer of bone cells, the *odontoblasts,* which send fine protoplasmic processes into *canaliculi* of dentine. In the incisors of rodents, lagomorphs and elephants, pulp cavity remains open basally so that these teeth continue to grow throughout life and are termed *open-rooted.* In the majority of mammals, including man, the basal aperture of pulp cavity becomes closed at a certain age so that nourishment stops and further growth ceases. Such teeth are termed *close-rooted.*

[VII] Development of a tooth

In mammals, teeth develop in the gum or the soft tissue, covering the borders of premaxillae, maxillae and dentaries (Fig. 7). As in all vertebrates, development of a tooth is similar to that of a placoid scale. Enamel of tooth is derived from epidermis, while the rest of tooth from dermis or mesenchyme. In the beginning there is a thickening of ectoderm, along the margin of jaw bone. The basal layer of ectoderm, the *Malpighian layer,* forms a continuous solid ridge-like vertical invagination into the underlying dermis. This forms the *dental lamina* which retains its connection with the outer epidermis. Mesodermal cells multiply rapidly beneath the ectodermal ingrowth or dental lamina forming a series of solid bud-like outgrowths at intervals, called *tooth germs.* Their number is as many as the number of milk teeth. In each tooth germ, the inverted cup-like epithelial cap will secrete the enamel, hence termed the *enamel organ.* The mesodermal aggregation beneath enamel organ is termed *dermal* or *dental papilla.* Its outer columnar cells become differentiated into *odontoblasts* which secrete a layer of *dentine* on their outer surface. The cells of inner epithelial layer of enamel organ similarly become *ameloblasts* which form a cap of hard enamel around the top and sides of dentine. No enamel is deposited on the root. Dental papilla is retained as *pulp.* Its central cavity goes on increasing to become the *pulp cavity.* Nerves and blood vessels enter the pulp cavity through the basal opening. Upto this stage the tooth remains inside the tissue (gum). Later, its eruption through the overlying epidermis is known as *cutting of tooth.* Around the root of tooth appears *cement* or *cementum* which is a modified bone. Odontoblasts become inactive when tooth is fully formed. However in rodents, lagomorphs, etc., the odontoblasts remain active throughout life and teeth continue to grow.

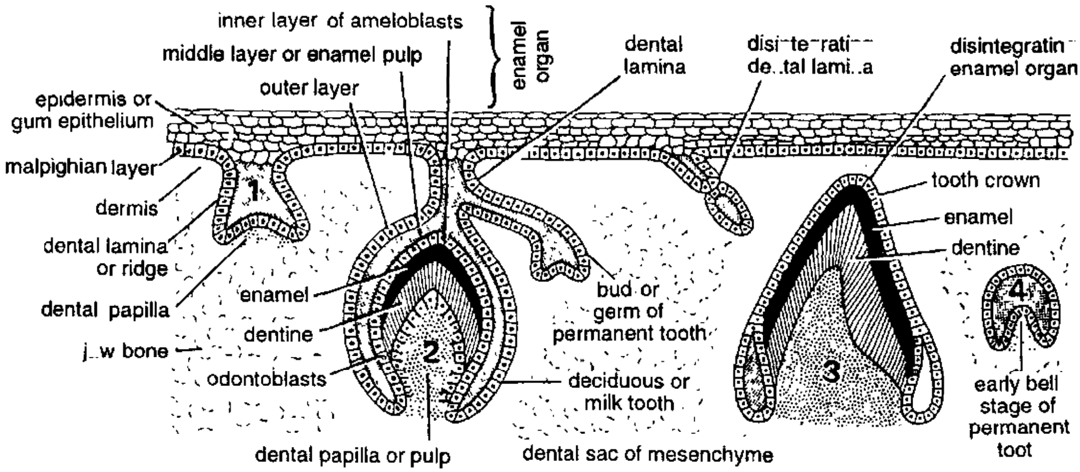

Fig. 7. Development of a mammalian tooth.

Aquatic Mammals and Adaptations

Mammals are primarily terrestrial animals. However, some of them have secondarily adopted an aquatic mode of life. The fact that all of them are not gill-breathers but breathe air through lungs, indicates their original terrestrial mode of life. They have reverted to water probably because of extreme competition on land for food and shelter.

[I] Aquatic mammals

Aquatic mammals belong to several orders and may be put under two categories depending on their degree for aquatic adaptation.

1. Amphibious mammals. These mammals do not live permanently in water. They live on land but go into water for food and shelter. They show only partial aquatic adaptations such as (i) small external ears, (ii) webbed feet, (iii) flattened tails, (iv) subcutaneous fat, etc. Examples are minks, seals, otters and walrus (Carnivora), beavers (Rodentia), hippopotamus (Artiodactyla), *Chironectes* (Marsupialia), *Ornithorhynchus* (Monotremata), etc.

2. Completely aquatic mammals. Members of two orders, Cetacea (whales, dolphins and porpoises) and Sirenia, (manatees and dugongs), are essentially aquatic forms. They never come to land and are perfectly at home in water.

[II] Aquatic adaptations

The specializations or adaptations of truly aquatic mammals (Cetacea and Sirenia) fall into 3 major categories : (i) modifications of original structures, (ii) loss of structures and (iii) development of new structures (Fig. 8).

A. Modifications of original structures

1. Body shape. Body shape is of primary importance in aquatic animals. The external fish-like form, elongated head, indistinct neck and tapering streamlined body offers little resistance and swims rapidly through water.

2. Large size and weight. Whalebone whale may grow upto 35 metres in length and weigh about 150 tons. Large size reduces skin friction and heat loss, but creates no problem for support in water due to buoyancy.

3. Flippers. Forelimbs are transformed into skin-covered, unjointed paddles or flippers, having no separate indication of fingers. They can move as a whole only at the shoulder joint. The broad and flattened flippers serve as balancers and provide stability during swimming.

4. Hyperdactyly and hyperphalangy. Extra digits (hyperdactyly) and extra phalanges (hyperphalangy), upto 14 or more in some cases, serve to enlarge the surface area of flippers for greater utility for swimming in water.

5. High and valvular nostrils. Nostrils are placed far back on top of head so that animal can breathe air without raising head much out of water. Nostrils can also be closed by valves during diving under water.

6. Mammary ducts. During lactation, ducts of mammary glands dilate to form large reservoirs of

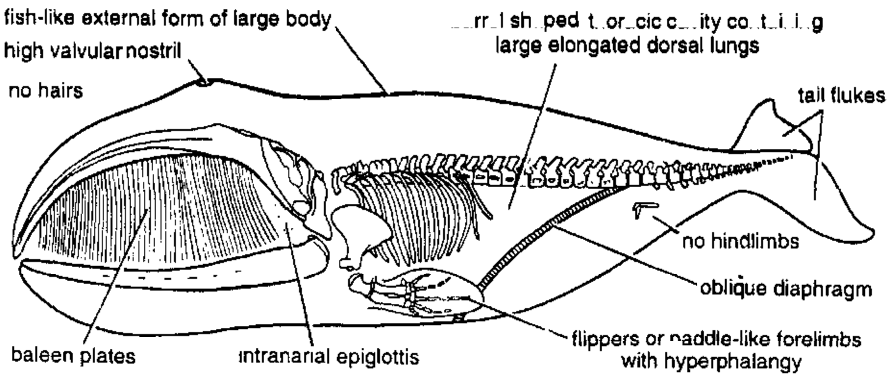

Fig. 8. Body outline and skeleton of Greenland right whale *Balaena mysticetus* showing aquatic adaptations.

milk, which is pumped directly into mouth of young by the action of a special compressor muscle. This arrangement facilitates suckling of young under water.

7. Oblique diaphragm. Oblique diaphragm makes thoracic cavity larger, dorsal and barrelshaped, providing more space to lungs for expansion.

8. Large lungs. Large unlobulated and highly elastic lungs ensure taking down maximum air before submergence. Like swim bladders of fishes, the dorsal lungs also serve as hydrostatic organs in maintaining a horizontal posture during swimming.

9. Intra-narial epiglottis. Elongated, tubular and intranarial epiglottis, when embraced by the soft palate, provides a continuous and separate air passage, thus allowing breathing and feeding simultaneously.

10. Endoskeleton. Cranium becomes small but wider to accommodate the short and wide brain. Facial part of skull projects forming elongated snout or rostrum (porpoise). Zygomatic arches are reduced. Cervical vertebrae are fused into a solid bony mass because of reduced neck. Zygapophyses are reduced. Sacrum is also reduced. Ribs become arched dorsally to increase thoracic cavity. Bones are light, spongy and in Cetacea, filled with oil.

11. Teeth. In toothed whales, teeth are monophyodont, homodont and numerous, as many as 250. This helps in seizing prey, prevent its escape and swallowing it without mastication. Usually, the mobility of jaws is reduced as they have no function in mastication.

B. Loss of structures

Skin surface usually remains smooth and glistening due to loss of *hairs* except for few sensory bristles on snout or lips in some cases. *Pinnae* are also absent. Presence of hairs and pinnae may impede or obstruct the even flow of water over body surface and interfere with the speed and elegance of movement through water. Eye cleansing *nictitating membranes, lacrimal glands* and all kinds of *skin glands* (sweat and sebaceous) are also absent because they would have been useless under water. Due to thickening and immobility, skin loses its muscles and nerves. *Hind limbs* are represented only by button-like knobs in the foetus but disappear in the adult. *Pelvis* is also rudimentary. *Fingernails* are absent except for traces in foetus. *Scrotal sacs* are also absent and testes remain inside abdomen.

C. Development of new structures

1. Tail flukes. Tail develops large, lateral or horizontal expansions of skin called *flukes*. These are not supported by finrays. Their up and down strokes not only propel the body through water but enable rapid return to the surface for breathing after prolonged submersion.

2. Dorsal fin. Most Cetacea develop an unpaired adipose dorsal fin without internal skeletal support. It serves as a rudder or keel during swimming.

3. Blubber. Blubber is the thick subcutaneous layer of fat, which compensates for the lack of hairy covering. Acting as heat insulator, it not only retains the warmth of the body but also provides a ready reservoir of food and water during emergency. The fat also reduces the specific gravity of the animal, thus imparting buoyancy. Blubber also provides an elastic covering to allow changes in body volume during deep diving and also counteracts the hydrostatic pressure.

4. Baleen. In whalebone whales, teeth are absent. Instead, the upper jaw carries two transverse rows of numerous triangular fringed horny plates of *baleen* or *whalebone*. These serve as an effective sieve for straining plankton (mostly krill) which forms their chief food.

5. Foam. Each middle ear cavity sends an inner pneumatic prolongation, which meets with the fellow on the other side below the skull. These extensions contain foam which is a fine emulsion of fat, mucus and gas. It probably serves to insulate sound and improves audition or hearing under water.

6. Melon. It is a receptor present in front of nostrils. It consists of a fatty mass traversed by muscle fibres. It possibly serves to detect pressure changes in water.

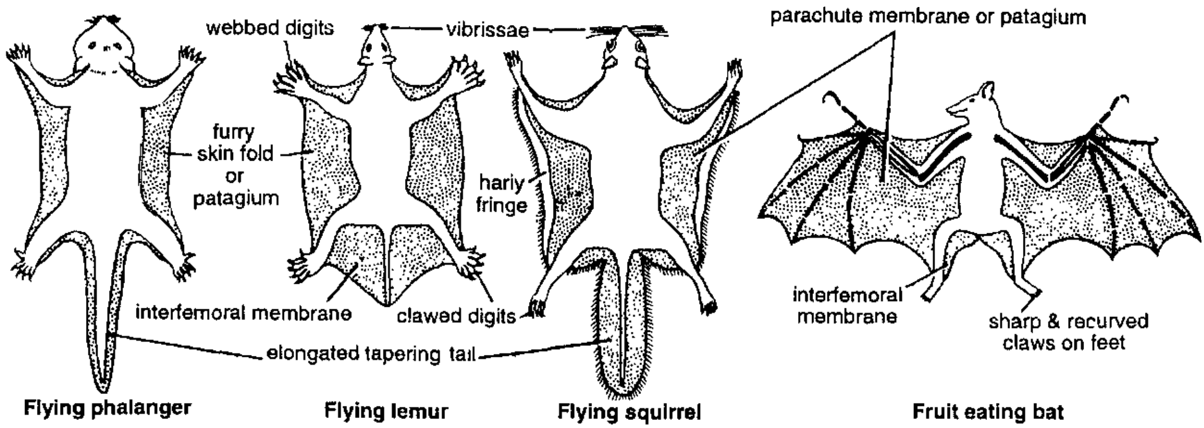

Fig 9. Gliding and flying mammals (diagrammatic representation).

7. Harderian glands. Eyes under water remain protected by a special fatty secretion of harderian glands.

Flying (Volant) Mammals and Adaptations

There are three possible modes of aerial locomotion or flight-gliding, soaring and flapping. *Gliding* is the rudimentary flight displayed by certain fishes *(Exocoetus)*, amphibians *(Rhachophorus)*, lizards *(Draco)*, and among mammals by some phalangers, flying lemurs and squirrels. *Soaring* and *flapping* are more efficient and need more profound morphological and physiological adaptations. Soaring flight is attained by certain birds, but flapping flight is accomplished both by birds and bats (Fig. 9).

[I] Gliding mammals and adaptations

1. Gliding mammals. Common examples are :

Order Marsupialia. Flying phalangers or possums *(Petaurus)* and feather tails *(Acrobates)*.

Order Dermoptera. Flying lemurs *(Cynocephalus)*.

Order Rodentia. Kashmir woolly flying squirrel *(Eupetaurus cinereus)* and brown flying squirrel *(Petaurista phillipensis)*.

2. Gliding adaptations. In gliding mammals, body is elongated, flattened and streamlined. Limbs are long and equal. Tail is long and gradually tapering. There is a double fold of furred skin, called *patagium* or *parachute membrane*, stretched on either lateral side between neck, limbs, body and tail. It is sometimes reinforced with a cartilaginous rod springing from the elbow or wrist. When the animal is at rest, the parachute is scarcely visible as it remains tucked or folded close to the body by its own elasticity.

3. Nature of gliding flight. Gliding is not a true continuous flight but merely a prolonged aerial leap, covering 10 to 20 metres at the most. The gliding mammal glides from one tree to another, smoothly and swiftly downwards, supported by the outstretched parachute and limbs. Aerial progress is in a straight line, rapidly losing height and with little manoeuvrability. However, the flight can be guided to some degree by changing the position of the limbs, by twisting the parachute membrane, and by using the tail. Before alighting, the animal raises the front body part to check speed and to soften its impact on the landing target.

[II] Flapping or flying mammals and adaptations

1. Bats. Bats belong to the order Chiroptera. They are the only mammals with true and sustained flight effected by the flapping or up and down strokes of wings. They are built for flight and compete very well with the birds.

2. Flight adaptations of bats. Adaptations of bats for flight are infinitely more profound. Modifications are not so conspicuous in their external features. However, radical changes have taken place internally in their skeleton and musculature. Their skull has been altered in the most exaggerated manner for special purposes.

(a) Wings. *Wings* or *patagia* of bats are paper-thin, elastic membranes, which are extensions of leathery skin from the lateral sides of body, legs and tail. Forearm is greatly elongated, carrying a hand with 5 fingers. In small insectivorous Microchiroptera, the first finger or *pollex* is short, free and sharply clawed. The other 4 fingers are clawless, enormously lengthened and embedded in the wing web to support it. Like the ribs of an umbrella, they open and close the wing and keep it taut when expanded. In large fruit-eating bats or Megachiroptera, the 2nd finger also ends in a claw. The 3rd finger is the largest, corresponding to the leading edge of the wing membrane.

In most bats, an *inter-femoral membrane,* also enclosing the tail wholly or partially, extends between the hindlegs. It is also supported by a spur of bone, the *calcar,* projecting from the tarsus of each foot. A similar *ante-brachial membrane* connects the neck with the humerus bone of upper arm. Thus, there is a continuous and uninterrupted parachute of skin around the bat's body.

Bat's muscles and other body structures are specially designed to support and operate the wings. Bat has a capacious *thorax* containing a remarkably large *heart* and *lungs.* The keeled sternum offers space for the attachment of great *pectoral muscles* which sustain the arms in flight.

Though converted into wings for flight, the bat's arms and hands are also used for walking, climbing, holding, food and killing prey in flight.

(b) Legs. The hindlegs are small, weak and with sharp curved claws on toes used for suspending the bat head down from a tree branch or perch, while resting or sleeping. Knee-joints are directed backwards, instead of forwards, which helps in maximum spread of wing membranes but is of little help in other movements.

(c) Tail. Tail is variable in size. It may be large, small or scarcely visible. When well-developed, the tail supports the inter-femoral membrane which can act as a brake to flight, used as a large pouch for holding prey or food, or even as an aerial cradle for the reception of a new born baby.

(d) Teeth. Milk dentition of bats is curious in adaptation to flight. The young are often born with small hook-like or needle-like teeth, similar and sometimes forked. These are supposed to serve the young for gripping firmly the maternal teats while the mother is flying.

(e) Senses. Bats are extremely modified for nocturnal flight. They are able to fly even in total darkness with ease and swiftness avoiding obstacles. They possess special sense organs which allow them to perceive prey and surrounding obstacles at a distance even in total darkness.

Bats are supersensitive to sound and possess a natural *echo-apparatus* or *radar system* of their own. In flight bats keep their mouth open and continually emit tremendous bursts of supersonic or ultrasonic sounds which are quite inaudible to human ear. The warning echos reflected back enable bats to locate and evade obstacles in their path. In numerous insectivorous bats sensitive accessory lobes on ears, called *tragus,* help to pick up warning echos. Besides, certain bats have skin flaps encircling nose, called *nose-leaf.* Its exact use is not well-understood, but probably it acts as an *antenna* for the perception of air vibrations. The *wing webs* are abundantly supplied with scattered nerves and blood vessels and probably act as tactile organs which also help in avoiding the obstacles in their course during nocturnal flights. So incredibly sensitive are bats that thousands of them may swirl around for hours in total darkness in a cave without a single collision. The aerodynamics of bats drive engineers mad and are quite beyond us ordinary mortals.

Adaptive Radiation in Mammals

During Mesozoic Era, the age of reptiles (dinosaurs), mammals were small, generalized and rare. By the end of Mesozoic or beginning of

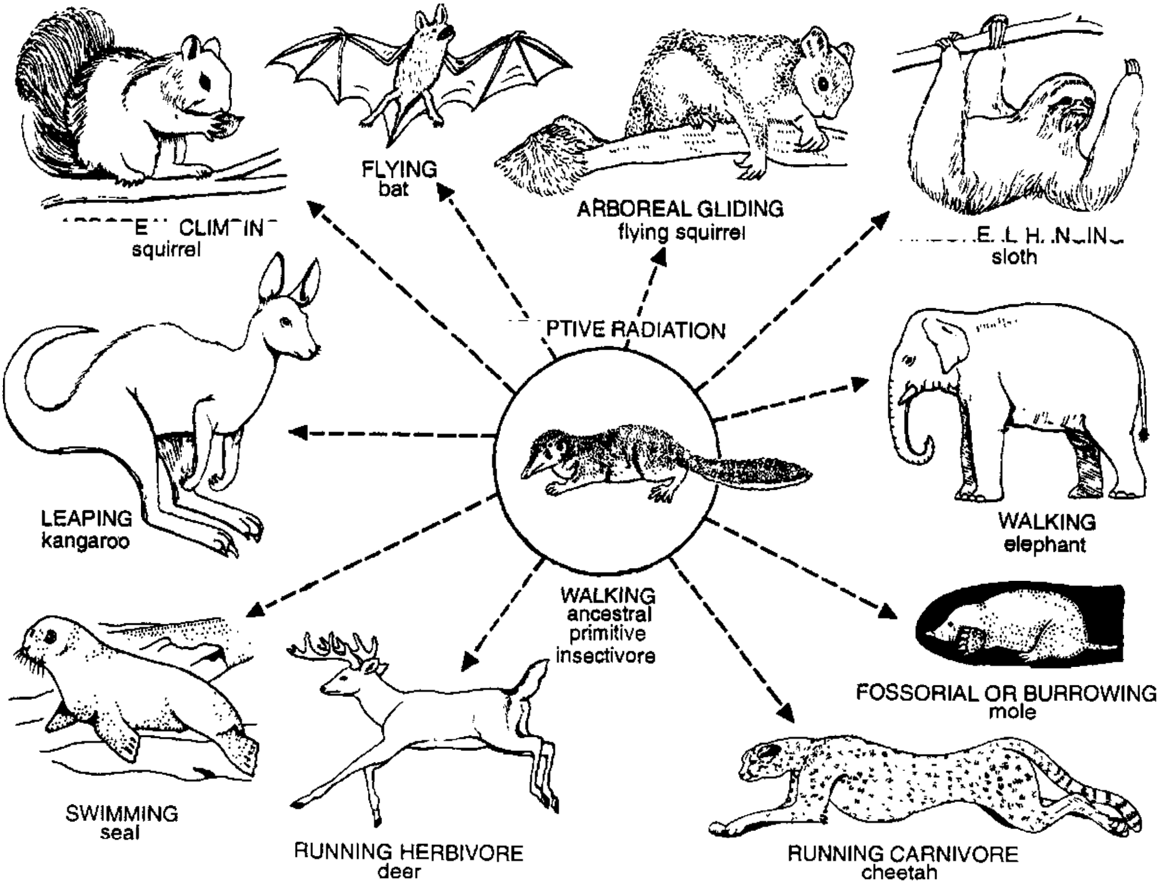

Fig. 10. Adaptive radiation or divergent evolution in mammals, based on locomotion.

Coenozoic, the dinosaurs vanished and the mammals suddenly expanded into varied evolutionary patterns. Early in Cretaceous period, placental mammals became distinct from marsupials. During Eocene and Oligocene, most of the orders of mammals originated moving into habitats and ecological niches vacated by the extinct dinosaurs. This evolution from a single ancestral species to a variety of forms which occupy different habitats is called *adaptive radiation* or *divergent evolution.* The concept of adaptive radiation in evolution was developed by H.F. Osborn in 1898. Examples often cited as evidence include Darwin's finches of the Galapagos Islands, varied limb structure of mammals, Australian marsupials, etc.

Figure 10 shows adaptive radiation in mammals. It is based on limb structure. The primitive common ancestor was a land animal, like modern shrews, with short 5-toed plantigrade limbs with no particular specialization. From this stem mammal, various modern types have evolved by the modification of limbs and other structures adapted to a wide variety of habitats. The five basic patterns of locomotion are running (cursorial), burrowing (fossorial), tree-climbing (arboreal), flying, and swimming. Their other modifications are walking, leaping, graviportal, hanging, gliding, amphibious, etc. Table 1 provides information about habitats and habits of mammals with major adaptations of limbs (locomotion), teeth and gut (diet) and other features.

Table 1. **Adaptative Radiation of Mammals for Special Habitats.**

	Habitat	Habits	Limbs	Teeth	Other features
1.	Terrestrial (ancestral)	Primitive, walking insectivores.	Generalized. Feet flat on ground (plantigrade).	Grasping incisors, piercing canines, cutting premolars, grinding molars	Generalized tongue, stomach & intestine. Caecum small.
2.	Terrestrial (horse, cow, deer)	Running (cursorial), herbivores.	Limbs elongate. Toes long, hoofed and reduced in number. Walking on tips of toes (unguligrade).	Incisors for ripping grass. Cheek teeth selenodont for grinding grasses.	Stomach (cow) or intestine (horse) large and complex. Caecum long. Neck elongated.
3.	Terrestrial (dog, cheetah)	Running, carnivores.	Limbs elongate. Claws often long & sharp. Walking on toes (digitigrade)	Canines large for tearing. Cheek teeth secondont for cutting flesh.	Stomach large. Intestine small.
4.	Terrestrial (elephant)	Walking, herbivores.	Limbs pillar-like. Bones massive, flat-jointed. Toes in circle around pads.	Molars teeth massive, lophodont, heavily ridged for grinding plant materials.	Nose elongated into trunk or proboscis to reach food on ground or in trees.
5.	Terrestrial (kangaroo, rabbit)	Leaping (jumping), herbivores.	Hindlimbs and feet large. 2nd & 3rd toes united (syndactyly) in kangaroo.	Incisors and molars numerous.	Tail massive, long, used as a prop and to balance.
6.	Terrestrial (anteaters, echidna)	Digging, mostly insectivores.	Claws enlarged for digging insects.	Teeth reduced or absent.	Snout elongated. Tongue long, stickly and extensile.
7.	Subterranean (mole, some rodents)	Burrowing (fossorial), Mostly insectivores.	Limbs short & stout. Forefeet enlarged, Shovel-like, Claws long, strong and sharp.	Teeth variable according to diet. Incisors in rodents gnawing.	External ears, eyes, tail and fur short.
8.	Trees (squirrel, monkey, sloth)	Arboreal, hanging, frugivorous or vegetarian.	Limbs elongate. Toes long, flexible.	Cheek teeth smooth surfaced or bunodont for crushing.	Tail long, sometimes prehensile, or absent.
9.	Trees (bats)	Flying, insectivorous or frugivorous.	Forelimbs form wings. Forearm, hand and fingers elongated to support wing.	Variable for diets of insects, fruits, nectar and blood.	Tongue, stomach and intestine variable according to diet.
10.	Trees (flying phalangers & squirrels)	Volant of gliding and herbivorous.	Limbs elongate to hold gliding membrane outstretched. Digits not included.	Show herbivorous adaptations.	Tail often flattened to serve for balance and as rudder.
11.	Sea water (whales, seals, sea cows)	Aquatic, piscivorous or planktivorous.	Limbs paddle-like. Hindlimbs absent in Cetacea.	Teeth simple several, homodont or absent and replaced by plates.	Form fish-like. Ears absent or reduced. Tail forming flukes.

Adaptive Convergence in Mammals

Distantly related animals inhabiting similar habitats, often develop independently similar morphological features that make them look similar. This phenomenon is termed *adaptive convergence* or *convergent evolution* which is the opposite of adaptive radiation. Following examples may be cited of adaptive convergence (Fig. 11) :

1. Aquatic vertebrates. Figure 11 shows various aquatic vertebrates, not closely related, showing a marked adaptive convergence (streamlined fish-like body, limbs paddle-like, digits webbed) due to living in the same

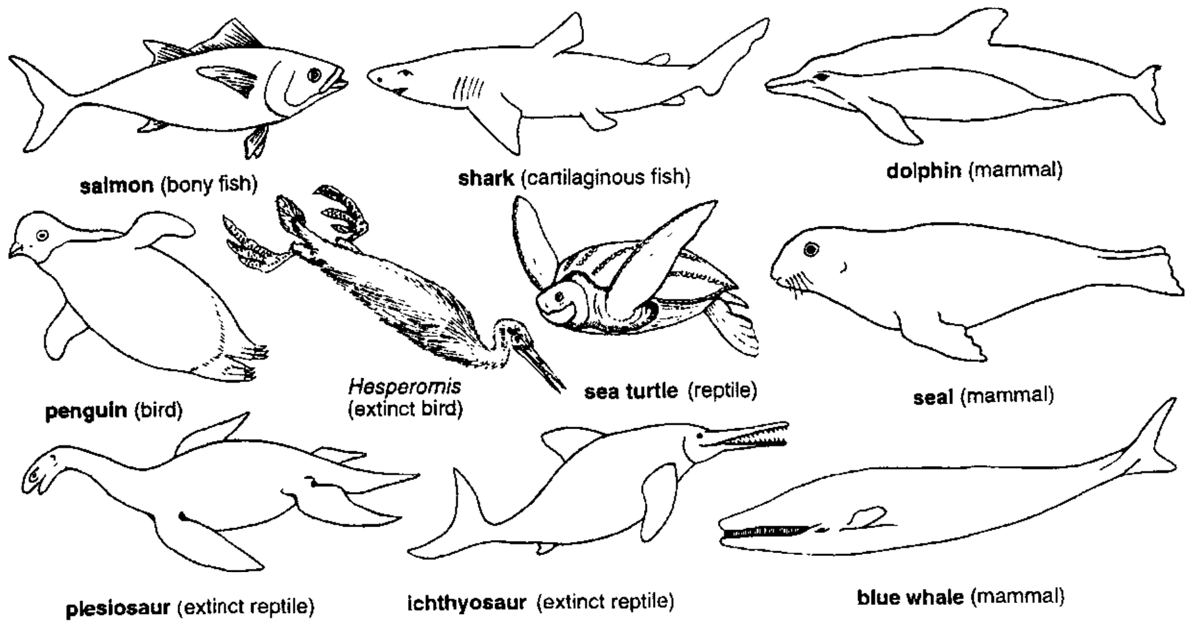

Fig. 11. Adaptive convergence in body shape in aquatic vertebrates.

environment. Their ancestors were probably much less similar, but Natural Selection has favoured in them to develop similar characteristics which fit them for life in water.

2. Placental and marsupial mammals. As already stated, during Paleocene, Eocene and Oligocene, the marsupials in Australia and the placentals in the rest of the world underwent much adaptive radiation, moving into habitats vacated due to extinction of dinosaurs. Marsupial and placental mammals are not closely related, but convergent evolution has resulted in similar looking members in both the groups occupying similar ecological niches and leading similar ways of life. Thus, there are native or marsupial wolves, mice, cats, anteaters, moles, sloths, flying phalangers and wombats. These are not related to their true counterparts in placental mammals but resemble them due to convergent evolution (Fig.12).

3. Anteaters. Anteaters belong to different orders of class Mammalia (Fig. 13), not closely related. They have evolved from different non-anteating ancestors independently, acquiring similar features or adaptations for a diet of ants, termites and other smaller insects. Thus all anteaters have teeth much reduced or absent, elongate snout, long extensile sticky tongue and sharp stout claws on front legs for digging into termite mounds, rotten logs, etc.

Origin and Ancestry of Mammals

1. Amphibian ancestry. It was T.H. Huxley (1880) who advocated amphibian ancestry of mammals since there are two occipital condyles in the skulls of both Amphibia and Mammalia and presence of left aortic arch in mammals. However Huxley's theory is not tenable because condyles are derived from exoccipitals in Amphibia but from basioccipital in Mammalia. Apart from this, the two classes have different modes of life and display many fundamental differences.

2. Reptilian ancestry. It may be hard to realize but all mammals living today have descended from reptiles. There is enough evidence from extinct reptiles and mammals for this universally accepted view that mammals had a reptilian ancestry. This view also gets strong support from the fact that the monotremes

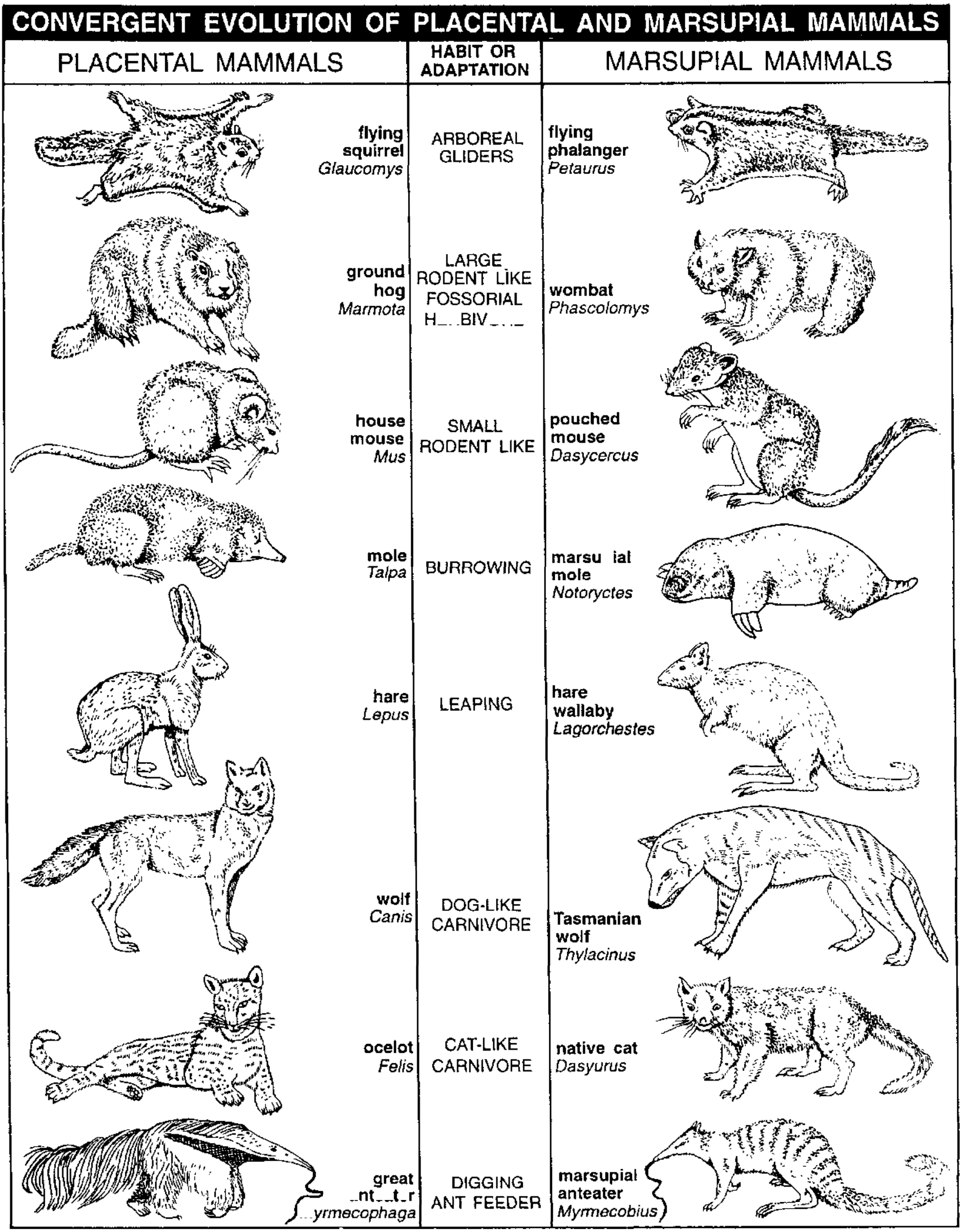

Fig. 12. Convergent evolution in placental and marsupial mammals.

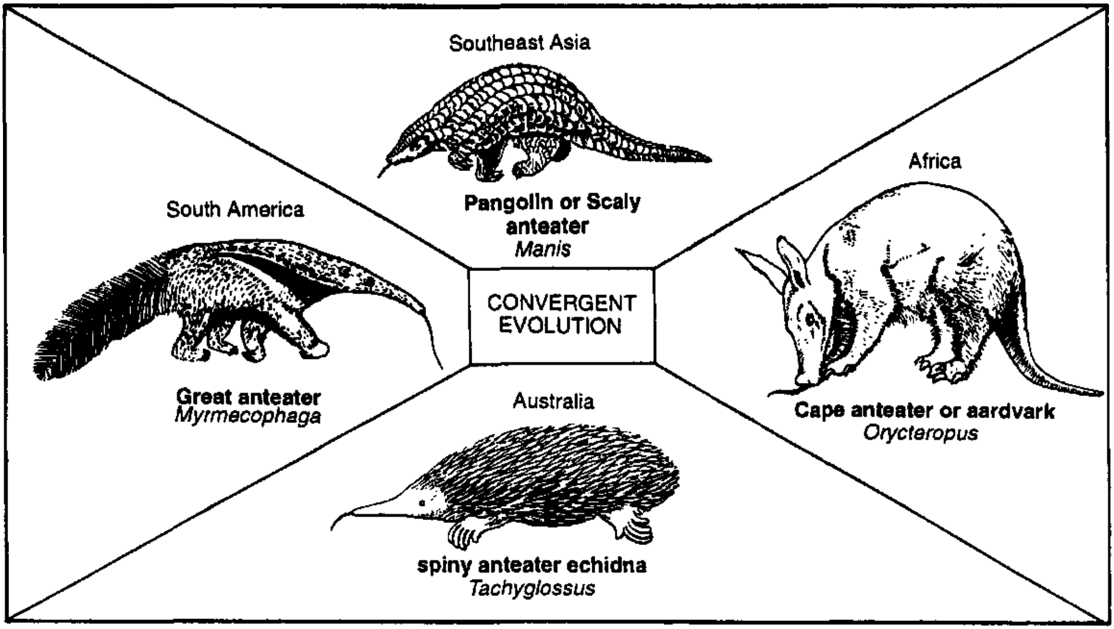

Fig. 13. Adaptive convergence in anteaters (mammals).

(primitive mammals) and living reptiles have close resemblances in their anatomical features, including soft as well as hard parts.

3. Ancestral mammal-like reptiles. Who were these ancient reptilian ancestors of mammals ? Long before the arrival of true mammals, one group of extinct reptiles, the *Synapsida*, acquired several mammalian characteristics. They lived throughout the Permian and Triassic periods, dating back 280 million years or more. The more mammal—like synapsids belonged to the order *Therapsida*. One of the more advanced carnivorous therapsids (suborder Theriodontia) was called *Cynognathus* (dog jaw). It lived during the early Triassic period. It was wolf-sized and showed the following mammalian characters :

(1) Typical upright mammalian limbs capable of generating considerable speed
(2) Skull with 2 occipital condyles, secondary palate, and enlarged lateral temporal fossa.
(3) Largest bone of lower jaw was dentary.
(4) Dentition consisted of incisors, canines and chewing molars.

Therapsids retained several reptile-like features also. Their skull was intermediate between that of reptiles and mammals, having small cranium, parietal foramen, single middle ear bone, reduced quadrate and quadrato-jugal, many lower jaw bones, etc. It is also not known whether therapsids were warmblooded, had hairs instead of scales and nursed their young. They were not necessarily the direct ancestors of present day mammals.

4. First true mammals. Fossil remains, mainly teeth and jaws, reveal very little about the first true mammals. They were mostly tiny creatures no bigger than rats and mice, and insignificant. But they could still manage to survive by exploiting different ways of life from those practised by the contemporary gigantic reptilian enemies. They were nocturnal, thus avoiding direct conflict and competition with the mostly diurnal reptiles. They were either burrowing hunting for insects, or arboreal in contrast to their ground-dwelling herbivorous or carnivorous contemporaries. They had a regulated high body temperature (endothermic), hairy integument, and probably carried their young in pouches for further development after birth, and safety. They were endowed with larger brains and greater intelligence.

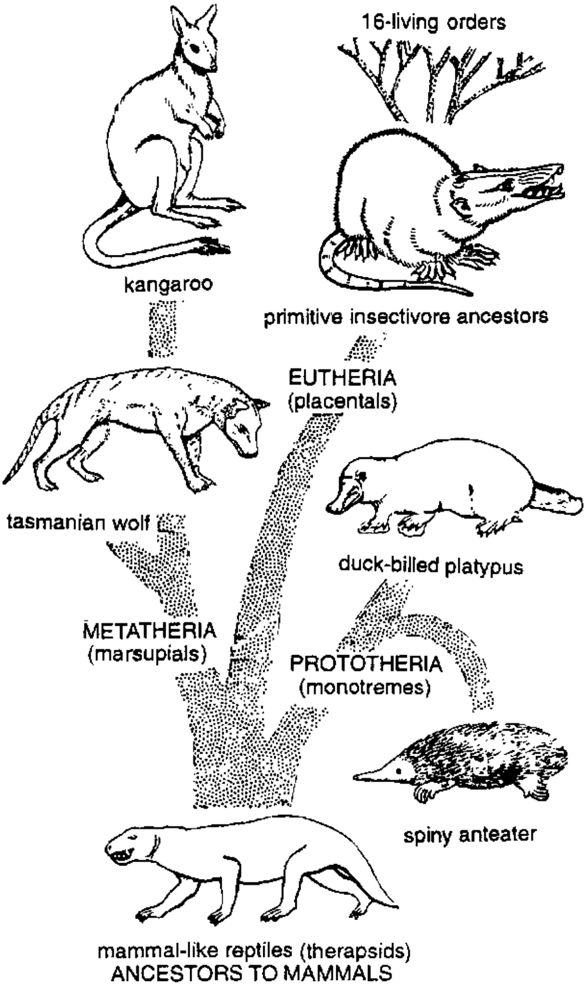

Fig. 14. Hypothetical phylogenetic tree to show evolution of major groups of class Mammalia.

By the end of Cretaceous period (Mesozoic age), the vast majority of dominant reptiles became extinct for reasons which are still not understood well. Many ecological niches were now left open to mammals who started their great adaptive radiation. By the close of Cretaceous period, placental mammals became distinct from marsupials. During Coenozoic age, there were established all the orders of placental mammals, so that it is called the *Age of Mammals.*

5. Polyphyletic origin. Living mammals represent two different reproductive groupings or subclasses. The primitive reptile-like egg-laying (oviparous) monotremes are in the subclass *Prototheria.* All other mammals give birth to living young (viviparous) and form the subclass *Theria.* The living therians are divided into marsupials or infraclass *Metatheria,* and placentals or infraclass *Eutheria* (Fig. 14).

Was mammalian evolution monophyletic or polyphyletic ? Nothing is known about the origin of primitive Prototheria, for fossils older than Pleistocene are unknown. They have remained primitive probably due to isolation from rest of the World in Australia and New Zealand. During Jurassic period, there were atleast 5 well-established orders of mammals, now all extinct. According to the phylogeny given in Figure 14, origin of mammals is polyphyletic because they derive from at least two Triassic reptilian stocks, cynodonts and ictidosaurs. It is generally assumed that the living Prototheria possibly evolved from the docodonts, while Metatheria and Eutheria evolved independently from the pantotherians, by the end of Cretaceous period.

Economic Importance of Mammals

The mammals are the most important group of animals from human point of view. They are economically important for many reasons, as they have served or harmed man from the earliest times.

[I] Beneficial mammals

1. Domesticated mammals. Since the beginning of civilization, man has been domesticating various mammals for work, food and clothing. Without mammals, particularly the domesticated species, man would probably not be able to survive. Table 2 provides useful information about the principal domesticated mammals the world over. While all provide meat and hides, some provide milk, wool and hair; others serve for transport, draft or hunting.

2. As food. Mammals have been serving as food for man since very ancient times.

(a) Meat. The domesticated mammals provide enormous quantities of various kinds of meat and meat products. Large even-toed ungulates, such as

Table 2. **Principal Domesticated Mammals.**

Order	Family	Domesticated mammals	Source or wild stock whence derived	Region of origin
Artiodactyla	*Bovidae*	Cattle	*Bos*	India, Europe
		Water buffalo	*Bubalus bubalis*	India
		Yak	*Poephagus grunniens*	Tibet
		Sheep	*Ovis*	Asia
		Goats	*Copra*	Western Asia
	Cervidae	Reindeer	*Rangifer*	Northern Europe
	Camelidae	Camels	*Camelus*	Mangolia
		Llama	*Auchenia*	South America
	Suidae	Hog or swine	*Sus*	Asia, Europe
Perissodactyla	*Equidae*	Horse	*Equus caballus*	Western Asia
		Grey ass	*Equus onager*	Western Asia
		White ass	*Equus asinus*	North Africa
Carnivora	*Canidae*	Dogs	*Canis familiaris*	Asia or Europe
		Cats	*Felis*	Asia or Africa
Rodentia	*Muridae*	Rats	*Rattus*	Western Asia
		Mice	*Mus*	Asia or Europe
Logomorpha	*Leporidae*	Rabbits	*Oryctolagus*	Europe, N. Africa
Proboscidea		Indian elephant	*Elephas*	Asia
		African elephant	*Loxodonta*	Africa

cattle, buffaloes, pigs, goats, sheep, reindeer, etc., furnish the bulk of meat supply of the world. Big game mammals, such as deers, provide the necessary proteins for many people. Rabbits, seals, whales and even rats, dogs and bears are also used as food in many parts of the world.

(b) Milk. Cows, buffaloes, goats, sheep, llamas, camels, reindeers, etc., provide milk which forms an important article of human food. *Ghee, butter, cheese* and *curd* and prepared from milk.

3. Commercial products. Mammals furnish countless items of commercial value.

(a) Hides. The hides of various domesticated as well as wild mammals provide *leather* and *fur* for the manufacture of clothing and for a variety of other purposes. Animal *pelts* have been used as clothing for many centuries. Eskimos in the Arctic use reindeer and bear skins for clothing, seal hides for footwear, and skins of other species for boats. Much of the early explorations of North America were made by trappers in search of furs. Otter, mink, weasel, marten, ermine, beaver, fur seal, muskrat, skunk, fox, raccoon, lynx, bear, rabbit, kangaroo, house cat and innumerable other mammals provide natural furs of soft texture and pleasing colours. Leather and fur are also used for the manufacture of suitcases, bags, shoes, harness, saddles, belts, purses, garments, etc., and support big industries. Muskrat is the leading fur-producing mammal in U.S.A. Many mink and fox farms running have proved quite profitable.

Most of the fur-bearing animals are fast becoming scarce so that man-made acrylic fibres, designed to look like fur, now compete with and replacing the natural furs.

(b) Hair and wool. The *wool* of sheep is the most important animal fibre, extensively used for weaving into cloth for winter. Goats, alpaca, camels, etc. also yield wool. *Hairs* of camels, pigs, horses, sables and a host of others are made into brushes, etc. *Lanolin* or fat obtained from wool is a mixture of palmitate oleate and stearate of cholesterol.

(c) Perfumes. *Ambergris,* used as a base in fine perfumes, is a product of intestinal canal of sperm whales. *Musk,* another substance used in perfumes, is obtained from the glands of muskdeer of Central and Eastern Asia.

(d) Oil and fat. *Blubber* of baleen whale and seal provides edible fat or oil. Eskimos use seal blubber as fuel oil. Oil of sperm whale is not edible. It is used as a base for cosmetics and in manufacture of candles and lubricants. Pigs provide cooking fat.

(e) Ivory and baleen. *Ivory,* used for making toys and in decorations, is obtained mainly from the tusks of elephant and walrus. *Whalebone* or *baleen,* formerly an important commercial article, is also obtained from toothless whales.

(f) Glue and gelatine. These are obtained from the skin, horns, hoofs and bones of cattle.

4. Beasts of burden. Various mammals have been domesticated by man to serve as beasts of burden form transport and draft of heavy loads. They have been greatly replaced by automotive vehicles in the more progressive countries. However, in the underdeveloped countries, cattle, horses, mules, sheep and goats are still being used for work in plains and mountains, elephants in jungles, camels and llamas in deserts, and reindeers and dogs on ice in cold countries. Of all the beasts of burden, perhaps the horse has played the greatest role in the development of human civilization.

5. In agriculture. Buffaloes, yak, horses and camels are employed for *ploughing* fields. They supply *manure* in the form of dung and urine which nitrify soil, and yield fuel biogas. *Bone meal* prepared by crushing bones of cattle, sheep, goats, etc. is a good fertilizer. Some carnivorous predators, such as mongooses, prey upon rats and mice which are serious pests of crops. Anteaters feed upon harmful insects. Skunks destroy grubs and cutworms, while moles and shrews consume enormous number of insect larvae.

6. As pollinators. Arboreal mammals which visit one tree after another in search of fruits such as bats, squirrels, monkeys, etc. may incidently help in the pollination of flowers. In East Indies, bats are said to pollinate bananas.

7. As scavengers. Hyaenas and jackals are of great utility to serve as scavengers in nature. The common pig also clears away the refuge in the Indian villages and town.

8. In recreation. When amusement is demanded no animal is safe.

(a) Pets. Man has tried to tame as pets a large number of mammals such as monkeys, bears, mongooses, rabbit, etc. But only dogs and cats have become popular and of general interest.

(b) Zoos. Lions, tigers, horses, elephants and monkeys are employed in sports and circuses. *Bull fights* are by no means confined to Spain. Larger and rarer varieties of mammals are exhibited in zoological gardens and national parks.

(c) Hunting. Civilized man now hunts not only for profit but also for pleasure and recreation. Dogs, leopards, elephants and horses are used in the hunting. Important game animals are deer, elk, moose, mountain sheep, bear, lion, tiger, rabbit, raccoon, opossum, tree squirrel, etc. They are sought for their heads, hides and meat. Various countries now protect their game animals to prevent their extermination.

(d) Decoration. Antlers heads, and pelts of various mammals are displayed as trophies or momentoes and for decoration of houses.

9. Laboratory animals. Rats, guinea pigs, rabbits, cats, pigs, monkeys, apes, dogs, etc. are the common mammals extensively used in laboratories for research and scientific studies.

[II] Harmful mammals

Some mammals are decidedly injurious to man.

1. Pests. Most dangerous mammals to crops are the rodents. They destroy crops in fields, commit ravages about houses and buildings, consume all kinds of foodstuffs and destroy property. Rabbits, mice, woodchucks and some others forage in vegetable fields and gardens and gnaw at the bark to trees. Pocket gophers eat roots of plants while squirrels damage grain and other crops. Besides, bigger herbivorus ungulates such as deer, bear, boar, hippopotamus, elephant, kangaroo, etc. also eat up crops. Cats in kitchen forage on food besides rats.

2. Predators. Many wild carnivorous or predatory mammals are constant menace to the lives of people and livestock. Lions, tigers, wolves and bears prey at times on domestic cattle, sheep, hogs, poultry, etc. Wolves and hyaenas sometimes attack sleeping persons. In tropical Africa, the sanguivorous vampire bats feed on blood of various mammals, including man.

3. Disease carriers. Rodents are the worst carriers and distributors of the germs of certain diseases. Important diseases transmitted to humans are bubonic plague, typhus, relapsing fever, spotted fever, tularemia, trichina, hydrophobia, etc. These are spread by rats, mice, pigs, cats, dogs, etc.

4. Economic importance of rats. Rats occur in almost all the terrestrial environment that support life. They multiply rapidly and soon establish their colony. They are omnivorous, feeding on seeds, roots, fruits, grains insects, snails and invertebrate and vertebrate bodies. They are mainly fossorial, nesting and living much of the time in burrows. They live freely in competition with humans.

Damage caused by rats includes grazing of young trees, roots destruction and seed eating. Generally very young plants have a high nutritional value than mature ones and are preferred by rats. These injured plants remain weak and small. The short tailed bandicoot rat *Nesokia indica* is found across Egypt to India. It is mainly a subterranean feeder. The lesser bandicoot, *Bandicota bengalensis* is found along with *Nesokia indica* and in Bangladesh and Myanmar. It causes 20-40% losses in cereals. The soft furred rat, *Millardia meltada* a pest of cereals is found in India and Pakistan. *B. bengalensis* and *M. meltada* cause 10% or more losses of various crops and wheat. *Rattus losea* and *B. indicata* are the principal pests of crops in China. In Australia various crops including seedling fruit are damaged by bark stripping. Here the number of rats increases tremendously reaching nearly 3000 holes in about 0.5 in one hactare. When the food is exhausted a large number of individuals die and enormous external parasites, grow on their dead bodies. Rice field rat, *Rattus argiventor* and other species of rat are serious pests of rice as they gnaw the small plants and eat grain in the fields. Rat population has one or two peaks correlated with the single or double rice crops per year. *B. bengalensis* causes 7 to 22% loss of rice is North India and 5-18% in South India and at some places the loss is upto 60%.

Rat populations are established in sugarcane fields where they find suitable shelter and food. They cause direct loss of cane by eating into internodes. This permits entry of harmful microorganisms and causes physiological stress, which can reduce weight of sugar content. Rats damage the oil palm crop by eating upon the ripe oil bearing fruitlets and carrying their with them. Unripe fruitlets are also gnawed by the rats *Rattus rattus diandi*, which is the commonest oil palm pest in Malayasia. Coconuts are attacked by rat species like *Rattus praetor, Rattus exulans*. Rats climb the palms of all ages to feed on developing nuts when then fall prematurely. In some regions loss due to coconut fall is upto 50%.

Rats also damage to large extent the crops of potato, groundnut, sweet potato, maize, casava and others. Upto 16% of ripening pine apples are damaged by *B. bengalensis* and *Rattus rattus*.

Rats as carriers of disease

Some rodent species are reservoirs of a large number of infections organisms of man which if transmitted to human and domestic animal populations may cause out-break of diseases often into high mortality. Some of the diseases for which rats are the reservoirs are listed below :

Disease (agent)	Reservoir
Lana fever	*Mastomys netalensis*
Venenzuelen haemorrhagic fever	*Sigmodon, Oryzomys*
Tick borne encephalitis	*Microtus*
Scrub typhus	*Rattus* spp.
Murine typhus	*Rattus* spp.
Rocky mountain spotted fever	*Sigmodon*
Leptospirosis	*Rattus* spp.
Salmonellosis	*Rattus* spp.
Toxoplasmosis	*Rattus norvagicus, Sigmodon, Rattus rattus*
Leishmamiasis	*Rattus* spp., *Oryzomys*
Chagas disease	*Rattus* spp.

Control of rats

For the control of rat population various methods are employed :

1. Repellants and attractants. Under this procedure chemicals like cyclohexamide and tributylin acetate are used as repellants. The repellants may be incorporated in the packing material to keep the rats away from the packed food stuffs. Various types of attractants (sugar, arachis oil) are used to attract the rats to the traps laid for them in the fields. Sometimes the poisons mixed into baits are used which are placed in rat burrows. Selective rodenticides like Norborne carboximide Quintos and Brodifacoum are also used.

Fumigation. Under this procedure fumes of chemicals like Fomafog, are sent into the rat burrows by suitable apparatus.

Rats as food

In India and Central Asian, African and some European countries some species of rats are used as food. The rats, *Ondalria zibethica* is served as a delicacy in restaurants in Holland and Belgium. In West Africa the cane rat, *Jhryononys swinderianus* constitutes an important component of the food of a majority of the population.

Use of rat skin

Skin of larger species of rats are tanned and can be used in preparation of gloves, purses and other small items. This helps in providing jobs to people and also controls the rat population.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Write an essay on— (i) Aquatic adaptations of mammals, (ii) Adaptive radiations in mammals, (iii) Dentition in mammals, (iv) Economic importance of mammals, (v) Flying mammals and (vi) Origin and ancestry of mammals.

» *Short Answer Type Questions*

1. Write short notes on— (i) Adaptive convergence in mammals, (ii) *Cynognathus*, (iii) Dental formula, (iv) Development of tooth and (v) Domesticated mammals.

» *Multiple Choice Questions*

1. Milk dentition in mammals lack :
   (a) Molars (b) Premolars
   (c) Canines (d) Incisors
2. First teeth on maxillae :
   (a) Lower canines (b) Upper canines
   (c) Upper molars (d) Lower premolars
3. Baleen is present in :
   (a) Lizards
   (b) Frogs
   (c) Whales
   (d) Elephants

ANSWERS

1 (a) 2 (b) 3 (c).

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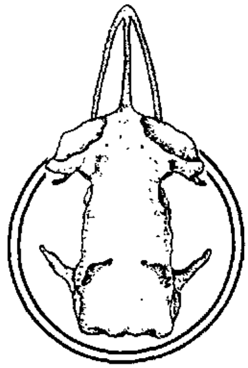

Endoskeleton of *Scoliodon*

The endoskeleton of dogfish is entirely made up of cartilage, there being no true bones apart from the basal plates of placoid scales. It shows several important advances over that of the sea lamprey. The *axial skeleton* includes (i) skull and (ii) vertebral column, while the *appendicular skeleton* comprises (i) pectoral and (ii) pelvic girdles and (iii) skeleton of fins.

Skull

Skull or chondrocranium (called condocranium because cartilaginous condition is retained in the adult) of dogfish consists of (i) cranium and capsules for sense organs, and (ii) visceral skeleton which provides the jaws and supports for tongue and gill mechanism (Figs. 1 & 2).

1. Cranium and sense capsules. Cranium or brain box encloses and protects the brain. It is composed of a single piece of cartilage to which the olfactory and auditory sense capsules are intimately fused. It is a simple structure, perforated by several foramina for nerves and blood vessels. In shape, it somewhat resembles the sound-box of a violin. Its arched roof or dorsal side remains incomplete leaving two spaces or *fontanelles.* Cranium is roughly divisible into 4 regions : (a) occipital, (b) auditory, (c) orbital and (d) ethmoidal.

(a) Occipital region. It forms the posterior part having a very large median hole, the *foramen magnum,* through which brain is continued into spinal cord. On either lateral side of foramen magnum is a small rounded *occipital condyle* for articulation with first vertebra. Just outside each condyle is a large exit foramen for X or vagus nerve. Dorsally, the occipital region shows a slight mid-longitudinal ridge or *occipital crest.*

(b) Auditory region. It lies in front of occipital region and consists of two lateral *otic* or *auditory capsules,* enclosing ears fused with the

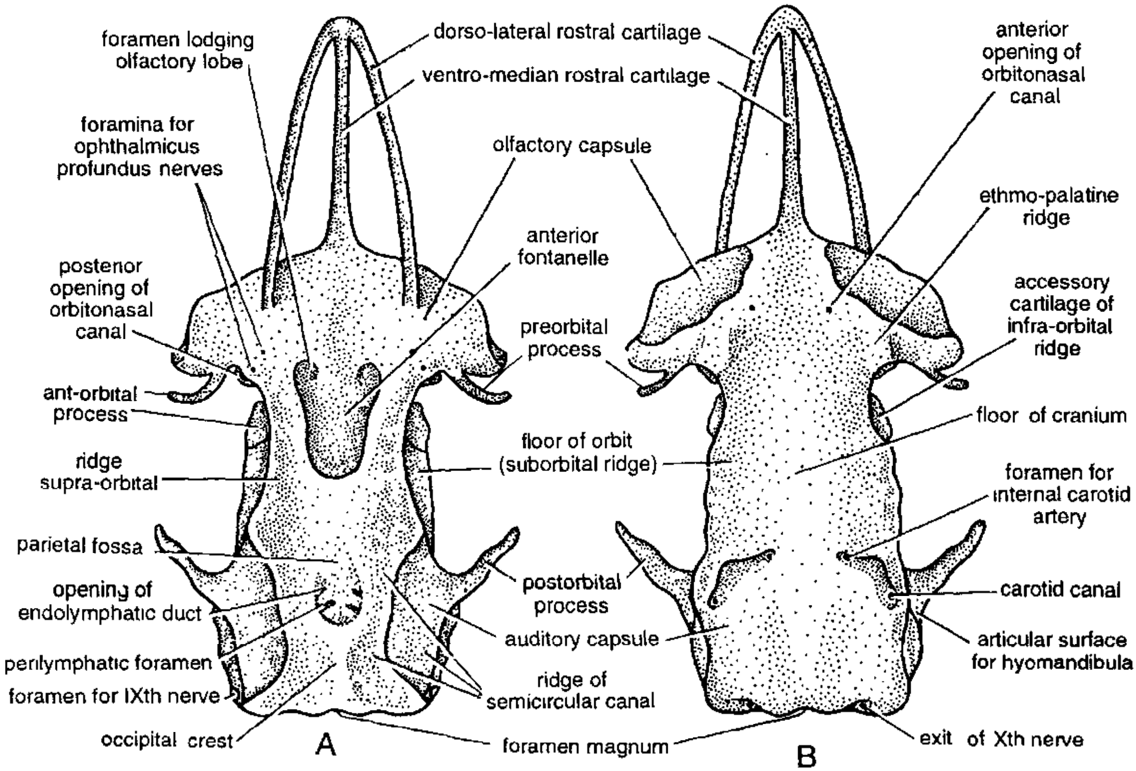

Fig. 1. *Scoliodon*. Skull. A—Dorsal view. B—Ventral view.

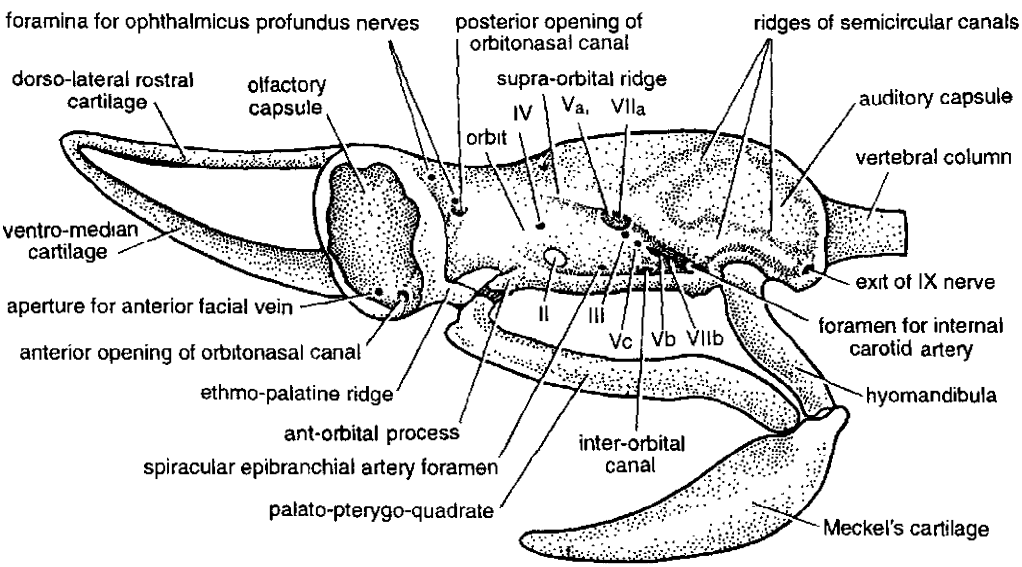

Fig. 2. *Scoliodon*. Skull and jaws in lateral view.

middle part of cran um. Dorsal s e of cran um shows a med an oval depress on, t e *parietal fossa*, containing two pairs of apertures, anterior, sm ll ... i g is th i gs f *endolymphatic ducts* and posterior larger opening is *perilymphatic fora ina*. Th... i g s ... ch u it y c psul indicate the internal positions of three semicircular canals of membranous labyrinth. Below the lateral postorbital groove is the articular surface for the yoman bu a of 2n or yo arc .

(c) ***Orbital region.*** It is the middle part lying in front of the auditory region. On each lateral side, it carries a large hollow, called *orbit*, containing the eye during life. Each orbit is bordered dorsally by a *supraorbital ridge*, ventrally y *nfra-or ta* or *su or ta ridge*, anter orly y a short slender *preorbital process*, and posteriorly by a longer and stouter *ostorbital rocess.* Within the orbit the cranial wall is pierced by a number of foramina for nerves.

(d) ***Ethmoidal region.*** It includes the anterior part of cranium, two nasal or olfactory capsules and rostrum. The lateral olfactor ca sules are thin-walled, open ventrally and each lodging an olfactory sac. Their cavities are separated from each other by a common, thin, median vertical plate, the *mesethmoid* or *internasal septum.* Postero-ventral aspect o each capsule bears a short but stout *ethmopalatine ridge.* The cranial roof presents a large depression, the *anterior fontanelle*, covered by a connective tissue membrane. In fron of he fon anelle projec ree rod-like *rostral cartilages*, one ventro-median and two dorso-lateral. The three meet anteriorly and form the skeleton of snout or rostrum.

2. Visceral skeleton. It forms the jaws and the skeleton of pharynx and includes a series of 7 pairs of U-shaped *visceral arches* that encircle the buccal cavity and pharynx (Fig. 3).

(a) ***First or mandibular arch.*** The first visceral or mandibular arch on either side is made up of two segments. The dorsal segment, called *palato-pterygo-quadrate*, forms the upper jaw which is attached to cranium by a ligament. The lower segment, called *Meckel's cartilage*, forms the

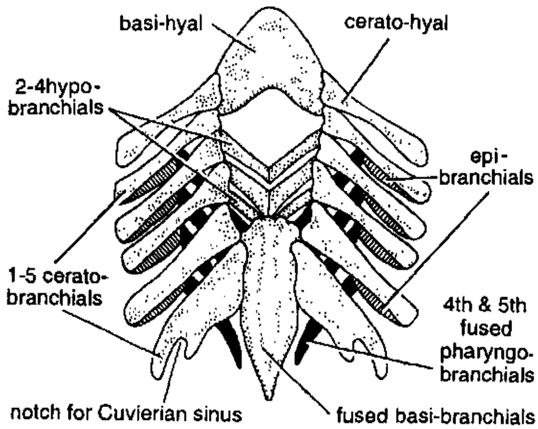

Fig. 3 *Scoliodon*. Visceral skeleton in ventral view.

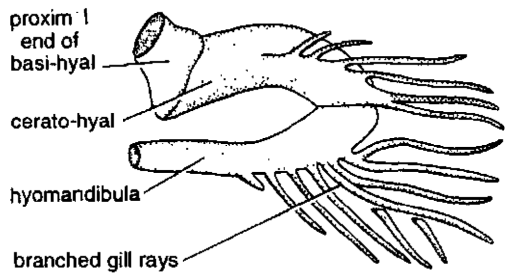

Fig. 4. *Scoliodon*. Skeleton of hyoid arch with gill-rays in ventral view.

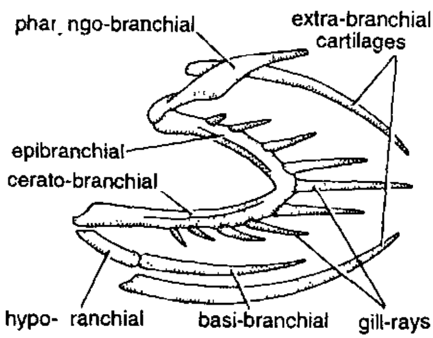

Fig. 5. *Scoliodon*. Skeleton of the first branchial arch of left side.

lower jaw. The two jaws bear teeth and are joined by a hinge joint at the angle of mouth.

(b) ***Second or hyoid arch.*** Second visceral or hyoid arch consists of three segments (Fig. 4). Ventral median and single *basihyal* is common to both sides. It supports buccal floor and tongue. The lateral *ceratohyal* also lies in buccal floor behind the Meckel's cartilage of first arch. The dorsal

segment or *hyomandibula* is short but stout and oblique cartilage. Its lower end connects to posterior ends of both jaws, while its upper end articulates with cranium. Thus, jaws are not connected directly to cranium in dogfish. Such an arrangement or suspensorium in which hyomandibula serves to suspend jaws from cranium is called *hyostylic.*

(c) Branchial arches. Behind the hyoid arch, the remaining 5 visceral arches are known as *branchial arches,* as they support the walls of pharynx and gills and serve in their respiratory movements. Typically, each branchial arch consists on either side of 4 rod-like segments connected by joints. These are : a dorsal *pharyngobranchial,* lateral *epibranchial* and *ceratobranchial* and a ventral *hypobranchial.* All the branchial arches are connected to a common mid-ventral dagger-shaped cartilage, representing the fused *basibranchial* segments of all arches. Only the epibranchials and ceratobranchials bear *gill rays* which support gills. Besides, there are 4 pairs of *extra-branchial cartilages* lying at right angles to the first 4 pairs of branchial arches (Fig. 5).

Vertebral Column

The vertebral column of adult dogfish consists of about 130 *vertebrae* arranged one behind the other. They develop around the persistent *notochord,* present as an elastic axis of vacuolated cells. There are only two regions in the vertebral column : trunk region and caudal region (Figs. 6 & 7).

1. Trunk vertebra. A typical body or trunk vertebra consists of a ventral, thick, cylindrical *centrum,* deeply concave at both ends. Such biconcave centra and called *amphicoelous.* The *notochord* piercing the centra presents a beaded appearance, thread-like and narrow within the centra but expanded in the intervertebral spaces. In a transverse section, the centrum shows four wedges of calcified fibrocartilage arranged like a cross which is called a *Maltese cross.* In between the calcified wedges are left uncalcified areas. Such a centrum or vertebra is known as *asterospondylous.* The centrum bears dorsally a *neural arch* enclosing a *neural canal.* The neural

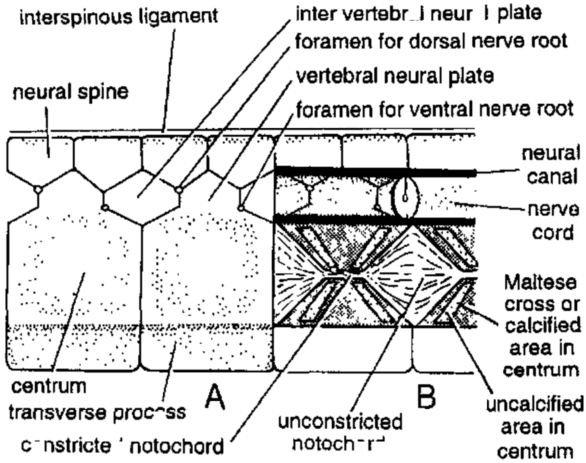

Fig. 6. *Scoliodon.* A portion of vertebral column of trunk region. A—Two entire vertebrae in lateral view. B—Two vertebrae in sagittal section.

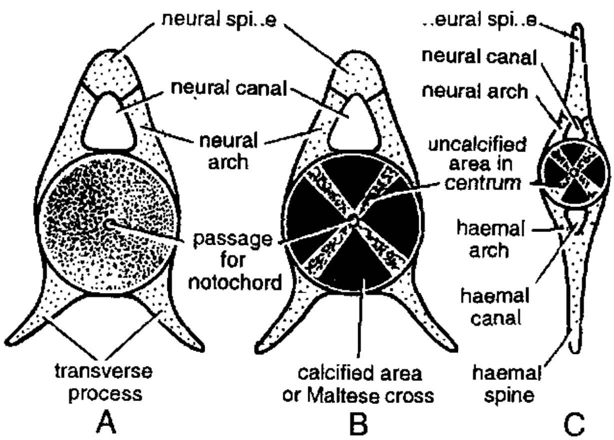

Fig. 7. *Scoliodon.* Vertebrae. A—Complete trunk vertebra in front view. B—Trunk vertebra in T.S. C—Caudal vertebra in T.S.

canals of vertebrae form together a long tunnel in which lies the spinal cord. A neural arch dorsally forms the median *neural spine.* Either side of neural arch is formed by a *vertebral neural plate.* The foramen for dorsal root of spinal nerve lies at its upper margin. An *intervertebral plate* fills the space between two adjacent neural arches. The foramen for ventral root of spinal nerve lies at its lower margin. To each ventro-lateral border of centrum is attached broad plate-like *transverse process* (Figs. 7A & B).

2. Caudal vertebra. A caudal vertebra differs from a trunk vertebra in one important respect. Its

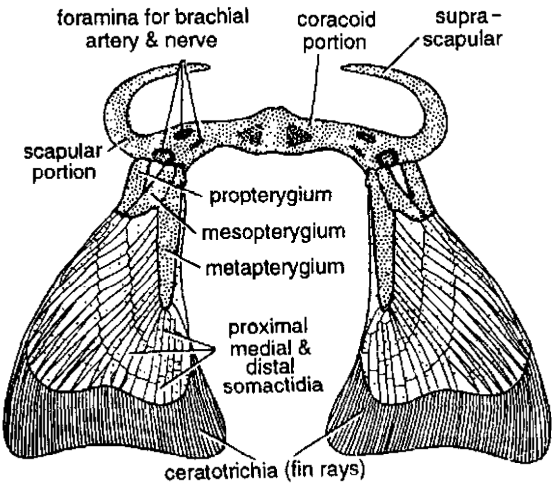

Fig. 8. *Scoliodon*. Pectoral girdle and fins in dorsal view.

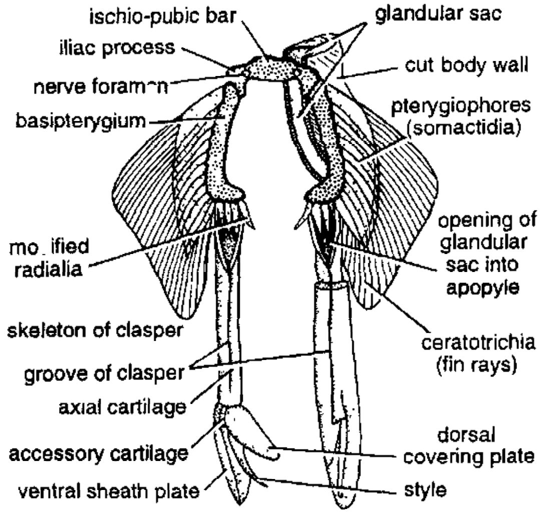

Fig. 9. *Scoliodon*. Pelvic girdle and fins of a male fish in dorsal view.

transverse processes meet and fuse to form below centrum a *haemal arch* enclosing a *haemal canal* in which run the caudal artery and vein. Haemal spine and neural spine are long but the neural arch is short (Fig. 7C).

Trunk vertebrae are *monospondylous* i.e., only one vertebra is found in each myotome but caudal vertebrae are *diplospondylous* i.e., two vertebrae are present in each myotome.

Pectoral Girdle and Fins

1. Pectoral girdle. Pectoral girdle is embedded in the lateral and ventral bodywall, just posterior to the gills, in the region of the heart, which it protects. It is not attached to the vertebral column. It is a U-shaped structure made of right and left halves united mid-ventrally. Each half is made of a dorsal rod-like *scapular portion* and a ventral flattened *coracoid portion.* A distinct *suprascapular cartilage* marks the dorsal end. Two pectoral fins are attached to pectoral girdle one on either ventro-lateral side (Fig. 8).

Pectoral girdle provides attachment to body myotomes, to muscles working for swallowing and breathing, to pectoral fins and muscles, and it also supports and protects the heart.

2. Pectoral fins. The basal part of each pectoral fin is made by 3 basal cartilages called *propterygium, mesopterygium* and *metapterygium.* These articulate with three little facets forming the glenoid surface at the junction of scapular and coracoid portions of pectoral girdle. From the basal cartilages, extend numerous radial cartilages or *somactidia,* each made of 2 or 3 segments. The distal somactidia bear two sets of long numerous thread-like, stiff and horny *fin rays* or *ceratotrichia* which support the peripheral membranous part or vane of the fin.

Pelvic Girdle and Fins

1. Pelvic girdle. Pelvic girdle is also not attached to the vertebral column. It consists of a simple, flattened and transverse cartilaginous rod, called *ischiopubic bar.* It lies embedded in the ventral abdominal wall in front of cloaca. It has a small blunt *iliac process* on either end, projecting above the *acetabular facet* for articulation of the basal cartilage of pelvic fin (Fig. 9).

2. Pelvic fins. Skeleton of a pelvic fin includes a single large and curved basal cartilage, the *basipterygium,* 15 or more slender radials or *somactidia* and numerous distal finrays or *ceratotrichia.*

3. Claspers. In the male dogfish, a clasper is attached to the distal end of basipterygium. Its skeleton includes an elongated tubular *axial cartilage* grooved dorsally. The anterior opening of groove or *apopyle* communicates with cloaca and a *glandular sac* or *siphon.* The posterior opening of groove, the *hypopyle,* opens on a sharp pointed *style* enclosed within a dorsal and a *ventral* *sheathing plate.* A small *accessory cartilage* with a serrated edge lies at the upper end of style.

Skeleton of *median fins* is similar to that of paired fins.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe by means of a diagram the articulation of jaws with cranium in an elasmobranch fish, and how it differs from that of frog ?
2. Give an account of vertebral column of frog.

» *Short Answer Type Questions*

1. Give an account of visceral skeleton of *Scoliodon.*
2. Draw labelled diagrams of dorsal and ventral views of the skull of *Scoliodon.*
3. Write short notes on — (i) Chondrocranium, (ii) Jaw suspension of *Scoliodon,* (iii) Meckel's cartilage.

» *Multiple Choice Questions*

1. Endoskeleton of *Scoliodon* is made up of :
   (a) Cartilage (b) Bone
   (c) Scales (d) Plates
2. The axial skeleton in dogfish comprises of :
   (a) Skull and girdles
   (b) Skull and vertebral column
   (c) Vertebral columns and girdles
   (d) Girdles and skeleton of fins
3. Which is not a part of cranium of dogfish :
   (a) Occipital region (b) Auditory region
   (c) Mandibular arch (d) Orbital region
4. The upper jaw in dogfish is formed by :
   (a) Plato-pterygo quadrate (b) Rostral cartilage
   (c) Mesethmoid (d) Meckel's cartilage
5. Jaw suspensorium in *Scoliodon* is called :
   (a) Hyostylic (b) Craniostylic
   (c) Autostylic (d) Holostylic
6. Number of vertebrae in an adult dogfish :
   (a) 128 (b) 130 (c) 132 (d) 134
7. The cross formed by calcified fibrocartilage in the T.S. of centrum of trunk vertebra is called :
   (a) Maltase cross (b) Maltose cross
   (c) Maltese cross (d) Malate cross
8. The pelvic girdle in dogfish articulates with basal cartilage by :
   (a) Somactidia (b) Ceratotrichia
   (c) Ischiopubic process
   (d) Iliac process

ANSWERS

1. (a) 2. (b) 3. (c) 4. (a) 5. (a) 6. (b) 7. (c) 8. (d)

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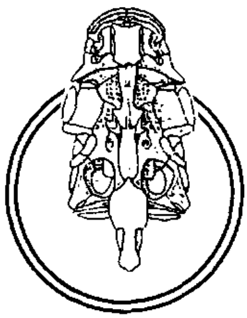

Endoskeleton of *Labeo rohita*

The bony endoskeleton of *Labeo* is completely ossified. The axial skeleton includes *skull, vertebral column* and *ribs,* while the appendicular skeleton includes *pectoral* and *pelvic girdles* and supporting elements of fins.

Skull

The skull comprises (i) the *cranium* housing the brain with paired auditory, optic and olfactory *capsules* for the respective sense organs, and (ii) the *visceral skeleton* of 7 pairs of arches. Skull is so closely joined to vertebral column that the fish cannot turn its head (Fig. 1).

1. Cranium and sense capsules. Cranium and sense capsules of *Labeo* are firmly united together forming a complicated structure, the detailed description of which is out of scope here (i) The posterior *occipital region* of skull shows 3 apertures — a small median *foramen magnum* and two large lateral oval *fenestrae,* characteristic of cyprinoid skulls. The bones included are a *supraoccipital* above, a *basioccipital* below and two lateral *exoccipitals.* A dorsal process of exoccipital meets that of the other side to enclose the foramen magnum dorsally. Thus the dorsal boundary of foramen magnum is not formed by supraoccipital which bears dorsally a median longitudinal vertical *occipital spine.* (ii) The *otic region* comprises four bones of an auditory capsule on either side—*prootic, epiotic, sphenotic* and *pterotic.* The opisthotic is absent in adult rohu. A small bean-like *supra-temporal* bone is present between pterotic and its posterior process. The four bones form a compact inverted cup-like cavity. (iii) The *parietal region* includes paired *parietals* above, *parasphenoid* below and paired *alisphenoids* on the sides. (iv) The frontal region next includes paired *frontals* above, *parasphenoid below* and paired *orbitosphenoids* on the sides. Parietals and frontals form the roof of cranium, while parasphenoid forms the floor. A basisphenoid is lacking. (v) The *orbits,* lodging the eyes during life, are somewhat triangular cavities one on either side. Each orbit is bounded dorsally by frontal, ventrally and mesially by alisphenoid and orbitosphenoid, anteriorly. by ectoethmoid, and

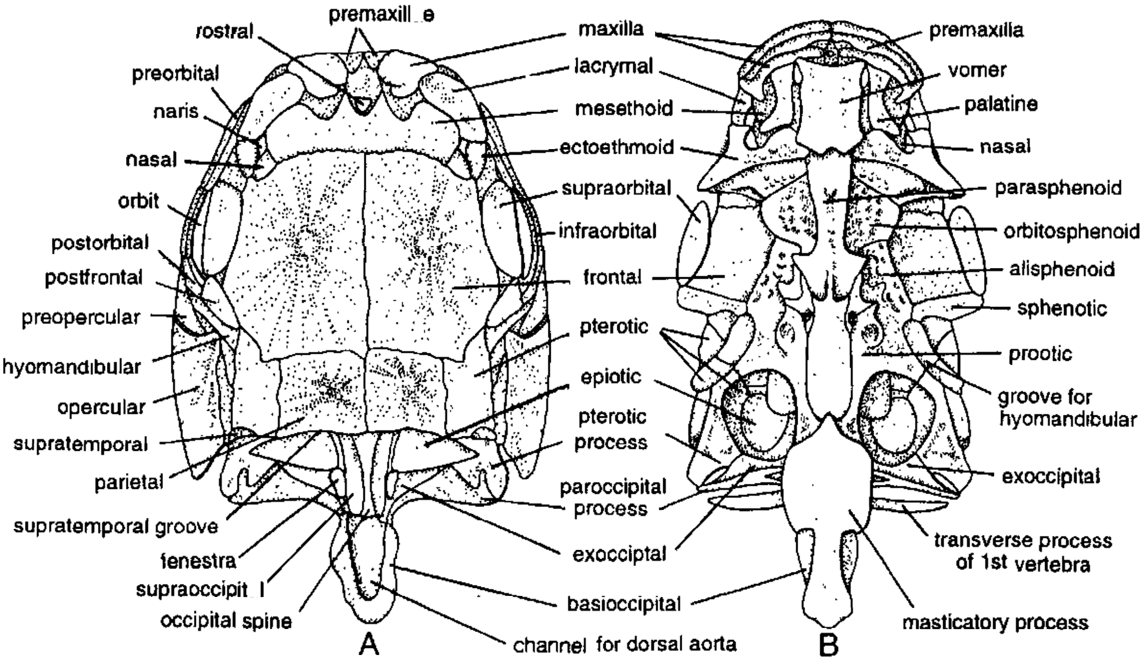

Fig. 1. *Labeo*. Skull. A—Dorsal view. B—Ventral view.

p 'eri ly by sp' en 'ic. Besides, each eye is encircled by a chain of 5 orbital bones—*supraorbital, postfrontal, postorbital, infraorbital* and *preorbital.* (vi) the *nasal* or *ethmoidal region* comprises 9 bones of nasal capsules and snout. Paired bones one on either side are *nasals, ectoethmoids* and *lacrymals.* Median single bones are *mesethmoid* (dorsal), *rostral* (anterior) and *vomer* (ventral).

2. Visceral skeleton. It includes 7 paired arches corresponding to those of the d--fish. (i) Th- fir-t -r ----*dib-l*-- ---*h* -----i--- two parts. The upper part (palatoquadrate bar) attaches to cranium forming the *upper jaw,* each half of which includes two membrane bones (*premaxilla* and *maxilla*) and three replacing bones (*palatine, metapterygoid* and *quadrate*). The lower part (Meckel's cartilage) forms the *lower jaw,* each half of which includes three bones—*dentary, angular* and *articular.* Articular hinges on quadrate which attaches to cranium. All the jaw bones lack teeth. (ii) The second or *hyoid arch* includes the upper *suspnsorium* including two large bones (*hyomandibular* and *symplectic*), and a lower *hyoid*

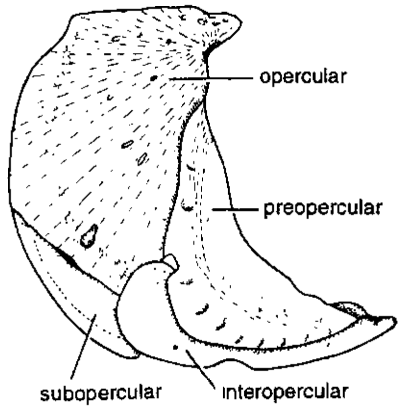

Fig. 2. *Labeo*. Opercular bones.

cornu which supports the tongue and floor of buccal cavity. Investing bones or bony plates supporting the operculum on either side are : *opercular, preopercular, interopercular* and *subopercular* (Fig. 2). (iii) Remaining 5 arches are called the *branchial* or *gill arches.* Each of the 3 to 6 arches bears gill lamellae on the outer border, and a double row of small spiny *gill rakers* on the inner pharyngeal border. The 7th arch is reduced on either side into a triangular *inferior pharyngeal*

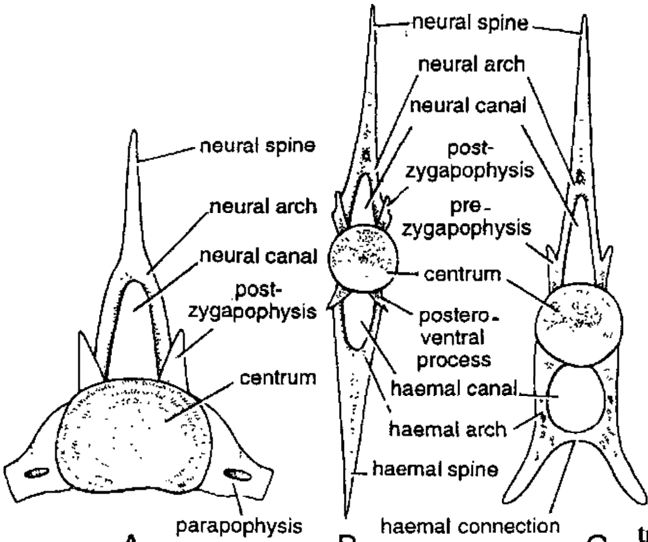

Fig. 3. *Labeo*. Vertebrae. A—Trunk vertebra in posterior view. B—Typical caudal vertebra in posterior view. C—First caudal vertebra in anterior view.

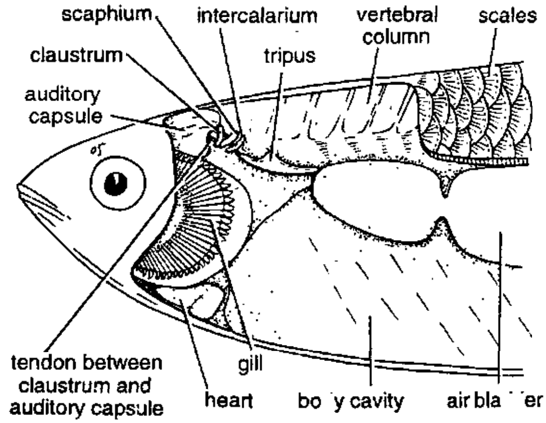

Fig. 4. *Labeo*. Weberian ossicales and air bladder of a teleost fish in left dissection.

bearing three rows of strong masticating plates or teeth. Typically, a branchial arch consists on either side of four bones, supporting the pharyngeal wall. These are dorsal *pharyngobranchial*, lateral *epibranchial* and *ceratobranchial*, and ventral *hypobranchial* which is connected to a common flat median *basibranchial* lying in the floor of pharynx.

Vertebral Column

The vertebral column is well ossified and composed of 37-38 simple and comparatively similar vertebrae.

1. Trunk vertebra. A typical *trunk vertebra* consists of : (i) a cylindrical centrum deeply concave at both ends (*amphicoelous*), (ii) a small dorsal neural arch around the spinal cord, (iii) a slender neural spine for muscular attachment, (iv) a pair of short transverse processes or parapophyses arising ventro-laterally from centrum, and (v) a pair each of small blunt facets on neural arch, called pre-and post- zygapophyses, by which adjacent vertebrae articulate. These articular facets do not occur in the vertebrae of elasmobranchs. *Ribs* are attached by ligaments to parapophyses of trunk vertebrae and serve as a protective framework for the bodycavity and its contents (Fig. 3A).

2. Caudal vertebra. A typical caudal vertebra basically has the same parts as a trunk vertebra. But there are no ribs. Also, the centrum bears ventrally a haemal arch around the caudal artery and vein and projecting below into a long slender haemal spine (Figs. 3B & C).

3. Weberian ossicles. In cyprinoids (*e.g. Labeo*) and siluroids (order Ostariophysi), a chain of four small bones connects the airbladder and the internal ear on either side. These are named *Weberian ossicles* after the name of their discover (Weber, 1820), who regarded them to be ear ossicles. However, they are not homologous to the ear ossicles of other vertebrates as they are formed by the segments of few anterior trunk vertebrae. The four Weberian ossicles are *claustrum, scaphium, intercalarium* and *tripus* (Fig. 4). Neural arch of first trunk vertebra forms a small dorsal *claustrum* and another small ventral *scaphium* which is in direct contact with the internal ear. The centra of second and third trunk vertebrae are completely fused together. The transverse process of third vertebra becomes modified into the large triangular and anteroposteriorly extended *tripus* which is in contact with the anterior end of air bladder. *Intercalarium* is a small bone with a backwardly directed spinous process. It lies embedded in a ligament between scaphium and

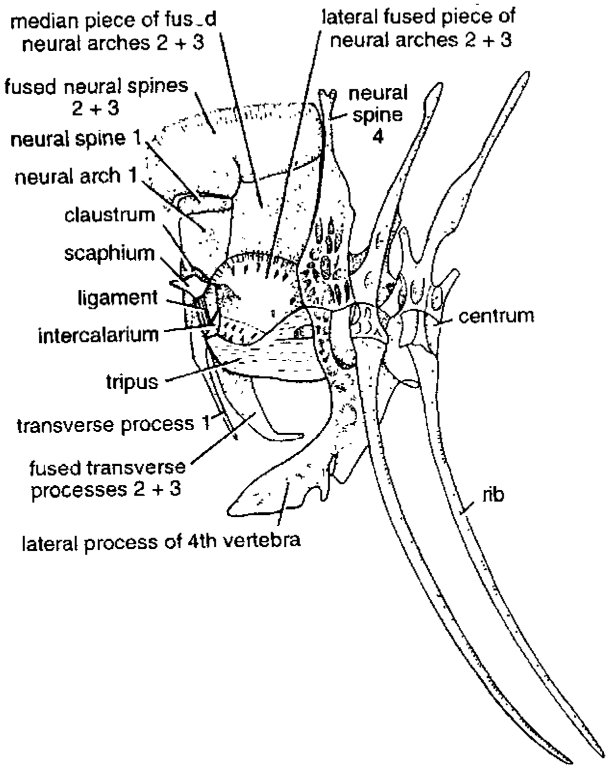

Fig. 5 *Labeo*. Weberian ossicles attached to vertebrae in left view.

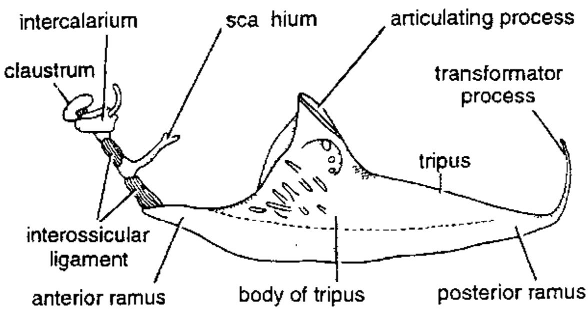

Fig. 6. *Labeo*. Chain of Weberian ossicles separated.

tripus. The actual derivations and functions of Weberian ossicles remain controversial. They probably help in maintaining equilibrium by conveying changes of air pressures in the air bladder to the internal ears (Figs. 4–6).

Median Fin Skeleton

The thick basal part of a median fin (dorsal or anal) is supported by a series of parallel, rod-like bones, the *radials* or *somactidia*, which remain

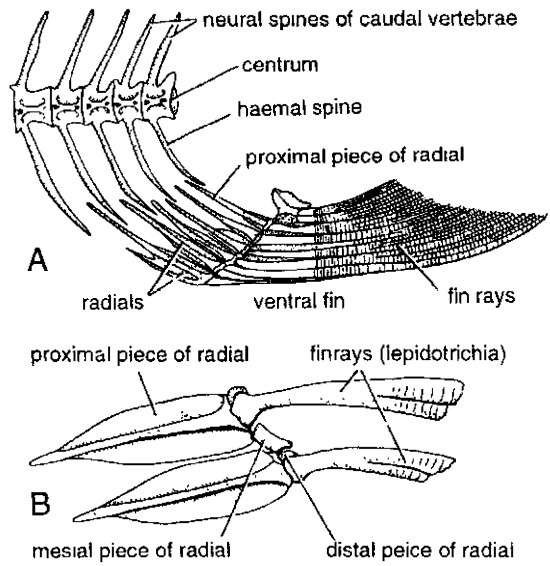

Fig. 7. *Labeo*. A—Skeleton of ventral fin and corresponding caudal vertebrae. B—Two radials and fin-rays of dorsal fin.

embedded in muscles. Typically, each radial or somactid is made of three segments : proximal, middle and distal. The *proximal* piece is large, dagger-shaped and attached by ligament to neural or haemal spine of corresponding vertebra. *Middle piece* is short and rod-like. *Distal piece* is very small and connected to the dermal, bony and branched slender finrays, called *lepidotrichia*, which support the membranous fin. At the free edges of fins are also present unbranched horny *actinotrichia*. In caudal fin, some radials fuse with vertebral neural spines to form *epurals* and with haemal spines to form *hypurals*. Caudal fin of *Labeo* has 2 epurals and 1 radial dorsally, and 9 hypurals ventrally. Lepidotrichia are arranged in 2 symmetrical halves (Fig. 7).

Pectoral Girdle and Fins

1. Pectoral girdle. It lies just behind the last branchial arch and consists of separate lateral halves. They do not meet mid-ventrally as in *Scoliodon*. Each half comprises an *inner primary* and an outer *secondary part*. Primary part is composed of 3 replacing bones : a ring-like *scapula* with a large scapular foramen, a large

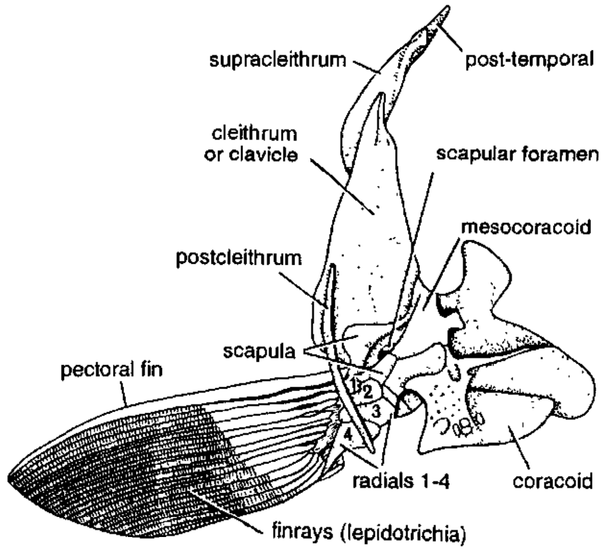

Fig. 8. *Labeo*. Left half of pectoral girdle with attached fin.

irregularly triangular and fenestrated *coracoid,* and a λ-shaped *mesocoracoid.* Scapula and coracoid provide the glenoid articulation to pectoral fin. Secondary part is composed of 4 investing bones : a small conical *post-temporal,* an elongated dagger-shaped *supracleithrum,* a large crescentic *clavicle* or *cleithrum,* and a stout curved *postcleithrum.* The post-temporal articulates with the pterotic process of skull (Fig. 8).

2. Pectoral fin. Each pectoral fin is supported by 19 finrays or lepidotrichia proximally joined with 4 radials or somactidia, 3 of which attach with glenoid articulation of scapula and coracoid.

Pelvic Girdle and Fins

1. Pelvic girdle. It lies in the ventral abdominal wall anterior to anal fin. Its two halves meet in

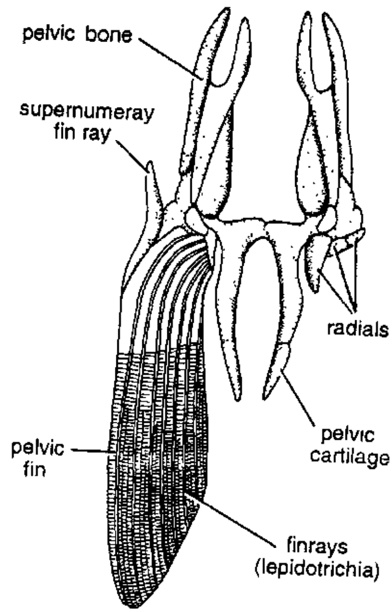

Fig. 9. *Labeo*. Pelvic girdle and right pelvic fin in ventral view.

the midventral line. Each half is made of a single large replacing bone, the *basipterygium* or *pelvic bone.* Its anterior broad part with forked end is connected in front by a ligament to the rib of the 12th trunk vertebra, while the posterior narrow rod-like part tapers behind into a small cartilage and also unites with the fellow of the other side in the mid-ventral line (Fig. 9).

2. Pelvic fin. Each pelvic fin is supported by 9 lepidotrichia, (fin rays), 3 somactidia (radials) and a supernumerary fin ray.

IMPORTANT QUESTIONS

» ***Short Answer Type Questions***

1. Draw labelled diagrams of dorsal and ventral views of skull of *Labeo*.
2. Describe the structure of typical trunk or caudal vertebra of *Labeo*. How does it differ from other vertebrae ?
3. Give the structure of pectoral or pelvic girdle of *Labeo*.

» *Multiple Choice Questions*

1. The advancement of axial skeleton of *Labeo* over that of *Scoliodon* is the presence of :
   (a) Ribs (b) Skull
   (c) Vertebral column (d) Girdles
2. The visceral skeleton in *Labeo* possesses how many pairs of arches :
   (a) 6 (b) 7 (c) 8 (d) 9
3. Median occipital spine is present in :
   (a) Exoccipital (b) Basioccipital
   (c) Supraoccipital (d) Prootic bone
4. The roof of cranium in *Labeo* is formed by :
   (a) Parasphenoid (b) Alisphenoid
   (c) Frontals (d) Parietals and frontals
5. On the dorsal side of orbits in *Labeo* lie the :
   (a) Frontal (b) Alisphenoid
   (c) Orbitosphenoid (d) Ectoethmoid
6. The unpaired bone of nasal region in *Labeo* is :
   (a) Nasals (b) Mesethmoid
   (c) Ectoethmoids (d) Lacrymals
7. The membrane bone of upper jaw in *Labeo* :
   (a) Palatine (b) Metapterygoid
   (c) Premaxilla (d) Quadrate
8. The visceral gill arches called as branchial arches are :
   (a) 2nd to 6th (b) 3rd to 7th
   (c) 4th to 8th (d) 3rd to 6th
9. The number of vertebrae in the vertebral column of *Labeo* :
   (a) 37-38 (b) 38-39 (c) 39-40 (d) 40-41
10. Trunk vertebra in *Labeo* is :
    (a) Procoelus (b) Amphicoelus
    (c) Acoelus (d) Opisthocoelus
11. Bones connecting air bladder and internal ear are collectively known as :
    (a) Tripus (b) Claustrum
    (c) Weberian ossicles (d) Ear ossicles
12. Each pelvic fin is supported by how many fin rays :
    (a) 7 (b) 8 (c) 5 (d) 9

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d)

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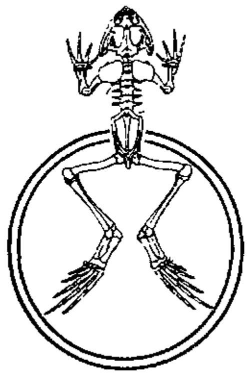

Endoskeleton of Frog

The living Amphibia do not possess an *exoskeleton.* The *endoskeleton* of frog is made partly of *cartilage* and partly of *bone.* In the early stages of development (tadpole), the skeleton is solely cartilaginous but, in the adult frog, it is greatly replaced by bones called the *cartilage* or *replacing bones.* Bones become also developed in other parts of skin or dermis of certains regions where there was no pre-existing cartilage. Such bones are termed *membrane bones.* A part of primary cartilaginous skeleton is impregnated by calcium salts and becomes hard. This is known as the *calcified cartilage.*

As usual, the skeleton is conveniently divided into *axial* and *appendicular* skeleton. *Axial* skeleton includes *skull, vertebral column* and sternum which lie along the median longitudinal axis of body. *Appendicular* skeleton comprises the skeleton of the *limbs* and the *girdles* supporting them (Fig. 1).

Characteristic Features of Skull

Skull of frog is characterized by the following important characters :

(1) It is triangular in shape, broad and dorso-ventrally flattened.

(2) A considerable part of chondrocranium of tadpole persists in the adult. A large part of cranium and sense capsules consists of cartilage.

(3) Cranium is comparatively small and narrow due to small size of brain which it encloses.

(4) Occipital region is greatly reduced.

(5) Skull is *dicondylic, i.e.,* it articulates with the atlas vertebra by two occipital condyles, one on each exoccipital.

(6) Basi-, ali-, orbito-, and pre-sphenoids and supra- and basi-occipitals are absent.

(7) Skull is *platybasic* because an interorbital septum is absent so that cranium reaches forwards, uninterrupted in the orbital region.

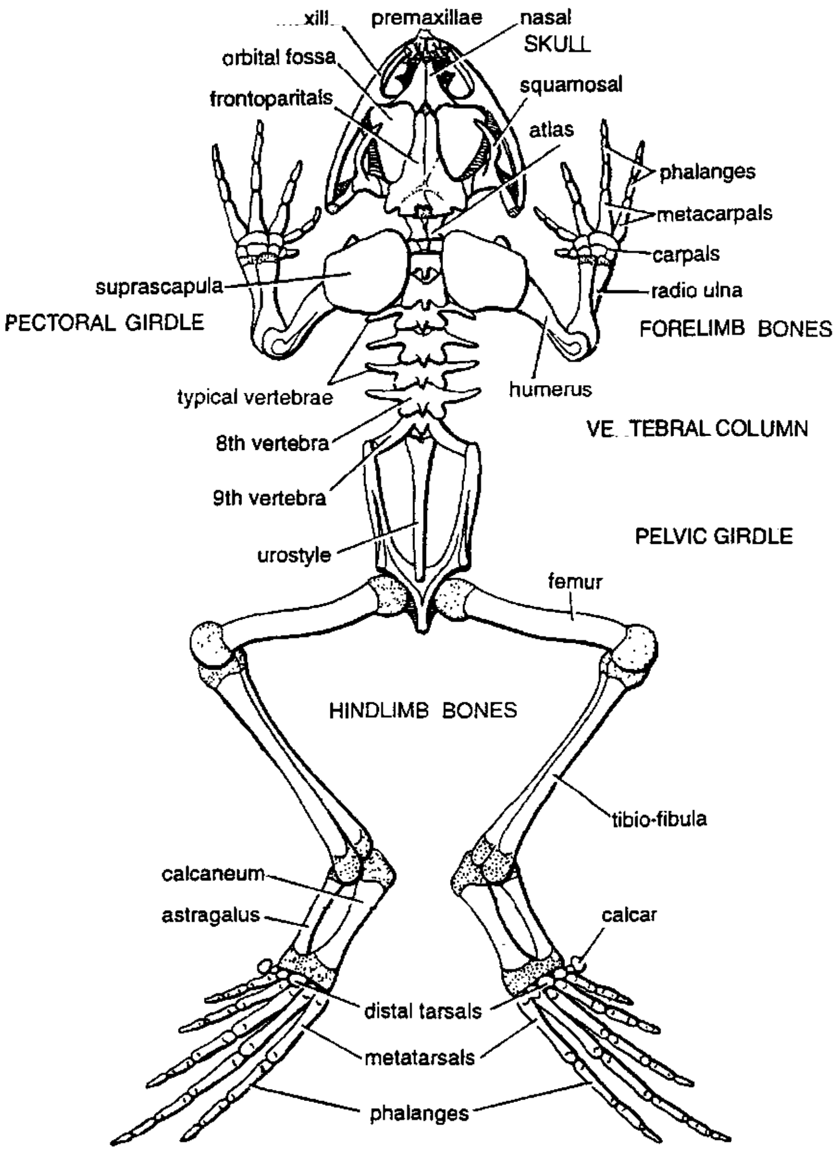

Fig. 1. Frog. Complete skeleton in dorsal view.

(8) Tabular *sphenethmoid* forms the posterior wall of olfactory chambers.
(9) Vomers bear vomerine teeth.
(10) Floor of cranium is formed by a large, dagger-like *parasphenoid* bone, whereas the roof is formed by *fronto-parietals.*
(11) Jaw suspensorium is *autostylic, i.e.*, the lower jaw is attached to skull through a rod-like cartilage, the *quadrate.*
(12) Tympanic ring-like. Tympanic bulla absent.

Parts of Skull

The skull includes 3 parts : *Cranium, sense capsules* and *visceral skeleton* (Figs. 2–7).

[I] Cranium

It encloses the brain, hence the name *brain box.* It is mostly cartilaginous (Fig. 2).

1. Occipital segment. It is the posterior-most part of cranium or brain-box. When detached from

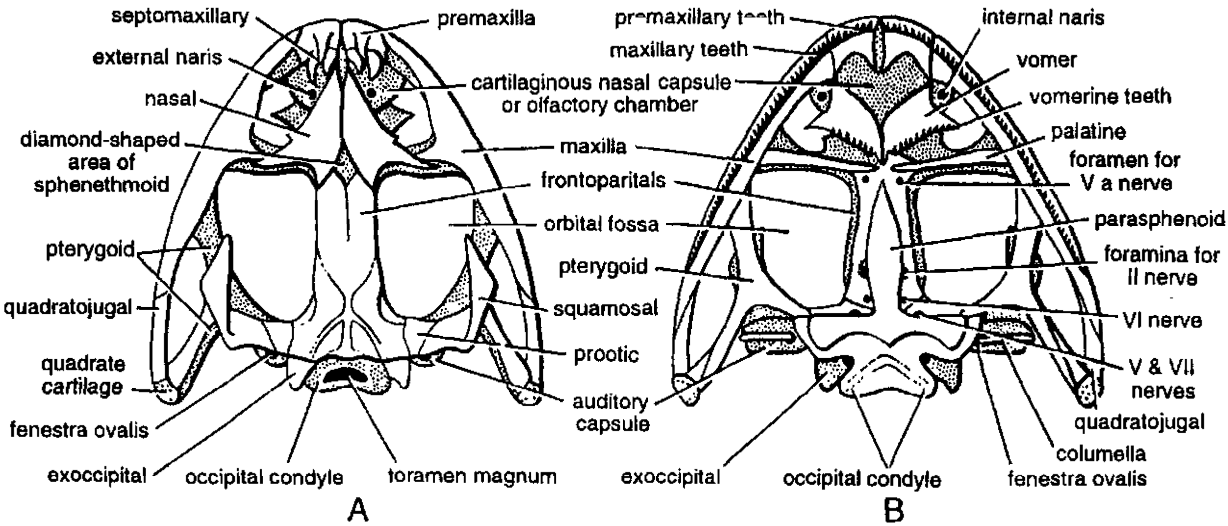

Fig. 2. Frog. Skull. A—Dorsal view. B—Ventral view.

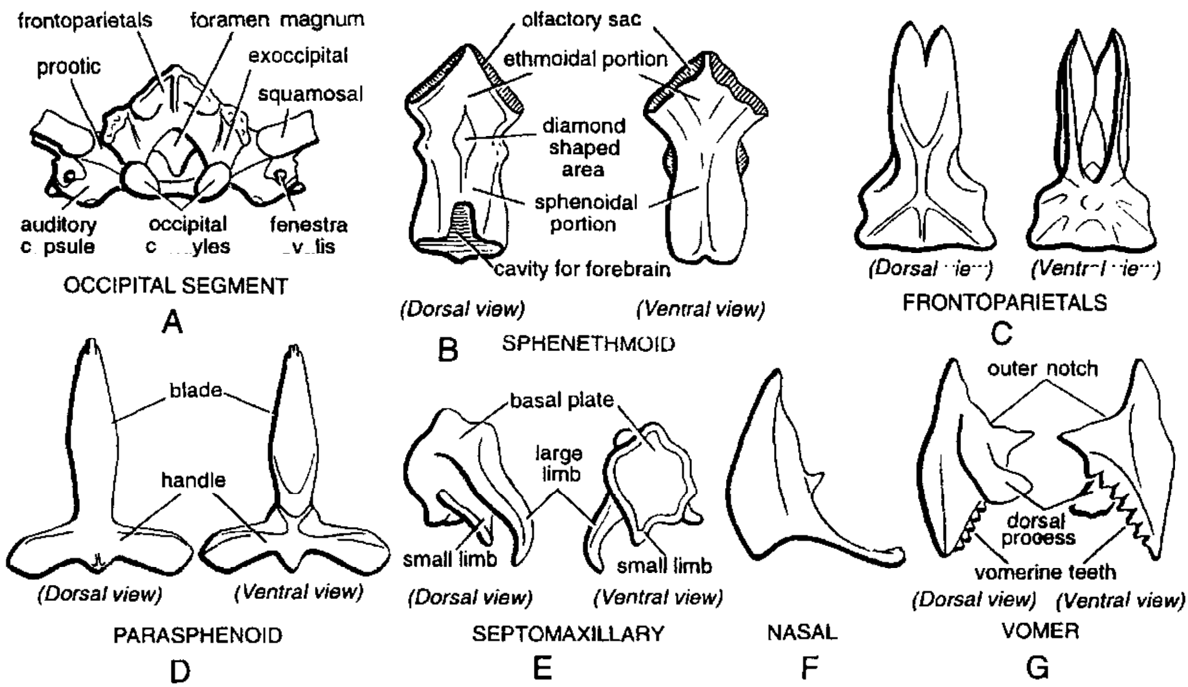

Fig. 3. Frog. Loose skull bones of cranium and sense capsules.

skull, it appears somewhat like a vertebra. It contains a large hole, the *foramen magnum,* through which spinal cord enters cranium. Two irregular cartilaginous bones, called *exoccipitals,* lie one on either side of the foramen and almost completely surround it. Exoccipitals bear, on their posterior surfaces, two large oval convexities, the *occipital condyles,* which articulate with the anterior two concavities of first vertebra or atlas. A cartilaginous *auditory capsule* is fused firmly on the outer side of each exoccipital, forming a wing-like projection. A minute opening, *fenestra ovalis,* leads into the auditory capsule of each side. The anterior wall and partly the roof and floor of each capsule are formed by an irregular cartilage bone, the *prootic*. It is partially covered on its outer dorsal surface by the squamosal (Fig. 3A).

Supraoccipital and basioccipital are absent. Dorsal side of occipital region is covered by the great frontoparietals, while its floor is occupied by the dagger-shaped parasphenoid.

2. Sphenethmoid. It is a tubular bone encircling the anterior end of cranial cavity, and forming the posterior wall of nasal cavity. It is divided by a transverse partition into an anterior ethmoidal region and a posterior sphenoidal region. The latter encloses the fore-brain while the former is further divided by a longitudinal partition into right and left portions, each enclosing an olfactory sac. The bone is exposed only on its two lateral sides, as it remains covered ventrally by the parasphenoid and dorsally by the two nasals and fronto-parietals except for a small diamond-shaped area (Fig. 3B).

3. Fronto-parietals. These are a pair of long, broad, flattened and membrane bones. They are united along the mid-dorsal line and form the whole roof of cranium. In larval frog, each fronto-parietal occurs into separate frontal and parietal parts, but in adult frog, they become fused to form a single fronto-parietal. They extend in front overlapping the sphenethmoid and behind upto the exoccipitals. Anteriorly the two bones slightly diverge so as to expose a small diamond-shaped area of the sphenethmoid. Anteriorly they articulate with the nasals while posteriorly with the prootics and the exoccipitals (Fig. 3C).

4. Parasphenoid. The entire floor of cranium is covered and strengthened by a large parashpenoid bone which appears like a dagger or ⊥ in shape. The blade, shaft or pointed long arm of the dagger is directed anteriorly below the sphenethmoid while its handle with the cross-piece lies across the auditory capsules (Fig. 3D).

[II] Sense capsules

There are a pair of *auditory capsules*, enclosing the organs of hearing; and a pair of *olfactory capsules* lodging the organs of smell, which are firmly fused with the cranium. They are mostly cartilaginous. The *optic capsules* enclosing the eyes are not fused with the skull.

1. Nasals. The anterior dorsal region of skull carries a pair of large, flat and triangular membrane bones, the *nasals*, which form the roof of olfactory capsules. The two nasals lie in contact in the median line. Their anterior ends reach up to the dorsal processes of premaxillae and partly form the boundry of the external nares. Their outer processes meet with the maxillae. Their posterior processes slightly diverge, before meeting the fronto-parietals, so that a small diamond-shaped gap is enclosed where the sphenethmoid is visible dorsally (Fig. 3F).

2. Septomaxillaries. A minute irregular-shaped bone, the *septomaxillary*, lies close to the anterior process of each nasal. It is formed by a broad basal plate and a pair of backwardly directed processes (Fig. 3E).

3. Vomers. Ventrally the floor of olfactory capsules is covered by a pair of small flat, membrane bones, the *vomers*. Irregular or somewhat triangular in outline, they form the inner margins of posterior nostrils. The postero-lateral edge of each vomer bears a few pointed *vomerine teeth* in a row (Fig. 3G).

[III] Visceral skeleton

The *upper* and *lower jaws*, the *hyoid apparatus*, the *columella auris* and the cartilages of the larynx, constitute the visceral skeleton.

1. Upper jaw. ***Premaxillae.*** The anterior-most bone of the maxillary arch or upper jaw on each side is *premaxilla*. It is a small irregular bone in the anterior tip of the snout, meeting its fellow in the middle line. Each premaxilla bears a few conical teeth in two rows along its anterior lower edge. Dorsally, it gives off a posteriorly directed process which forms part of the inner boundary of external nostril. On outer side the premaxilla meets the maxilla of its side (Fig. 4).

Maxillae. Each premaxilla articulates behind with a maxilla which forms the greater portion of the outer margin of upper jaw. It is a long, thin and slightly curved bone provided along its whole length with numerous sharp, pointed and back–

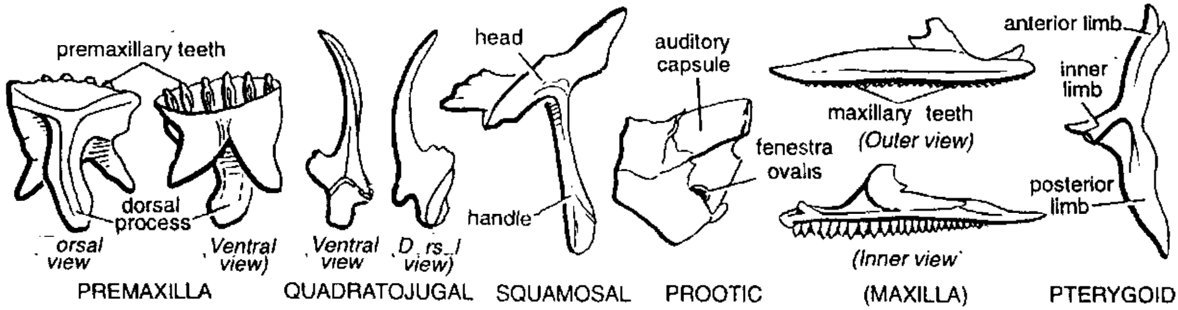

Fig. 4. Frog. Loose skull bones of upper jaw.

wardly directed conical teeth, firmly ankylosed with the bone. Maxilla is connected behind with quadratojugal while it articulates at about the middle of its length with palatine and anterior limb of pterygoid.

Quadratojugals. Quadratojugal is a small, slender bone with a characteristic comma-like shape. It lies behind maxilla forming the posterior part of outer margin of upper jaw. Its posterior broad end unites with quadrate cartilage.

Quadrate cartilages. The *suspensorium* at each angle of the mouth, connecting the mandible with the skull, is formed by a small thin rod of cartilage, named the *quadrate cartilage.* In adult frog, it is rather completely covered over by the pterygoid and squamosal. The inner or anterior end of quadrate cartilage is fused with auditory capsule and outer or posterior end attached to the hind end of quadratojugal.

Squamosals. Squamosals are T-shaped or hammer-shaped bones attached dorso-laterally to the posterior end of cranium above the pterygoids, and helping to support the annular tympanic bones. The anterior limb of T or head remains free while the shorter posterior limb is attached to auditory capsule and prootic. Stem or handle of T articulates with the quadrate cartilage. Squamosal also forms the posterodorsal margin of orbit of its side.

Pterygoids. These are present ventral to squamosals attached laterally to posterior end of cranium. Each pterygoid is a large three-rayed or Y-shaped bone. Its anterior ray or limb joins with maxilla and outer end of palatine. Its inner ray joins with parasphenoid and auditory capsule. Its posterior ray articulates with quadratojugal and quadrate cartilage. Pterygoid contributes to the postero-ventral margin of orbit of its side.

Palatines. The ventral, anterior side of each orbit is bounded by a transversely elongated, slender, delicate, rod-like bone, called *palatine.* It connects the anterior side of cranium with the middle of maxilla.

2. Lower jaw or mandible. *Lower jaw* or mandible, is semicircular in outline. It is composed of two halves or rami, united anteriorly by a ligament. Teeth are altogether absent. Each half or ramus consists of a core of *Meckel's cartilage* surrounded by three bones, as follows (Fig. 5) :

Mento-meckelian. It is a small cartilage bone formed as an ossification at the extreme anterior end of Meckel's cartilage, at the anterior symphysis of two halves of mandible.

Angulosplenial. It is a long and curved bone forming most of the inner and posterior portion of each ramus of mandible. Its anterior end is tapering while its posterior extremity bears dorsally a condyle or knob-like articular surface for the

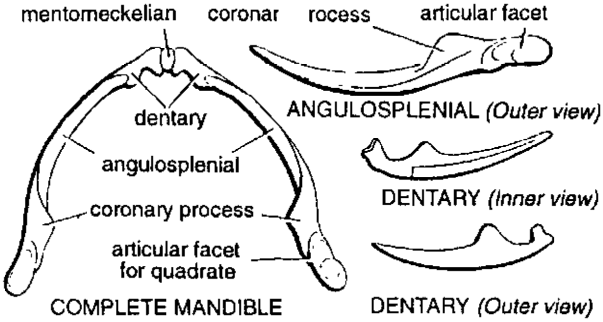

Fig. 5 Frog. Bones of mandible.

quadrate cartilage of the skull. Just in front of this articular surface, it is produced upwards into a small *coronary process.*

Dentary. It is a small, flat, dagger-like bone, covering the outer surface of anterior portion of Meckel's cartilage. It extends anteriorly up to Mentomeckelian bone, whereas its posterior part [illegible] of angulosplenial.

3. Hyoid apparatus. In tadpole, the skeletal framework supporting gills is formed by hyoidean arch and branchial arches. In adult frog, gills disappear and their skeletal framework is also reduced to form *hyoid apparatus.* It lies below tongue in the floor of mouth and provides surface [illegible] (Fig. 6).

Hyoid apparatus is almost exclusively cartilaginous and is made of three parts :

Body of hyoid. It is a thin membranous and broad squarish plate of cartilage, formed by the fusion of ventral ends of visceral arches. It lies beneath the tongue and gives off several processes. A short process is found at each angle of the plate.

Anterior cornua. Anteriorly, body of hyoid gives rise to a pair of long, slender and curved, rod-like cartilaginous processes, called *anterior cornua* or *horns.* These are homologous with ceratohyals of lower forms. They run anteriorly, then curve backward and finally upward to become attached with auditory capsules of skull just below fenestra ovalis.

Posterior cornua. Posteriorly, the body of hyoid gives off a pair of short but stout, straight and diverging ossified (bony) processes, called *posterior cornua* or *thyrohyals,* corresponding to the fourth branchial arches. They run one on either side of glottis or arytenoid cartilages supporting the laryngo-tracheal chamber.

4. Columella auris. In the living frog, the cavity of each middle ear contains a single rod-like ear ossicle, called *columella auris.* It is made up partly of bone and partly of cartilage. At its outer end, it is attached to the middle of tympanic membrane or eardrum. Its inner end is inserted upon the outer wall of auditory capsule in

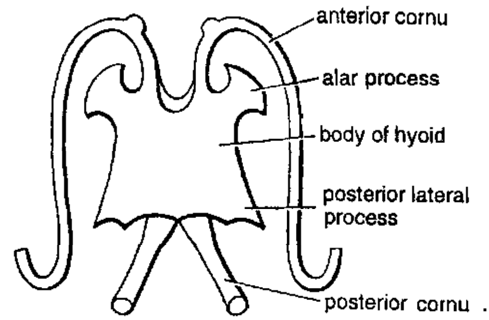

Fig. 6. Frog. Hyoid apparatus.

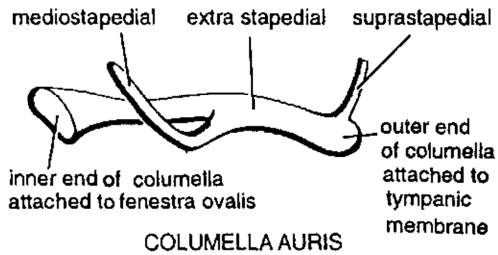

Fig. 7. Frog. Columella auris.

an aperture called *fenestra ovalis.* Columella serves to conduct sound vibrations from tympanic membrane to the inner ear located deep in the head (Fig. 7).

Vertebral Column

Vertebral column lies mid-dorsally in body, hence also called the *backbone.* It encloses and protects the spinal cord. Vertebral column of frog is exceptionally short in the absence of a tail. It is formed by ten separate bony elements arranged one behind the other in a linear series. First nine bones are small, ring-like and termed *vertebrae.* The last or the 10th bone is long, rod-like and termed *urostyle* (Fig. 8).

1. Atlas vertebra. The first vertebra is called *atlas.* It is in the form of a very small bony ring with reduced centrum and neural spine and without transverse processes and prezygapophyses. Anterior face of centrum carries a pair of large concave facets into which, fit the knob-like occipital condyles of skull. Postzygapophyses are present on the posterior margin of neural arch.

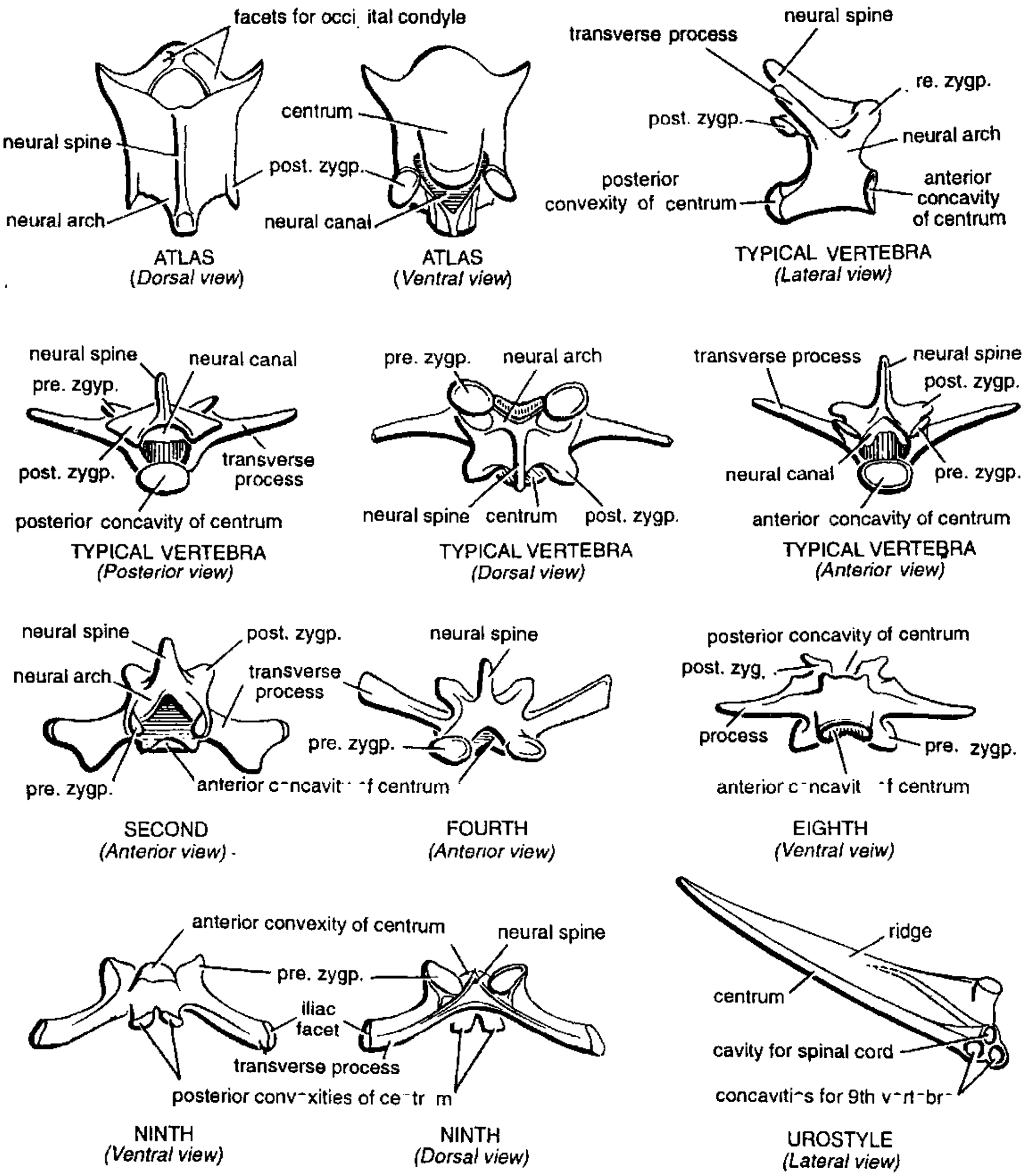

Fig. 8. Frog. Vertebrae.

2. Typical vertebra. In frog, third to seventh vertebrae are typical in structure. Each has a ring-like form with a large hole, called *neural canal*, through which the spinal cord passes. The ventral thick and solid rod-like part of the ring is *centrum* or *body*. It is *procoelous* as its anterior face is concave and posterior face convex. Dorsal arch of the ring is called *neural arch*. On either side, at its junction with the centrum, is given out an outwardly directed long and tapering process, called *transverse process*. Neural arch bears a small and blunt mid-dorsal process, the *neural* *spine,* which is obliquely directed backwards. Anterior margin of neural arch bears, at the base of neural spine, upwardly, and inwardly directed articular facets, called *prezygapophyses.* Posterior margin also bears similar pair of *postzygapophyses* which are directed downwards and outwards.

3. Second vertebra. Second vertebra is typical in structure with a slight variation. Its neural spine is short and conical while transverse processes are small, and distally broad and flat.

4. Fourth vertebra. It is also typical in structure except that the transverse processes are broader distally.

5. Eighth vertebra. It resembles a typical vertebra in all respects, but its centrum is *amphicoelous* or *biconcave.* The anterior concavity receives the posterior convexity of seventh vertebra, while its posterior concavity receives the anterior convexity of ninth vertebra.

6. Ninth vertebra. Ninth or *sacral vertebra* differs in many respects from the typical structure. Its centrum is *biconvex,* bearing one anterior convexity, fitting into the posterior concavity of eighth vertebra, and two posterior convexities fitting into the anterior concavities of urostyle. Transverse processes are large, cylindrical, stout and directed backwards, their distal ends supporting the ilia bones of the pelvic girdle. Neural spine is inconspicuous. Pre-zygapophyses are well developed while Post-zygapophyses are entirely absent.

7. Urostyle. The posterior unsegmented part of vertebral column is called *urostyle* which is as long as the rest of vertebral column. It is somewhat triangular in outline with the pointed apex directed backward. Its centrum is rod-like with a broad anterior face bearing two concavities for articulation with the ninth vertebra. Its dorsal surface is raised up in the form of a prominent vertical ridge, highest in front but gradually tapering behind. Anteriorly, the ridge contains a short narrow neural canal which encloses the terminal part of spinal cord. Close to the anterior end, on either side opens a small aperture for the exit of tenth spinal nerves. These apertures correspond to the intervertebral foramina thus reflecting the compound nature of urostyle, but they are generally absent in *Rana tigrina.*

Sternum. Sternum lies in the mid-ventral line intimately connected between the two halves of pectoral girdle. It includes four parts. *Episternum* is a flat circular and cartilaginous disc lying anteriormost. *Omosternum* is a bony rod connecting it with the clavicles. *Mesosternum* is a cartilaginous rod projecting behind the epicoracoids. *Xiphisternum* is the terminal broad, cartilaginous plate. Ribs are absent in frog.

Pectoral Girdle

Pectoral girdle of frog is in the form of an inverted arch, buried in bodywall around the thoracic region of body. It protects the inner softer parts and provides support and attachment to the anterior limbs and their muscles. It is made both of bones and cartilages, and consists of two similar halves united midventrally with sternum but separated dorsally. Each half is further divisible into two regions (Fig. 9) :

1. Scapular region. It is the dorso-lateral region comprising two bones. *Suprascapula* is a broad, flat, somewhat rectangular plate covering dorsally the first four vertebrae. Its upper free margin is made of calcified cartilage; while the lower part is bony and articulates with scapula. *Scapula* is a stout, flat bone, broader towards the ends but constricted in the middle. Posteriorly it forms the upper half of a deep cup-like depression, the *glenoid cavity,* for articulation with the head of humerus. A prominent conical process arises from its anterior side.

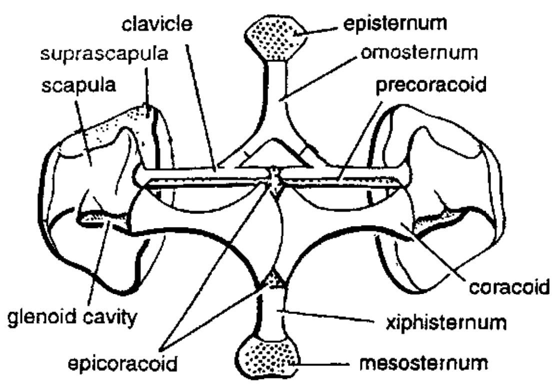

Fig. 9 Frog. Pectoral girdle and sternum in ventral view.

2. Coracoid region. It includes two bones and two cartilages. From the lower end of scapula run two bones, *clavicle* an *coracoid,* to unite mid-ventrally with sternum and their fellows of other side through a strip of cartilage, called *epicoracoid.* The *clavicle* is a slender rod, [illegible] *coracoid foramen.* A narrow strip of calcified cartilage, called *precoracoid,* lies attached to it posteriorly. The *coracoid* is dumb-bell shaped with its inner end broader than the outer one which forms the lower half of the glenoid cavity.

Pelvic Girdle

Pelvic girdle of frog is a V-shaped structure [illegible] k. I g v support to pelvic region and hind limbs. Two limbs of the V run parallel to vertebral column. They diverge anteriorly but converge posteriorly and unite into a median disc which supports the posterior end of urostyle. Each lateral side of the disc carries a prominent cup-like de ression, the *acetabulum,* or articulation wit t e ea o femur. The girdle is made of two similar halves. Each half, or *os innominatum,* includes three elements all of which share the disc and the acetabulum (Fig. 10).

1. Ilium. It forms the major part of the *os innominatum.* It is a greatly elongated bone running forwards to meet the transverse process of ninth vertebra. It is dorsally produced into a prominent vertical ridge, the *iliac crest.* The two ilia meet posteriorly at an iliac symphysis in the median plane and form the anterior and upper half of the disc and acetabulum.

2. Pubis. Pubis is much reduced, triangular piece of calcified cartilage, occupying the ventral part of the disc and sharing nearly one-sixth of acetabulum. It is completely fused with its fellow of other side in a median pubic symphysis.

3. Ischium. It forms the posterior one-third of the disc and acetabulum and unites completely with the bone of the other half at a median ischiatic symphysis. It is slightly bigger than pubis and oval in shape.

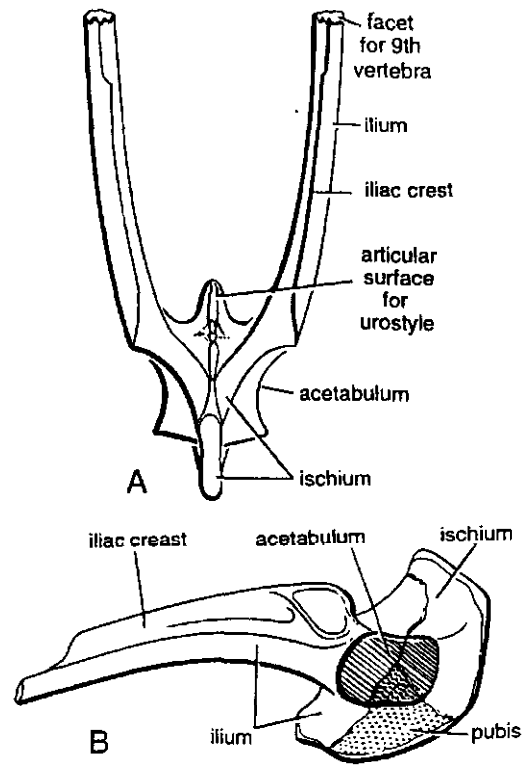

Fig 10. Frog, Pelvic girdle. A—Dorsal view. B—One half (os innominatum) in lateral view.

Forelimb Bones

1. Humerus. Bone of the upper arm is called *humerus.* It is a short and cylindrical bone with a slightly curved *shaft.* Its proximal end is swollen to form a rounded *head,* which fits into the glenoid cavity of pectoral girdle. Head is covered by calcified cartilage. Below the head, the proximal half of shaft bears anteroventrally a prominent vertical process, the *deltoid ridge,* to which muscles are attached. Distal end shows a round prominence, the *capitulum* or *trochlea,* with a *condylar ridge* on either side. It articulates with the groove of radio-ulna (Fig. 11).

2. Radio-ulna. Forearm contains a compound bone, called *radia-ulna,* formed by the fusion of radius and ulna bones. Proximally, the radio-ulna shows a concavity to receive the trochlea of humerus and further projected into an *olecranon process* forming the *elbow joint.* Distal half of

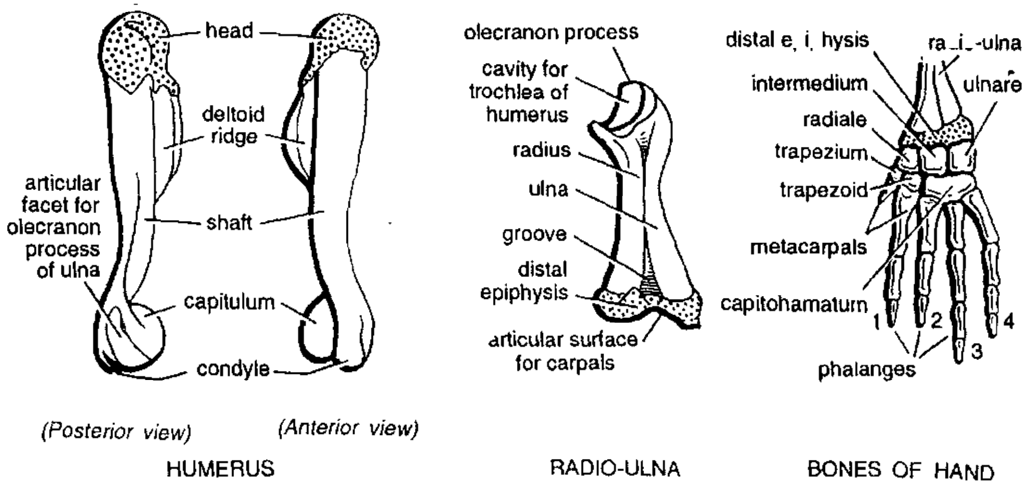

Fig. 11. Frog. Fore limb bones.

radio-ulna is somewhat flat and a groove imperfectly divides it into an anterior or radial part and a posterior or ulnar part, each terminating into a facet for articulation with the proximal row of carpal bones.

3. Bones of hand. Bones of wrist or *capus* are called *carpals*. In frog, carpal bones are six in number and arranged in two rows, each containing three. Bones of proximal row, which articulate with radio-ulna, are called *radiale*, *intermedium* or *centrale* and *ulnare*. Bones of distal row, which articulate with metacarpals, are termed *trapezium*, *trapezoid* and *capitatohamatum*.

Hand or *manus* is supported by five slender, rod-like bones, the *metacarpals*. First metacarpal is rudimentary.

Manus bears only four digits. Pollex or thumb is absent. Digits are internally supported by short bony rods, called *phalanges*. First and second digits bear 2 phalanges each, while third and fourth digits bear 3 phalanges each.

Hind limb Bones

1. Femur. Thigh is supported by a single long and slender bone, called *femur*. It has a slightly curved *shaft* and expanded ends covered by calcified

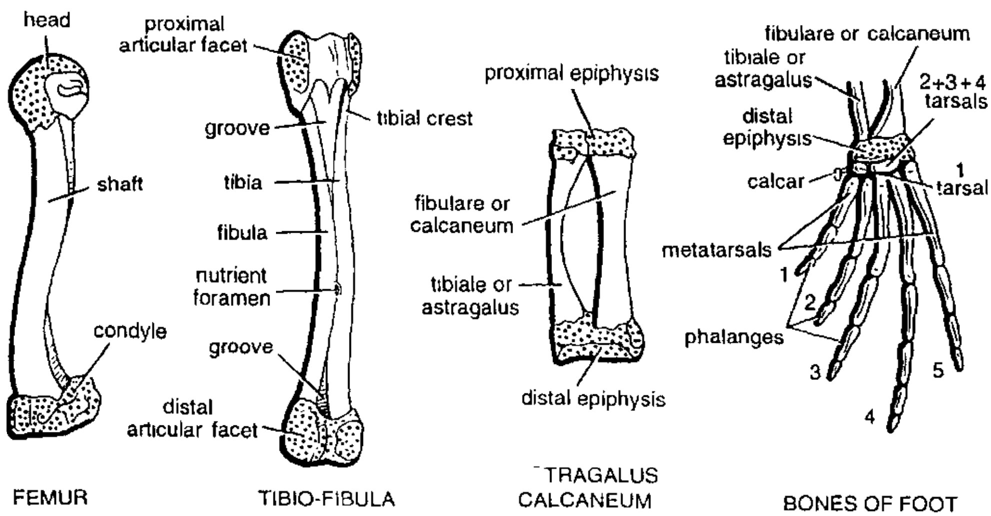

Fig 12. Frog Hind limb bones.

cartilage. Proximal rounded end, or *head,* articulates with acetabulum forming a ball-and-socket joint, while the distal end articulates with tibio-fibula (Fig. 12).

2. Tibio-fibula. Shank or crus is supported by a large compound bone, called *tibio-fibula.* It is the longest bone in frog. Its shaft is slightly curved while two extremities are expanded and covered by cartilage. It is formed by the fusion of two bones, an inner tibia and an outer *fibula,* as indicated by the presence of a longitudinal median *groove.* Near its proximal end, tibia bears a small longitudinal ridge, called *cnemial* or *tibial crest.* Tibio-fibula articulates proximally with femur and distally with astragalus-calcaneum.

3. Astragalus-calcaneum. Ankle or *tarsus* of frog contains two rows of *tarsal* bones, each having two bones. Proximal row consists of two greatly elongated bones fused together at their proximal and distal ends, but with a wide gap in the middle. Outer thicker and straight bone is *calcaneum* or *fibulare.* Inner, thinner and slightly curved bone is *astragalus* or *tibiale.* Their fused ends are covered by *epiphyses* of calcified cartilage.

Distal row of tarsals consists of two very small bones.

4. Bones of foot. Foot or *pes* is supported by five long, slender bones, called *metatarsals,* bearing five true *toes* with 2, 2, 3, 4 and 3 *phalanges,* respectively. In addition, a tiny preaxial sixth toe, made of 2 or 3 bones, is present on the inner side of the first toe or hallux. This supplementary toe is called *prehallux* or *calcar* and it does not project from the foot.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the vertebral column of *Rana tigrina.*
2. Give an account of the pectoral girdle and sternum of frog.

» *Short Answer Type Questions*

1. Describe the structure of chondrocranium of frog. Name various membrane bones present in the skull of frog.
2. Write short notes on— (i) Lower jaw of frog, (ii) Pelvic girdle of frog, (iii) Urostyle.

» *Multiple Choice Questions*

1. In living Amphibian exoskeleton is :
(a) Absent (b) Scaly (c) Dermal plates (d) Spiny
2. The skull in frog is :
(a) Monocondylic (b) Platybasic
(c) Tropibasic (d) Holostylic
3. In frog the spinal cord enters the cranium through :
(a) Exoccipitals (b) Occipital condyles
(c) Foramen magnum (d) Fenestra ovalis
4. The posterior wall of nasal cavity in frog is formed by :
(a) Nasal (b) Fronto-parietals
(c) Prootic (d) Sphenethmoid
5. Roof of cranium in frog is formed by :
(a) Fronto-parietals (b) Parasphenoid
(c) Sphenethmoid (d) Prootic
6. In frog organs of smell are enclosed in :
(a) Auditory capsule (b) Olfactory capsule
(c) Optic capsule (d) Nasal capsule
7. Nasal bones of frog are :
(a) Replacing bones (b) Cartilage
(c) Membrane bones (d) Ossified cartilage
8. Vomerine teeth are present on :
(a) Maxillae (b) Premaxillae
(c) Quadratojugal
(d) Vomer
9. In frog, teeth are not present on :
(a) Quadratojugal (b) Vomer
(c) Premaxillae
(d) Maxillae

10. The core of lower jaw is formed by :
    (a) Mento-meckilian (b) Meckel's cartilage
    (c) Angulosplenial (d) Dentary
11. Collumella auris is inserted on inner side into :
    (a) Foramen magnum (b) Septomaxillary
    (c) Fenestra ovalis (d) Tympanum
12. Tenth bone of vertebral column in frog :
    (a) Vertebra (b) Pygostyle
    (c) Atlas (d) Urostyle
13. The centrum of 8th vertebra of frog is :
    (a) amphicoelus (b) Procoelus
    (c) Acoelus (d) Opisthocoelus
14. Sternum in frog is connected to clavicles by :
    (a) Mesosternum (b) Omosternum
    (c) Xiphisternum (d) Episternum
15. Proximal row of tarsal bones in frog consists of :
    (a) Tibia fibula (b) Radio ulna
    (c) Astragalus calcaneum (d) Haullex and phallenges

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (c) 12. (d) 13. (a) 14. (b) 15. (c)

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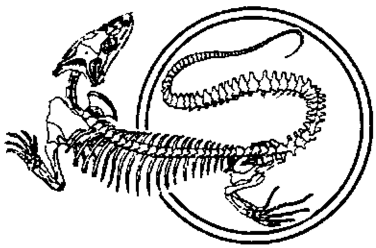

Endoskeleton of *Varanus*

The endoskeleton of *Varanus* is made partly of cartilage and partly of bone. Bones are of two types : *cartilage* or *replacing bones*, and *membrane* or *investing bones*. Endoskeleton of *Varanus* may be conveniently divided into axial and appendicular portions. Axial skeleton forms the median longitudinal axis of body and includes *skull*, *vertebral column*, *ribs* and *sternum*. Appendicular skeleton includes *limb-bones* and *girdles* supporting them (Fig. 1).

Characteristics of Skull

Skull of *varanus* is characterized by the following important features :

(1) It is more or less elongated and flattened with narrow anterior end.
(2) It is quite complicated in structure and form, and includes a large number of replacing and investing bones.
(3) It is *monocondylic*, as a single condyle formed by basioccipital which articulates with atlas vertebra.
(4) It is *tropibasic* because a thin median, vertical interorbital septum separates the two orbits.
(5) Cranium is small.
(6) Alisphenoids, orbitosphenoids and presphenoid bones are absent, but prefrontal, supra-orbital and postorbital bones are present.
(7) Two parietals become fused into a single bone, perforated by a median *parietal foramen*. Anteriorly, two premaxillae become fused into a single bone.
(8) Temporal region of skull on either side shows three vacuities or *temporal fossae*-posterior, lateral and superior.
(9) A single ear-ossicle, called *columella*, occurs in the small tympanic cavity of each ear.
(10) Teeth are present on premaxillae, maxillae and dentary bones. They are polyphyodont, homodont and pleurodont.
(11) Suspensorium is *autostylic* as the lower jaw articulates with quadrate bone of the skull.

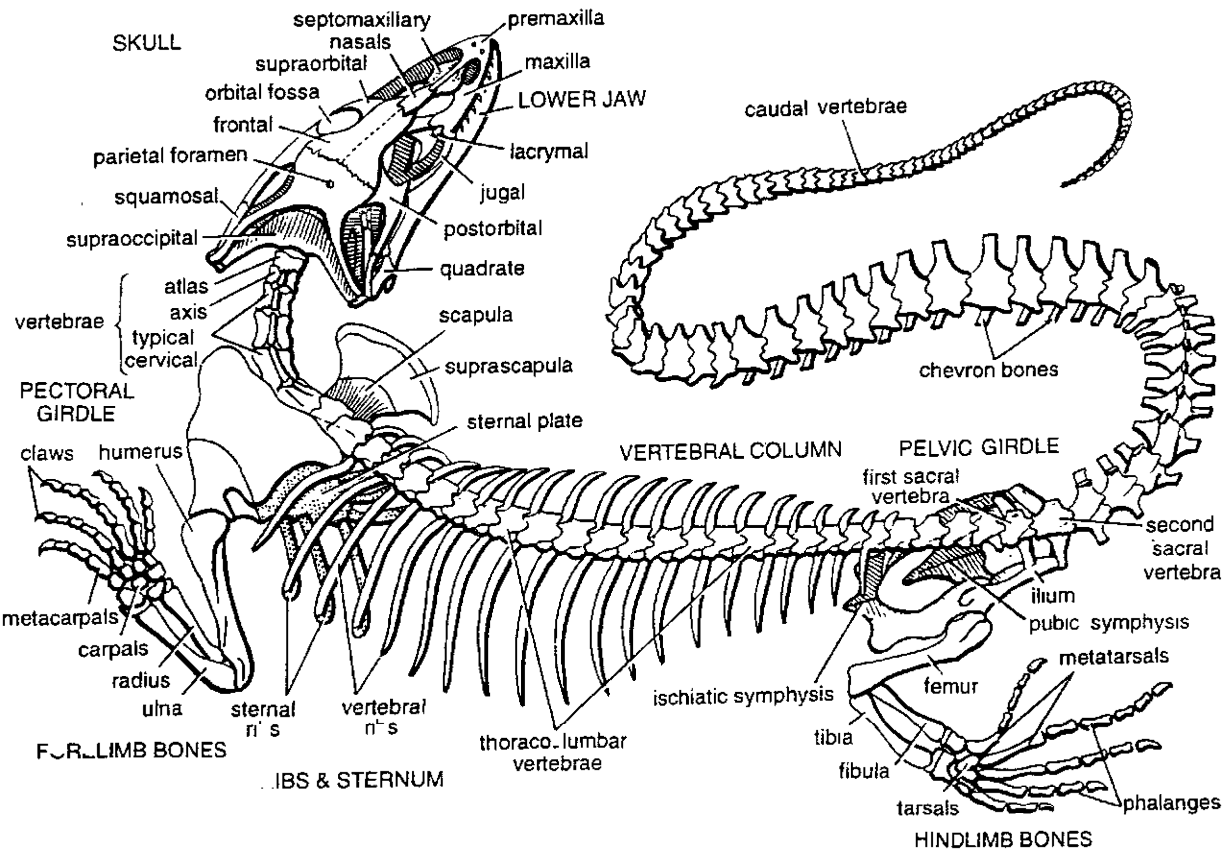

Fig. 1. *Varanus*. Complete skeleton in dorso-lateral view.

Parts of Skull

For convenience of study, skull may be divided into *cranium*, *sense capsules* and *visceral skeleton*.

[I] Cranium

It encloses the brain. Cranium of *Varanus* consists of three regions, rings or segments. Posteriormost is the *occipital segment*, next in front is *parietal* and the anteriormost is *frontal region*.

1. Occipital segment. It is the posteriormost region of cranium, surrounding a large rounded aperture the *foramen magnum*. It is composed of four bones-*supraoccipital*, paired *exoccipitals*, and *basioccipital*. All these bones are firmly fused together. The supraoccipital, forming the roof, is somewhat rectangular and articulating with parietals and prootic anteriorly. There is a single rounded *occipital condyle* lying below the foramen magnum. It is composed mainly of the basioccipital, which forms the floor of the most posterior portion of the cranial cavity. Each exoccipital is perforated by a combined jugular and condylar foramen for the passage of nerves (Xth, XIth and XIIth), vein and artery. Besides, each exoccipital is extended laterally into a broad paroccipital process articulating with supratemporal.

2. Parietal region. ***Basisphenoid.*** Floor of parietal region of cranium is occupied by a broad, flat and somewhat rectangular bone, the *basisphenoid*. It is composed of sphenoid and occipital elements. Posteriorly it articulates with the basioccipital bone. Laterally, it remains free. Anteriorly, it bears a pair of lateral processes, called basipterygoid processes with cartilaginous pads at their tips and each articulating with the

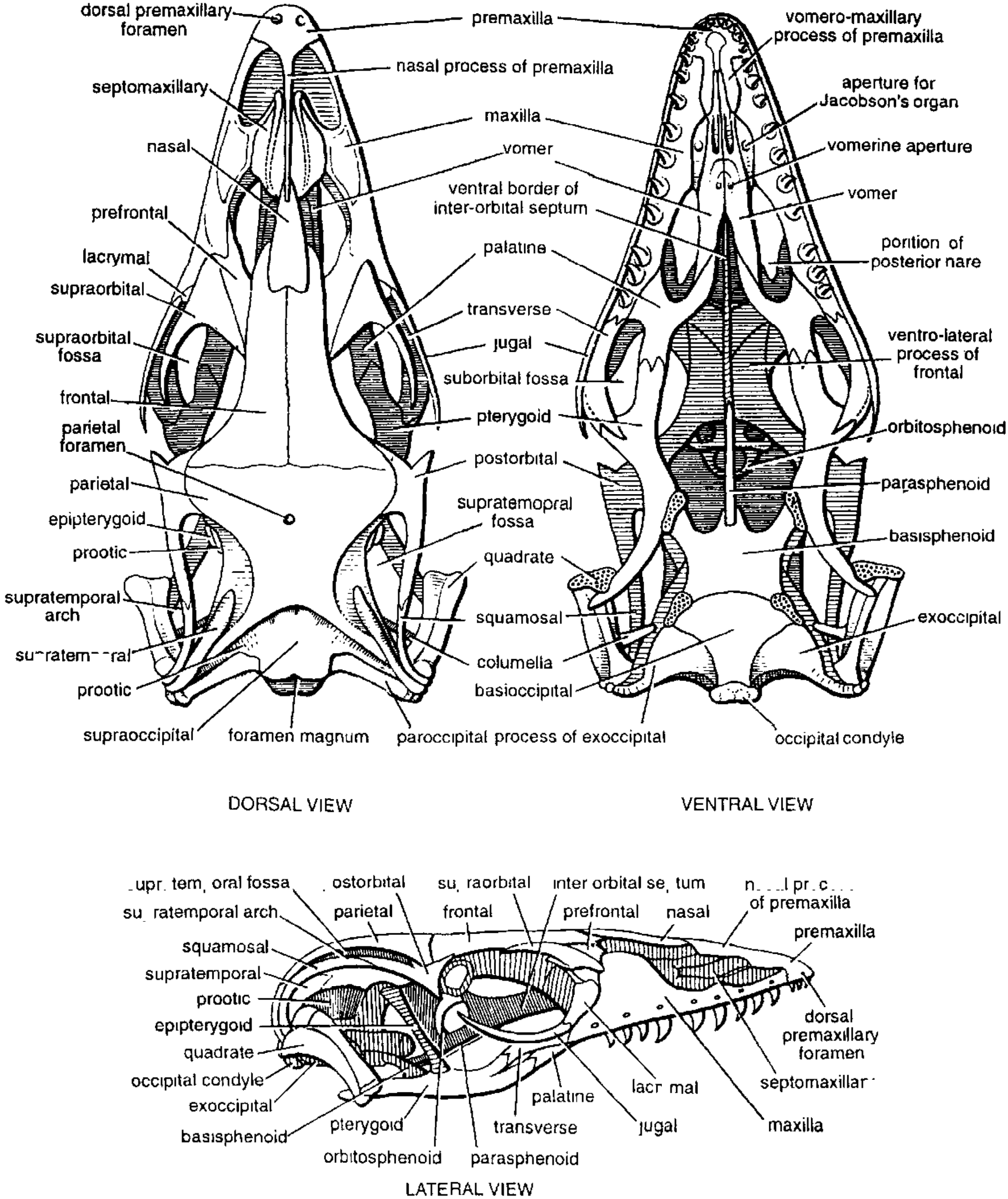

Fig 2 *Varanus* Skull in dorsal, ventral and lateral views.

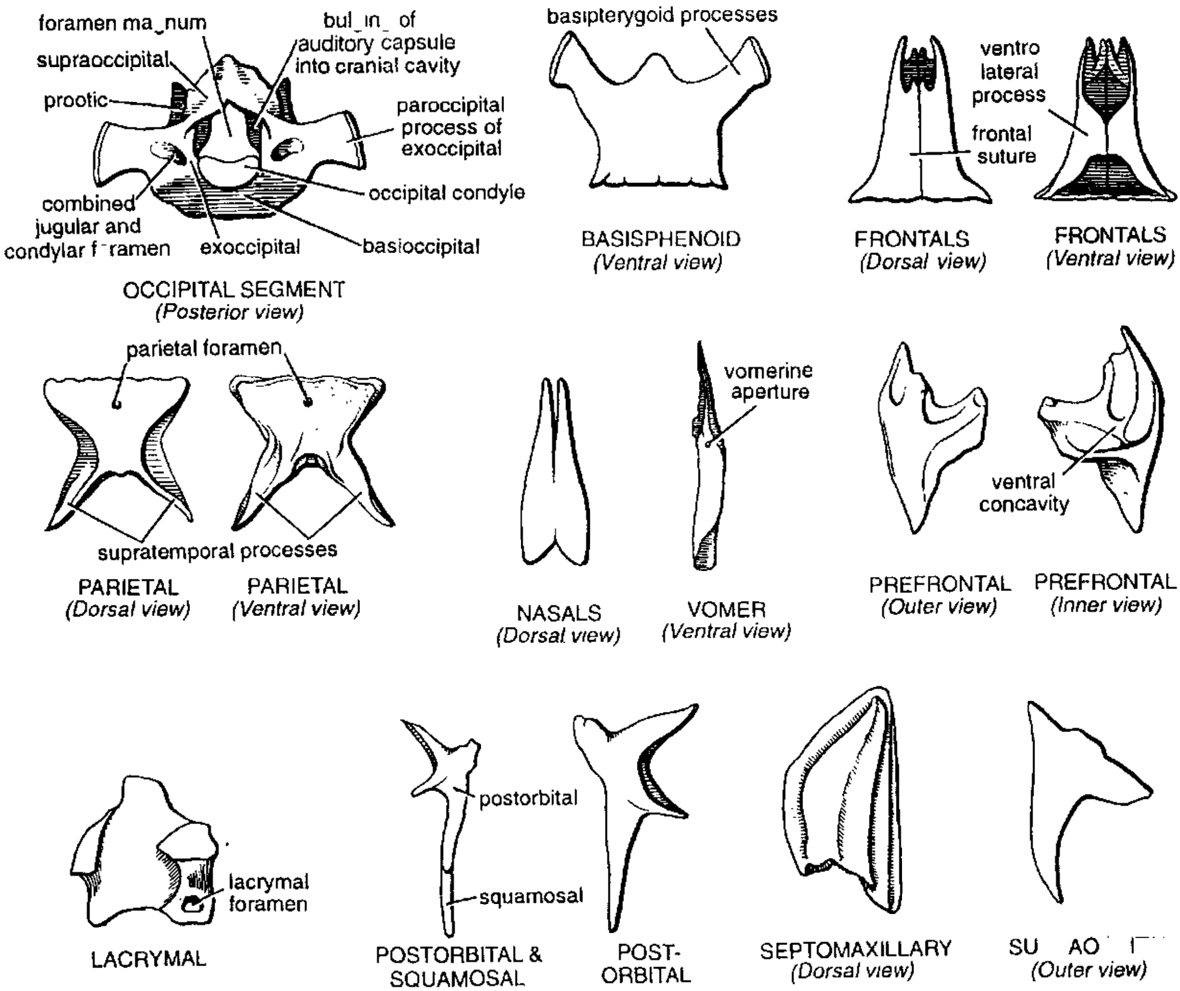

Fig. 3. *Varanus*. Loose skull bones of cranium and sense capsules

pterygoid of its side. Besides, the anterior margin of basisphenoid bears a median knob-like process, produced in front into a rostrum which corresponds with the *parasphenoid* bone of frog, but greatly reduced in *Varanus*.

Parietals. In parietal region, the roof of cranial cavity is formed by a pair of parietal *bones*, which are fused completely in the adult, without any visible suture in between the two, except for a median hole, called the *parietal foramen*. The fused parietals are broader in front but narrower behind. They articulate anteriorly with the frontals by a prominent suture, but posteriorly, they are separated from supraoccipital by a distinct gap, though it remains filled up with fibrous tissue. Each Postero-lateral angle is produced backwards into a prominent *supratemporal process* which articulates with quadrate, squamosal, supratemporal and prooccipital process of exoccipital of its side. The supratemporal process form the outer margins of the post-temporal fossae. The two lateral sides are slopping and uncovered as there are no alisphenoid bones, like those of higher animals.

3. Frontal region. *Frontals.* Frontal segment of *Varanus* is composed of three bones viz., a pair of *frontals* and *parasphenoid.* Roof of frontal region of cranium is formed by a pair of *frontal* *bones*. They remain separated from one another by a median *frontal suture* and also from the parietals behind by a distinct *coronal suture*. Each frontal is a large triangular bone, narrower anteriorly and broader posteriorly, and produced into a large ventrolateral process which unites with the corresponding process of the other side at a midventral suture. Each frontal remains free on its outer lateral side as there is no orbitosphenoid in *Varanus*. Anteriorly it articulates with the nasal, antero-laterally with prefrontal, postero-laterally with post-orbital, behind with parietal beneath with parasphenoid.

Parasphenoid. Is a large narrow rod like bone, located at mid ventral line.

[II] Sense capsules

These are three pairs : a pair of *olfactory capsules* possessing the organs of smell, a pair of *auditory capsules* containing the organs of hearing, and a pair of *orbits* enclosing the organs of sight.

1. Olfactory capsules. One olfactory capsule is attached to each antero-lateral side of the cranium. Each capsule consists of a dorsal *nasal*, a ventral *vomer* bone and anterior *septomaxillary*.

Nasals. The olfactory chambers are roofed over by a pair of small, slender *nasal* bones. The two nasals are fused along the median line forming a flat, triangular bone. The narrower anterior end articulates with the nasal process of premaxillae and the two septomaxillaries, while the broad posterior end runs over the frontals mid-dorsally, for a short distance.

Vomer. The two vomers lie on the floor of the olfactory chambers, forming the anterior part of the roof of the mouth and also the inner margin of the posterior nares. They are slender, rod-like bones which remain separated posteriorly but fused together anteriorly. Each vomer is perforated in the middle by a vomerine aperture. Each articulates with the premaxilla and maxilla anteriorly, and with the palatine posteriorly.

Septomaxillary. Exterior to the nasal process of premaxilla, on either side there is an irregular flat bone called septomaxillary.

2. Auditory capsules. Auditory capsule encloses the organ of hearing the ear. These are attached to each posterolateral region of cranium. Each capsule consists of three bones-*opisthotic, epiotic* and *prootic*. The opisthotic is fused with exoccipital and the epiotic with supra-occipital while the prootic remains free.

3. Orbits. These are two orbits, one on either lateral side of cranium. They are large in size and separated from each other by a thin, vertical, *interorbital septum*. The following bones are present in association with each orbit :

Prefrontal. A prefrontal lies in front of the frontal, between it and the maxilla. It helps to bound the orbit anteriorly. It is a small and somewhat triangular bone bearing a deep cup-like concavity on its ventral side. The prefrontal also articulates with supra-orbital posteriorly and with lacrymal ventrally.

Lacrymal. It is a small bone squarish lying at the orbit just within its border. It is perforated by a small aperture for the lacrymal duct. It articulates in front with the maxilla, behind with jugal, and above with prefrontal.

Supraorbital. It is a small triangular bone, overhanging the anterior portion of the orbit. Its broad base articulates anteriorly with the prefrontal in between the maxilla and the frontal, while its free pointed apex is directed posteriorly towards the post-orbital (post-frontal).

Post-orbital. It lies behind the frontal, hence the named *post-frontal* also. It is termed *post-orbital*, because it forms the postero-dorsal boundary of orbit. It is an irregular bone, drawn out into four processes. Two inner processes bound a deep notch, which lodges a part of both parietal and frontal along with their suture. Outer process is connected anteriorly by a ligament with jugal. Posterior process is the longest, articulating behind with squamosal to form the supra-temporal arcade.

[III] Visceral skeleton

It includes the *upper* and *lower jaws*, *suspensorium* and *hyoid apparatus* (Figs. 4–6).

1. Suspensorium. Suspensorium includes bones which help in the suspension of lower jaw

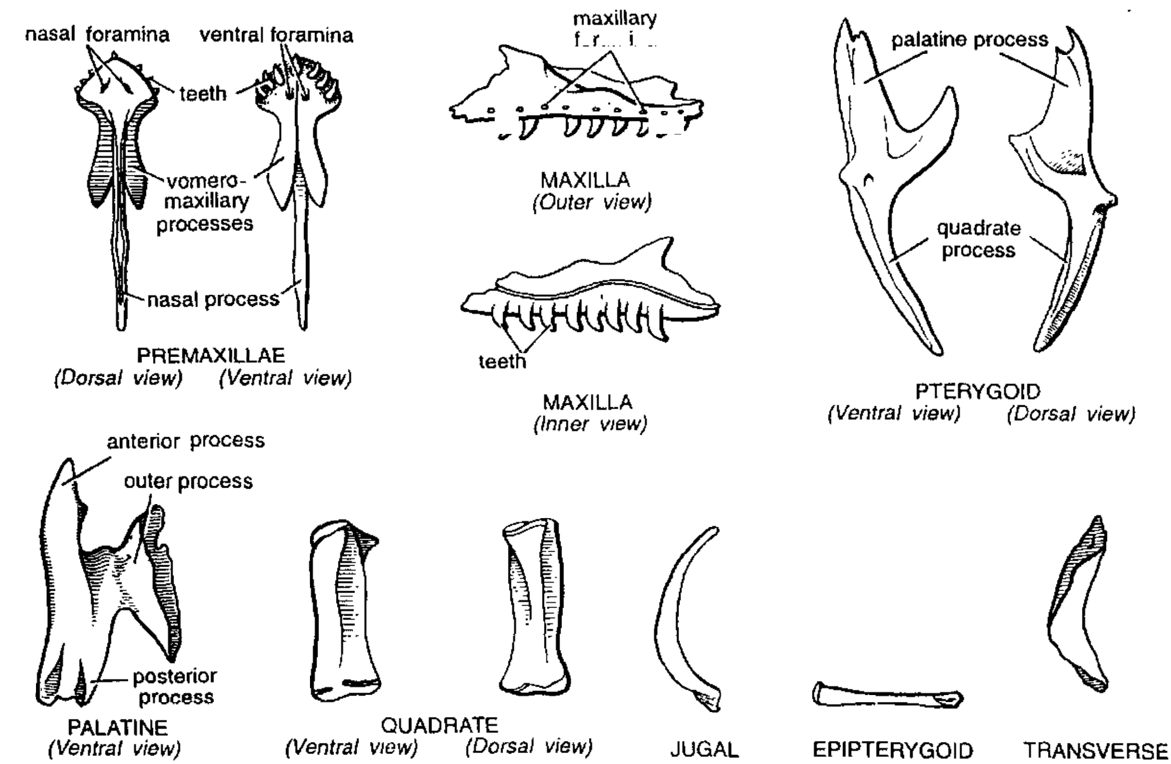

Fig. 4. *Varanus*. Loose skull bones of suspensorium and upper jaw.

from cranium and upper jaw. The two bones involved are *quadrate* and *squamosal*.

Quadrate. Quadrate is a small but thick, rod like bone of the suspensorium. It is attached somewhat obliquely to the outer posterior lateral side of cranium. Its lower end is attached with the quadrate process of pterygoid and also articulates with the articular bone of the lower jaw. Its upper end articulates with squamosal, supra-temporal, parietal and exoccipital. In the absence of quadrato-jugal, a gap is left between quadrate and jugal.

Squamosal. It is a small, slender bony rod forming the posterior portion of the supra-temporal arcade. Its anterior end articulates with the post-orbital, while the posterior end bends downwards to articulate with the quadrate, supra-temporal, parietal and the paroccipital process of exoccipital.

2. Upper jaw. The upper jaw is intimately fused with cranium on either lateral side. Bones included are *premaxilla, maxilla, jugal, septomaxillary, palatine, pterygoid, transverse* and *epipterygoid.*

Premaxillae. The two premaxillae are fused into a single median bone lying at the anterior extremity of snout. It bears 6 to 8, small, conical teeth along its ventral margin, while a pair of premaxillary foramina on the dorsal surface. Posteriorly, it gives off three processes, a single elongated, median, dorsal nasal process articulates with anterior notch of fused nasals, a pair of winglike ventral vomero-maxillary processes articulate with vomers. On either side, the fused premaxillae articulate with maxillae. Dorsal nasal process runs between external nares and two septomaxillaries.

Maxilla. Anterior half of upper jaw on either side is contributed by a large irregular bone, the *maxilla*. Its main portion or body is termed the alveolar part which bears a row of 8-10 teeth along its ventral margin. Teeth are small, conical, slightly pointed backward and pleurodont, as they are ankylosed by their sides just inside the ventral edge of maxilla. Outer surface of maxilla is perforated by a series of small *maxillary foramina.* On the inner side, the palatine process is only poorly developed so that a gap is left between maxilla and palatine. An ascending process of maxilla articulates with the prefrontal, nasals and the lacrymal. Anteriorly it articulates with premaxilla, septo-maxillary and vomer, while posteriorly with palatine, jugal and transverse.

Jugal. Outer ventral boundary of orbit is completed by a small slender bone, the jugal. It articulates anteriorly with maxilla and lacrymal , inwardly with transverse, but posteriorly remains free. A wide gap separates jugal from post-orbital.

Transverse. On the inner side of jugal is present a small and slightly curved bone, the *transverse*, *transpalatine* or *ectopterygoid.* It extends backward from the junction of maxilla, palatine and jugal to the pterygoid and contributes to the floor of orbit.

Septo-maxillary. A pair of small, irregular septo-maxillary bones lie in the nasal region, dorsally above the vomers and one on the either side of nasal process of premaxillae. Each articulates laterally with maxilla and posteriorly with nasal.

Palatine. Two palatines are small, flat and somewhat irregular bones present in the roof of mouth cavity. Each palatine is produced into three processes. Anterior elongated process articulates with vomer, posterior smaller process with pterygoid, and outer broader process with maxilla and transverse. Palatines also form the posterior boundary of inner nares.

Pterygoid. Roof of mouth also contains a pair of large, elongated and widely apart irregular *pterygoid* bones. Anteriorly, each pterygoid articulates with palatine on the inner side and with transverse on outer side. Posteriorly, it articulates with basipterygoid process of basisphenoid on inner side and with inner face of quadrate on outer side.

Epipterygoid. A slender bony rod, called *epipterygoid*, extends almost vertically between pterygoid (below) and prootic (above) of the corresponding side. Epipterygoid is also termed *columella crani* which should not be confused with *columella auris*, which is another small rod, partly cartilaginous and partly bony, extending between the tympanic membrane and fenestra ovalis of auditory capsule.

3. Lower jaw or mandible. Lower jaw or mandible is made of two similar halves or rami, united anteriorly but diverging posteriorly. Each ramus is composed of six bones - articular, angular, supra-angular, coronoid, splenial and dentary surrounding an axial *Meckel's cartilage.* All these bones are investing with the exception of articular.

Articular. It is the proximal or posteriormost bone of ramus. Dorsally it bears an articular surface for quadrate of skull. It is prolonged behind into a stout angular process terminating into an articular cartilage.

Angular. It is a small, splint-like bone wedged in between the dentary and articular. It covers the ventral edge and lower half of outer surface of articular. It is perforated by an angular foramen.

Supra-angular. It is a flat, elongated and somewhat rectangular bone in the middle of ramus. It covers the dorsal edge and upper-half of outer surface of articular. It also bears a pair of mandibular foramina for mandibular nerves.

Coronoid. Coronary or coronoid is a small, somewhat conical bone, forming the dorsal side of the middle part of ramus. Just behind the last tooth, the coronoid gives off a prominent upward and slightly backwardly directed coronoid process.

Splenial. It is an irregular, flat and membranous bone, lodged in a groove on the inner side of dentary.

Dentary. It is the largest bone of ramus, forming nearly its anterior half portion. It is elongated with a blunt anterior end which is united suturally with the fellow of opposite side. Dorsal edge of dentary bears a row of 8-10 small,

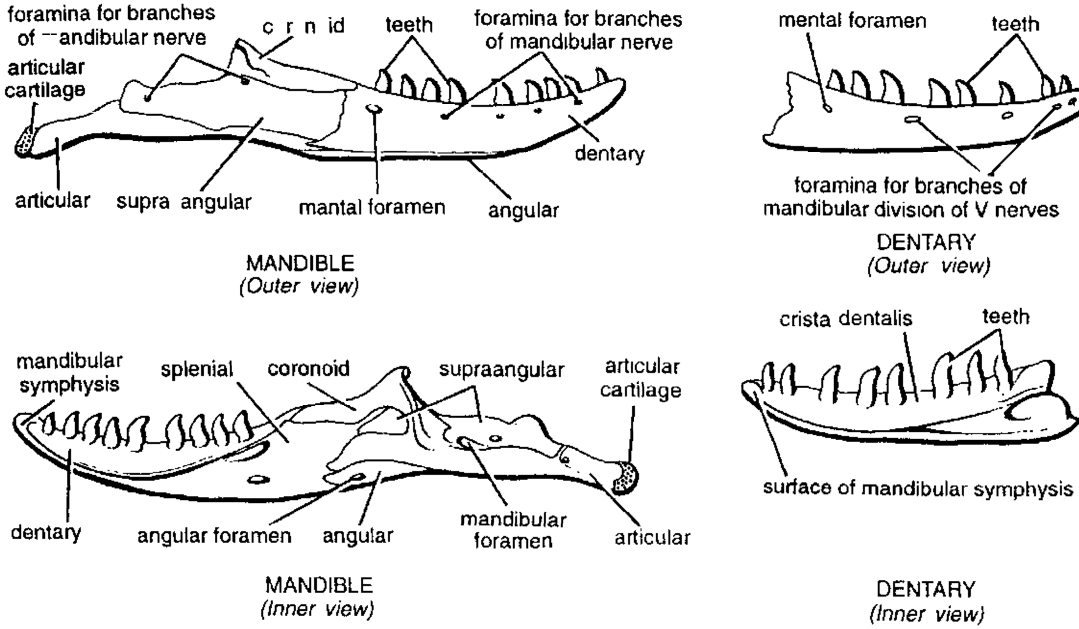

Fig. 5. *Varanus*. Bones of mandible.

conical and pleurodont mandibular teeth. Outer surface also bears several foramina for the branches of mandibular nerve.

4. Hyoid apparatus. Hyoid apparatus lies buried in the floor of mouth. It is a cartilaginous structure which also supports the tongue. The hyoid apparatus consists of body proper and two pairs of cornua arising from it.

Bashihyal. It is the body proper of hyoid apparatus. It is in the form of an elongated, median and cartilaginous rod, tapering anteriorly into the *process lingualis* or *os entoglossus*.

Anterior cornua. A pair of anterior cornua are derived from hyoidean arch during development. These are elongated, cartilaginous rods running upwards, curving round the gullet and terminating on the ventral surface of auditory capsule of their side. Each cornua is two-segmented and flattened at its free end. The two segments or limbs are joined together by a ligamentous sheet.

Posterior cornua. A pair of posterior cornua arise posteriorly from the basihyal and run backwards. These are also cartilaginous, two segmented and derived from branchial arches.

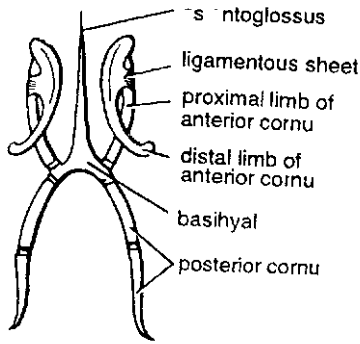

Fig. 6. *Varanus*. Hyoid apparatus.

Vertebral Column

Vertebral column is completely ossified and consists of a large and variable number of vertebrae. The number of vertebrae ranges from 83-85. Characteristic feature of constituent vertebrae are – epiphyses are absent and centra are strongly procoelous. Vertebral column is clearly distinguished into cervical, thoraco-lumbar, sacral and caudal regions having 8,22,2 and 51-53 vertebrae respectively. Thoracic vertebrae bear ribs.

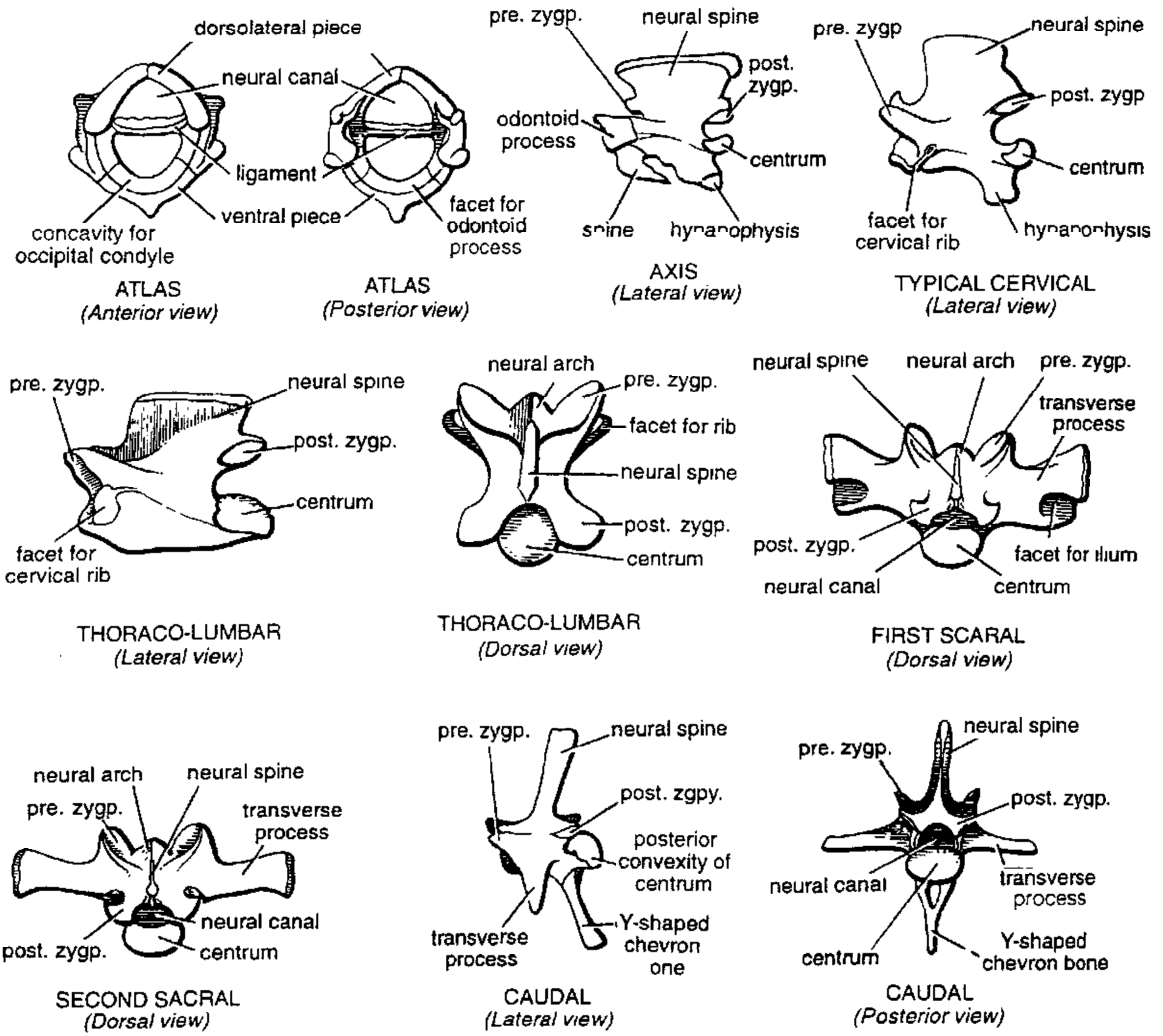

Fig. 7. *Varanus*. Vertebrae.

1. Atlas. First cervical vertebra or atlas is greatly modified to articulate with skull. It is small, ring-like in form and has no distinct centrum. It consists of three distinct bony pieces, a small ventral and two dorso-lateral, surrounding the neural canal. Two dorso-lateral pieces do not actually fuse mid-dorsally but remain separated by a space filled by membrane. In live condition a transverse ligament divides the neural canal into a dorsal and a ventral portion. Ventral piece occupies the place of centrum. Anteriorly, it bears an articular facet to receive the single occipital condyle of skull. Posteriorly also it bears an articular facet for the odontoid process of axis vertebra. A small spine projects downward from the ventral piece. Zygapophyses are altogether absent.

2. Axis. Second cervical vertebra is also termed axis. It is slightly bigger than a typical cervical. Its neural spine is large forming a vertical crest or ridge. Prezygapophyses are rudimentary, represented by mere notches, but postzygapophyses are normally developed. From anterior face of centrum projects a conical *odontoid process*, which represents a part of centrum of atlas. This process is not actually fused with, though firmly fixed to the centrum of axis. Below the odontoid process, the centrum carries a characteristic posteriorly directed spine-like *process*, representing the intercentrum or hypapophysis of atlas vertebra. A distinct hypapophysis is also present below the posterior end of centrum.

3. Typical cervical. There are 8 cervical vertebrae in *Varanus*. A typical cervical vertebra has a stout and elongated centrum which is strongly procoelous, i.e., the anterior face is concave and the posterior convex. Its neural spine is prominent, crest-like. Neural arch bears anteriorly a pair of well-formed articular facets or prezygapophyses which are directed upwards. Posteriorly also it bears a pair of postzygapophyses which are directed downwards. Ventrally, the posterior region of centrum carries a backwardly directed hypapophysis. Each cervical vertebra, behind the third, bears laterally articular facets for cervical ribs.

4. Thoraco-lumbar. There are 22 thoracolumbar vertebrae. They are slightly bigger than cervical. In structure they are similar in essential respects to the cervical, having strongly procoelous centrum and well-formed pre-and postzygapophyses. But, unlike cervical, they lack the hypapophysis and each bears on either side, at the junction of neural arch and centrum, a prominent capitular facet for articulation with a thoracic rib.

5. Anterior or first sacral. Sacral vertebrae are two in number and strongly built as they provide support to the pelvic girdle. Anterior sacral vertebra is stouter in build. Its centrum is short and conspicuously procoelous. Pre- and postzygapophyses are strongly built. Neural spine is in the form of a low crest. Transverse processes are massive and much expanded at the tips which are also deeply notched to articulate with ilia bones of pelvic girdle. A hypapophysis is absent.

6. Posterior or second sacral. It is similar to first sacral vertebra in having a short but stout and strongly procoelous centrum, lower crest-like neural spine and strongly formed zygapophyses. But transverse processes, though enormous and expanded, are not notched at the free ends. In case of both sacral vertebrae, transverse processes are separately ossified, so that they may be regarded as sacral ribs.

7. Anterior caudal. Caudal vertebrae are numerous and become gradually reduced in size backwards. A typical anterior caudal vertebra is like the sacral, but it has a longer and procoelous centrum, slender transverse processes and longer neural spine. Zygapophyses are also of normal build. The most characteristic feature is the presence of a Y-shaped *chevron bone*, attached to the ventral surface of centrum, which bears a pair of small nodules for this purpose. Stem or median limb of chevron extends downwards and articulating with centrum, encloses a haemal canal for the passage of haemal artery and vein.

8. Posterior caudal. Posterior caudal verterbrae lack the chevron bones and become gradually smaller in size as we pass backwards. The various processes also get reduced so much so that, at the posterior end of tail, the whole vertebra is represented merely by a rod-like centrum.

Ribs

All the precaudal vertebrae, except the first three cervical, bear ribs. These are slender curved rods of bone or bone and cartilage. Ribs are *unicephalous*, that is, single-headed as their vertebral ends articulate only with capitular facets of corresponding vertebrae, there being no tubercular facets (Fig. 8).

1. Thoracic ribs. Thoracic ribs are relatively large. Each is differentiated into a dorsal bony *vertebral portion*, which articulates with the vertebra, and a ventral cartilaginous *sternal portion*. First three thoracic ribs are connected ventrally with sternum by their cartilaginous sternal parts. Remaining thoracic ribs do not reach sternum and their short sternal portions remain free at their ventral ends.

2. Cervical ribs. All the cervical vertebrae, except the first three, bear cervical ribs. These are relatively much shorter without cartilaginous parts and none of them is connected with sternum.

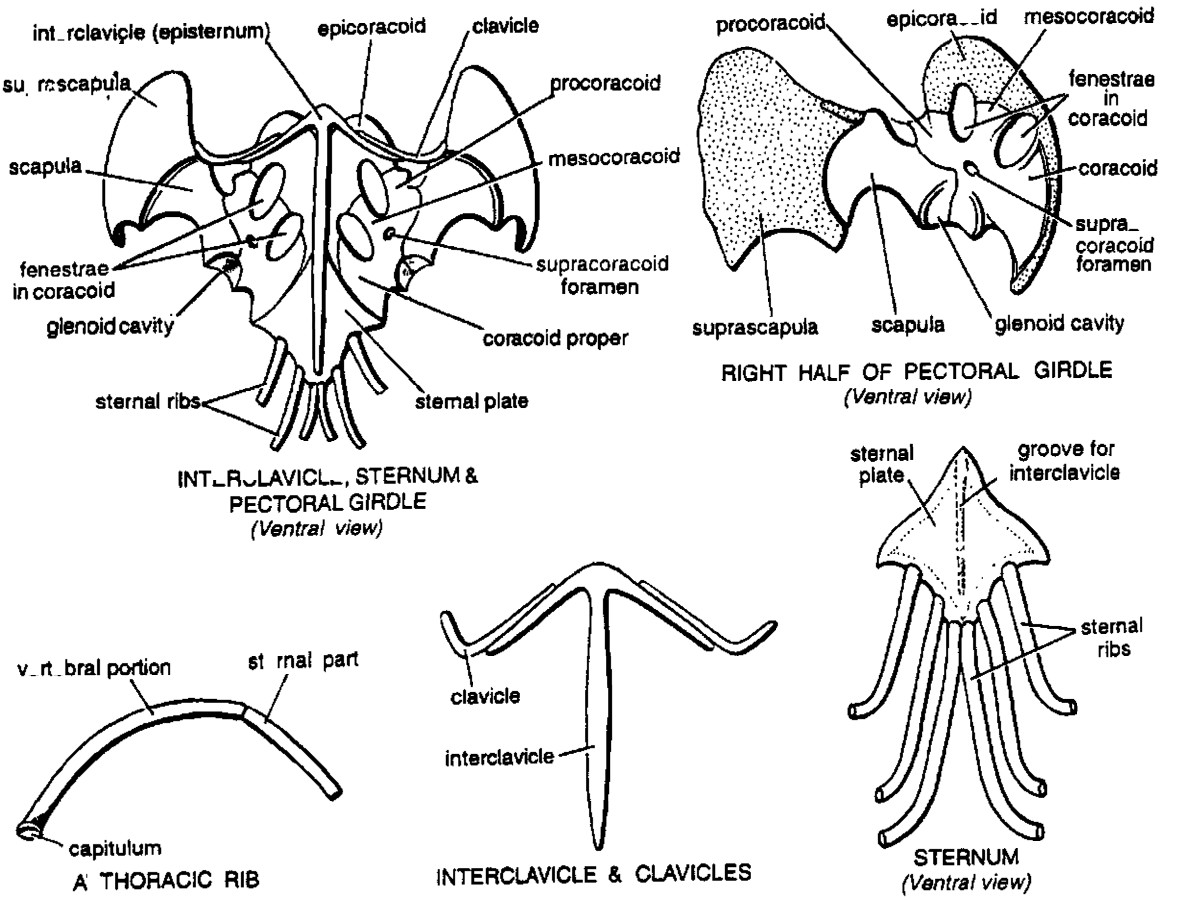

Fig. 8. *Varanus*. Thoracic rib, sternum and bones of pectoral girdle.

Sternum

Sternum of *Varanus* is in the form of a rhomboidal plate of calcified cartilage embedded in the ventral thoracic wall. Its antero-lateral borders articulate with coracoids and epicoracoids of pectoral girdle, while each postero-lateral border bears two small facets for sternal ribs. Posterior end of plate also bears two sternal ribs. Posterior elongate stem of a T-shaped cartilaginous interclavicle is applied to the mid-ventral surface of sternum, reaching nearly up to its posterior edge (Fig. 8).

Pectoral Girdle

Pectoral girdle of *Varanus* consists of two similar halves lying one on either side of the T-shaped interclavicle. Each half is made of the following typical bones :

1. Supra-scapula. It is a thin of flat plate of calcified cartilage. Proximally of ventrally it articulated with scapula, while its distal or dorsal border remains free and slightly curved inwards towards vertebral column.

2. Scapula. It is a well-ossified, unfenestrated and somewhat oblong flattened plate of bone, which is constricted in its middle, due to a prominent notch on its posterior face. Its dorsal or outer end articulating with supra-scapula is broader than its ventral or inner end which unites with coracoid. Lower end also forms the dorsal half of *glenoid cavity* posteriorly, and gives out a completely ossified process, the *mesoscapula*, anteriorly.

3. Coracoid. It is a large, flat but stout and fenestrated bone partly ossified and partly cartilaginous. Two large gaps or fenestrae divide the ossified part of coracoid into three distinct parts— a narrow anterior *procoracoid*, a narrow middle *mesocoracoid* and a broad posterior *coracoid proper*. The last named articulated with the antero-lateral border of sternum. Anterior and inner parts of coracoid remain cartilaginous forming an irregular-shaped *epicoracoid* lying over the fenestrae. Epicoracoids of two sides medially about against the median, posterior stem of inter-clavicle. Ventrally, the coracoid articulates with sternum.

4. Interclavicle. *Interclavicle* or *episternum* is a T-shaped or anchor-shaped, investing or dermal bone, placed longitudinally in between the two halves of pectoral girdle. The crosspiece of T or its lateral limbs are situated somewhat anterior to the scapulae. Posterior median longitudinal stem of T is closely applied to the mid-ventral surface of sternum, reaching up to its posterior end.

5. Clavicle. It is a small, narrow, flat and curved dermal bone lying attached to anterior side of lateral limb of interclavicle. Its outer end articulates with the junction of scapula and suprascapula, but inner end reaches short to meet the inner end of clavicle of other side, in middle line.

Pelvic Girdle

The pelvic girdle also consists of two similar halves or *ossa innominata*. Each os innominatum is a triradiate structure, each ray represented by a distinct bone. The three bones (ilium, pubis and ischium) are very hard and solid and joined with each other but not fused together. On the outer surface, at the point where the three bones meet, is a concave articular surface, the *acetabulum*, into which fits the head of femur. In the depression of acetabulum, the lines of union of the bones are clearly visible (Fig. 9).

1. Ilium. Ilium is a strong, compressed, rod-like bone, directed backwards and upwards to articulate with sacral vertebra. Ilium contributes to nearly one-third of acetabulum, in front of which it gives off from its outer side a small, knob-like preacetabular process.

2. Pubis. Pubis is a flattened, somewhat curved bone, passing downwards and forwards from the acetabulum to meet its fellow of the other side at a *pubic symphysis* along the

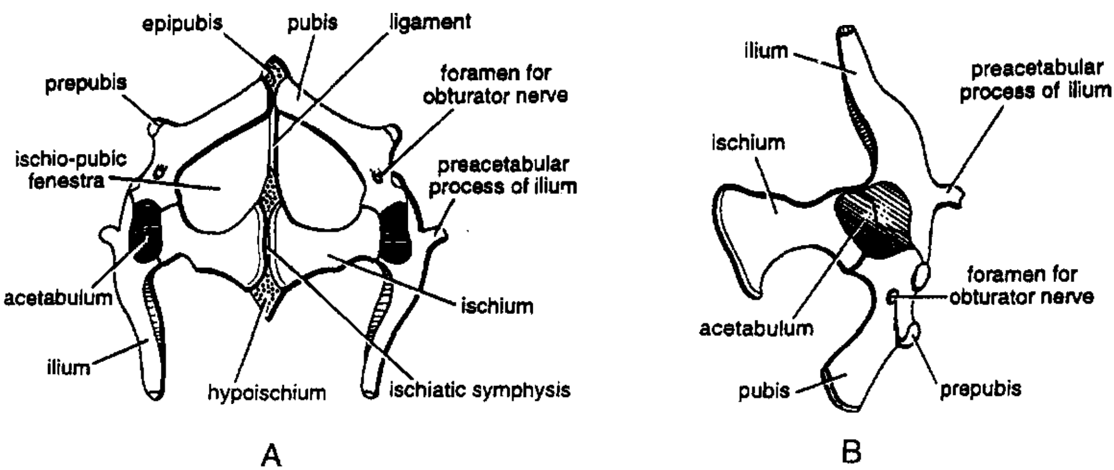

Fig. 9. *Varanus*. Pelvic girdle. A—Complete in ventral view. B—Left half in ventral view.

mid-ventral line. A small nodule of cartilage, the *epipubis*, is present in front of symphysis between the antérior ends of two pubis. Pubis also contributes to about one-third of acetabulum, near which it is performed by a small foramen which transmits the obturator by nerve. Just external to and slightly posterior to this foramen, pubis is produced into a small rod-like process, called *prepubis*, which is directed outward.

3. Ischium. It is a flat, somewhat oblong and curved bone, running medially from acetabulum to meet its fellow of other side at an *ischiatic symphysis*. A small rhomboidal or rod-like piece of calcified cartilage, called *hypoischium*, or *os* [illegible], [illegible] backward from ischiatic symphysis and supports the ventral wall of cloaca.

A wide space is enclosed between pubes and ischia, which is divided by a median ligament into two lateral *ischio-pubic fenestrae*. The median ligament extends between the two symphyses and is often lost in a dried girdle.

Forelimb Bones

1. Humerus. Upper arm contains a single bone called *humerus*. It is made of an elongated shaft with greatly expanded extremities covered by epiphyses of calcified cartilage. Proximal end bears a rounded *head*, which fits into the glenoid cavity of pectoral girdle. A *bicipital fossa* is enclosed between head and a *medial process* of proximal end. Below head is present a prominent crest-like *deltoid ridge*. Distal end of humerus bears a pulley-like structure, the *trochlea*, made of two articular surfaces, or epicondyles, one for radius and other for ulna (Fig. 10).

2. Radius and Ulna. Forearm contains two bones, radius and ulna. *Radius* is slender and composed of a shaft and two epiphyses. Distal end of radius bears a concave articular facet for carpus, and a preaxial styloid process.

Ulna is stouter than radius. Proximally it is produced into an upwardly directed *olecranon process*, while distally it bears a convex articular surface for carpus.

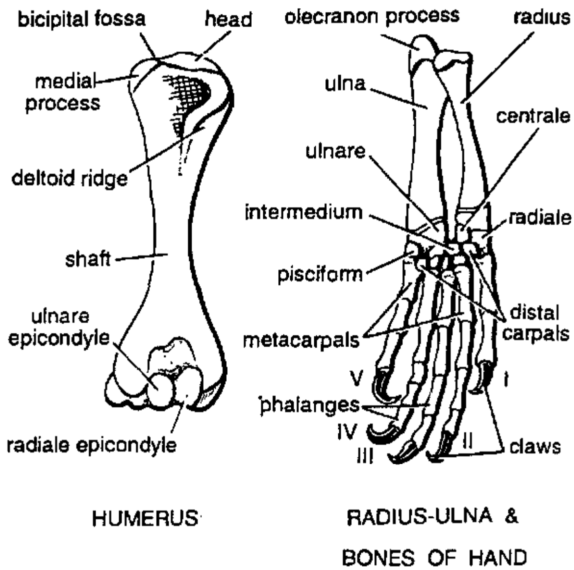

Fig. 10. *Varanus*. Fore limb bones.

3. Bones of forefoot. Wrist or *carpus* contains 10 small bony pieces or *carpals*. These are rounded, polyhedral in shape and arranged in two rows. Proximal row contains 3 carpals— *radiale*, *ulnare* and *intermedium*. Distal row has 5 carpals. A centrale lies in between the two rows, while a pisciform is attached to the distal epiphysis of ulna on its postaxial side.

The manus is supported by five elongated *metacarpals* and bears five digits composed of 2, 3, 4, 5 and 3 *phalanges*, respectively. Terminal phalanx bears a horny claw.

Hind limb Bones

1. Femur. Thigh contains a single stout bone, the *femur.* It has an elongate shaft and two epiphyses. Proximal end bears a rounded *head* which fits into acetabulum. Besides, it shows a prominence on preaxial side, called *lesser trochanter*, and a minor prominence on postaxial side, called *greater trochanter*. Distal end of femur is pulley-shaped, composed of two condyles and a tuberosity, for articulation with tibia and fibula (Fig. 11).

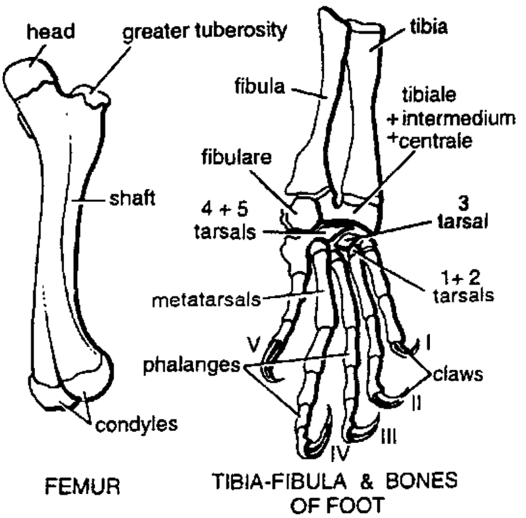

Fig. 11. *Varanus*. Hind limb bones.

2. Tibia and fibula. Shank or crus conta'ns two bones, tibia and fibul.. *Tibia* i. ... p...xi.l side. It is a stout and somewhat curved bone. Its proximal end bears two concave facets for distal condyles of femur. Proximal end also carries, on its anterior or dorsal surface, a longitudinal ridge, called *cnemial crest*. *Fibula* is comparatively slen'er an' proximally articulates with distal tuberosity of femur. Distally, both tibia and fibula articulate with tarsus.

3. Bones of hind foot. Tarsus contains five *tarsal* bones, wo in proximal row an' three in distal row. Pes of foot is supported by five elongated *metatarsals*, each carrying a toe. Number of phalanges in five toes is 2, 3, 4, 5, and 3 respectively. Terminal phalanx bears a horny claw in each toe.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the skull of *Varanus* mentioning the investing and replacing bones.
2. Give an illustrated account of pectoral girdle, sternum and pelvic girdle of *Varanus*.
3. Describe the vertebral column of *Varanus*.

» *Multiple Choice Questions*

1. Nerves passing through exoccipital in *Varanus* :
(a) X, XI, XII (b) IX, X, XI
(c) XI, XII, XIII (d) XII, XIII, XIV
2. Outer margins of post-temporal fossae in *Varanus* is formed by :
(a) Quadrate (b) Supratemporal processes of parietals
(c) Squamosal (d) Alisphenoid
3. Frontals are separated from parietals by :
(a) Frontal sutures
(b) Supratemporal processes
(c) Coronal suture
(d) Parietal foramen
4. Olfactory capsule in *Varanus* is formed by :
(a) Nasals (b) Vomer
(c) Nasal and orbits (d) Nasal and vomers
5. Lachrymal duct passes through :
(a) Lachrymal (b) Prefrontal
(c) Orbits (d) Supraorbital
6. Collumella crani is better known as :
(a) Collumella auris (b) Epiterygoid
(c) Pterygoid (d) Palatine
7. Largest bone of lower jaw in *Varanus* :
(a) Supra angular (b) Coronoid
(c) Dentary (d) Splenial
8. First cervical vertebra :
(a) Axis (b) Typical cervical
(c) Thoraco-lumbar (d) Atlas
9. Typical cervical vertebrae :
(a) Procoelus (b) Acoelus
(c) Opisthocoelus (d) Amphicoelus
10. Cheveron bone is attached to the ventral surface of the centrum of :
(a) Posterior caudal vertebra
(b) Anterior caudal vertebra
(c) First sacral vertebra
(d) Second sacral vertebra

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b).

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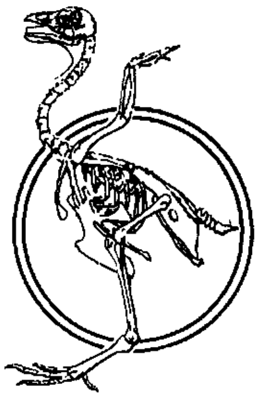


Endoskeleton of Fowl

Endoskeleton of birds is fully ossified and lightly built on the 'hollow girder principle', with greater strength and surface for its weight. The larger bones are often pneumatic and without marrow. The endoskeleton of fowl is being described here because of its larger size which is more convenient for study than that of the pigeon.

As usual, the axial skeleton includes *skull*, *vertebral column*, *sternum* and *ribs*, while the appendicular skeleton includes *girdles* and *limb bones* (Fig. 1).

Characteristic Features of Skull

Skull is the skeletal framework supporting the head. In a bird, it is distinguished by several characteristic features :

(1) It is extremely *light* in weight due to pneumatic bones.
(2) Number of bones is reduced.
(3) *Sutures* disappear in skull of adult as most of the bones become firmly fused together.
(4) A toothless (edentulus) *beak* is formed by the jaw bones.
(5) It is *monocondylic*, having a single occipital condyle.
(6) *Cranium* is large and rounded to accommodate the well-developed brain.
(7) It is *tropibasic*, i.e., cranium does not extend forward into orbital region.
(8) Two *orbits* are greatly enlarged to accommodate relatively larger eyes and separated by only a very thin membranous inter-orbital septum.
(9) *Foraman magnum* faces downwards.
(10) Jaw suspensorium is *autostylic*.
(11) In fowl, skull palate is *schizognathous* i.e. with short vomers allowing the palatines to meet.

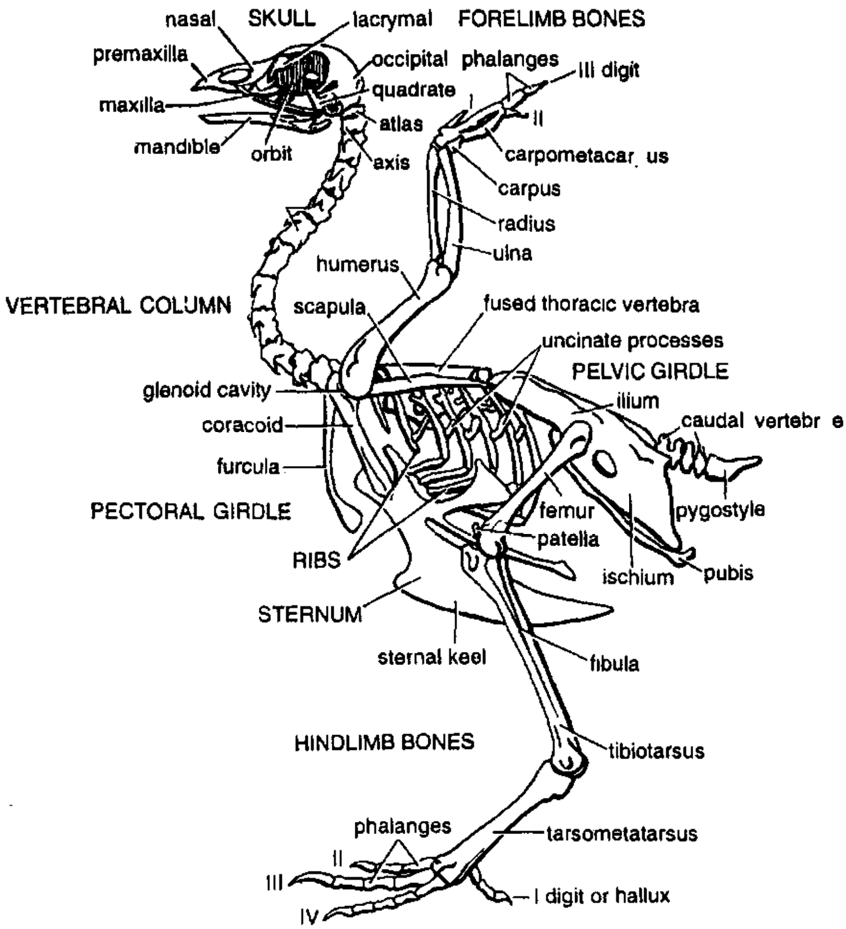


Fig. 1. Fowl. Complete skeleton in lateral view.

Regions of Skull

The skull of fowl broadly consists of three parts : *cranium*, *sense capsules* and *visceral skeleton*, which includes upper and lower jaw and hyoid apparatus (Figs. 2 & 3).

[I] Cranium or brain case

It houses the brain and forms the posterior, median, hollow and conical box-like part of skull. It is further divisible into three regions or segments : *occipital*, *parietal* and *frontal*.

1. Occipital segment. It is the hind part of cranium. It is formed by the usual bones, *basioccipital* (base), two *exoccipitals* (lateral sides), and *supraoccipital* (top), all of which enclose a large rounded opening, the *foramen magnum*. Spinal cord passes through this foramen to join the brain. Immediately below the foramen is a single, rounded *occipital condyle*, mostly formed by the basioccipital. Where supraoccipital joins the parietal, a prominent semi-circular ridge of bone, the *lambdoidal crest* is present.

2. Parietal segment. It lies in front of occipital region. Its roof is formed by two fused *parietals*, which are squarish in outline. Lateral sides of parietal region are formed by *squamosals* and *alisphenoids*, and floor by a large *basisphenoid*. Ventrally, the basisphenoid is covered over by a broad membrane bone, the *basitemporal*. Basisphenoid is continued forwards,

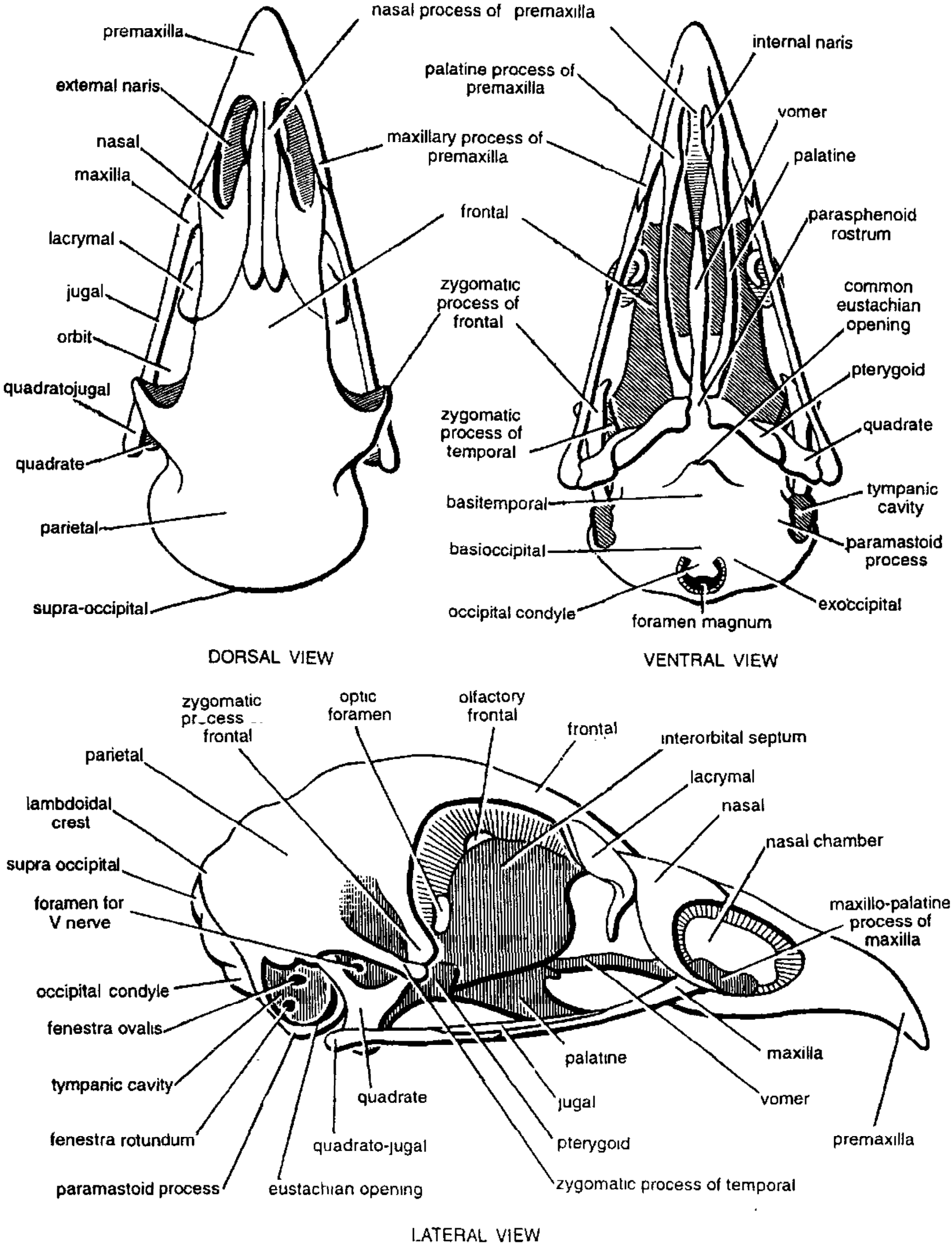


Fig. 2. Fowl. Skull in dorsal, ventral and lateral views.

as in lizards, by a slender *parasphenoid rostrum*. Each squamosal is produced outwards into a zygomatic process.

3. Frontal segment. It is the anteriormost segment of cranium, lying in front of parietal region. Roof of frontal region consists of a pair of large *frontal* bones. Lateral posterior end of each frontal is drawn out into a strong *zygomatic* or *post-orbital process*, which joins the zygomatic process of squamosal. Alisphenoids are continued forward into *orbito-sphenoids*, forming the sides of frontal region, while its base is formed by a poorly-developed *presphenoid*, lying above the parasphenoid rostrum.

[II] Sense capsules

Sense capsules remain closely attached with the cranium. They lodge and protect the organs of special senses. Three pairs of sense capsules occur enclosing the organs of hearing (*auditory*), sight (*optic*) and smell (*olfactory*).

1. Auditory capsules. A pair of auditory capsules, enclosing the organs of hearing or internal ears, are attached one on either lateral side of the occipital region of skull. Each capsule is mainly formed by *prootic* bone. A large cup-like *tympanic cavity* of middle ear is present on each postero-lateral side of skull bounded by squamosal above and basitemporal below. Tympanic cavity contains a *tympanic membrane*, attached just within its prominent outer edge, and an ear ossicle, the *columella*, which is made of bone and cartilage. Its inner part is in the form of a slender rod-like bone, called *columella auris*. Its outer part is in the form of a triradiate cartilage, called *extra columella*. The three rays of extra columella are the *supra-stapedial*, *extra-stapedial* and *infra-stapedial*. Inner end of columella auris, or *stapes*, fits into *fenestra ovalis*, while outer end of extra columella touches the tympanic membrane. Inside the tympanic cavity there are several openings. Two openings are present above the middle (pre-equatorially). The upper one, *fenestra ovalis* and lower one is *fenestra rotunda*. The inner end of collumella fits into the former. Tympanic cavity communicates with mouth through a *eustachian canal*. Eustachian canal runs forwards and inwards between basitemporal and basisphenoid, and joins with its fellow of opposite side to open by a common median aperture in the roof of posterior part of mouth cavity.

2. Optic capsules or orbits. Orbits are very large to accommodate the relatively massive eyes. They are separated from one another by a narrow, longitudinal, vertical partition, the *inter-orbital septum*, which is mainly formed by *mesethmoid* together with *presphenoid*, *parasphenoid rostrum* and *orbitoshenoids*. Each orbit is bounded anteriorly by frontal and posteriorly by post-orbital process of frontal and alisphenoid. Ventrally the orbit is incomplete. Inter-orbital septum is perforated by many openings. *Foramen of olfactory nerve*, lies in front of cranium between septum and frontal bone. A large median *optic foramen* lies in the posterior part of orbit. It actually perforates orbitosphenoid bone and communicates the two orbits with one another as well as with cranium. Small openings by which 3rd and 4th crarnial nerves leave cranium, are immediately lateral to optic foramen, frequently blending with it.

A large *lacrymal* bone forms the anterior boundary of each orbit. In fowl, it bears a characteristic foramen and is produced below into a curved pointed process.

3. Olfactory capsules. Olfactory capsules or nasal sacs are cartilaginous and greatly reduced in size in accordance with the poor sense of smell. They lie in front of cranium, close together. *Internasal septum* is a cartilaginous continuation of inter-orbital septum. *Ectoethmoids* or turbinals are comparatively poorly developed.

Three bones are associated with olfactory capsules. Two *nasal* bones cover the roof and sides of nasal chambers. They remain separated from each other by the ascending or dorsal nasal processes of premaxillae. Each nasal is a thin plate-like bone and rather Y-shaped bone giving off three processes. Single posterior process meets frontal and also articulates with lacrymal. Two anterior processes, superior and inferior, with a deep notch in between, form the posterior boundary of external nare and unite with processes of premaxillae.

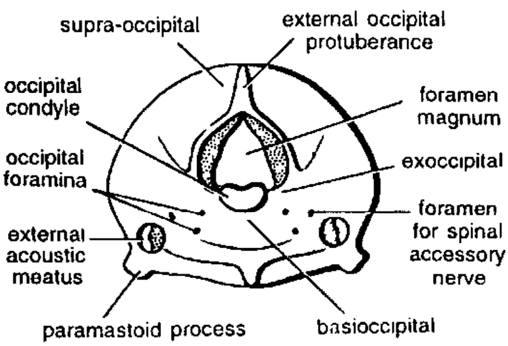
Two *vomers* fuse into a small, slender, median bone, lying in continuation of parasphenoid rostrum at the base of nasal chambers. Vomers are absent in pigeon.

[III] Visceral skeleton

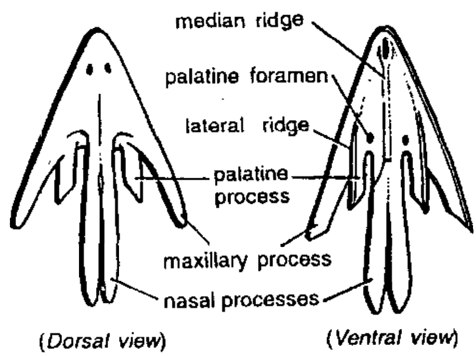
It includes *upper* and *lower jaws* and *hyoid apparatus*. Jaws are toothless and form borders of mouth, whereas hyoid apparatus provides support to the tongue.

1. Upper jaw or maxillo-palatine apparatus. Upper jaw or maxillo-palatine apparatus on each side forms two bony arches or *arcades* outer and inner. They remain widely separated but become united anteriorly and meet together posteriorly. *Outer arcade*, forming the border of mouth, is also termed *infra-orbital arcade* or *sub-orbital bar*. It consists of four bones : *premaxilla, maxilla, jugal* and *uadrato-jugal*. *Inner arcade*, forming the roof of buccopharyngeal cavity, is also termed *palato-pterygoquadrate bar*. It consists of three bones : *palatine, pterygoid*, and *quadrate*.

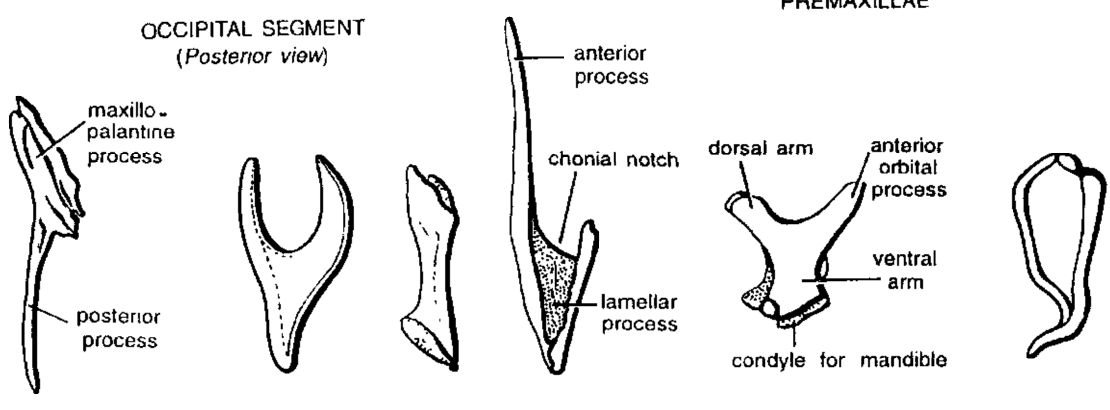
Premaxillae. Premaxilla is the anterior-most bone of outer arcade of upper jaw. It is completely fused with the fellow of opposite side forming a large, stout, triradiate and compound bony mass. It is produced backwards into three pairs of processes : *nasal, maxillary* and *palatine*. The large slender, ascending or *nasal processes* run behind in close proximity, along the inner sides of nasal bones to join the mesethmoid and frontals and complete the upper boundaries of external nares. Outer or *maxillary processes* are shorter than nasal processes and run backwards and outwards to form the anterior part of upper jaws. Inner or *palatine processes* are the smallest. They run behind somewhat horizontally to meet the palatines. They form the anterior part of palate, i.e., roof of buccal cavity.



OCCIPITAL SEGMENT
(*Posterior view*)



PREMAXILLAE



MAXILLA NASAL PTERYGOID PALATINE QUADRATE LACRYMAL

Fig. 3 Fowl. Loose skull bones.

Maxilla. It is a slender rod-like bone. Its anterior end articulates with maxillary process of premaxilla and is produced inward into a thin spongy horizontal lamina, the *maxillo-palatine process*. It does not meet with its partner of opposite side in middle line so that the bony palate remains incomplete with a median cleft. Posterior zygomatic process of maxilla forms the anterior half of outer arcade.

Jugal. It is a very slender rod. It forms the middle upper border of sub-orbital bar, lying dorsally upon the other two components-maxilla and quadrato-jugal.

Quadrato-jugal. It is also a slender, rod-like bone forming the posterior half of outer arcade. Its hind end is thickened and articulates medially with quadrate.

Quadrate. Quadrate is a stout, triradiate or Y-shaped bone, lying just in front of tympanic cavity, and forming the *suspensorium* with the squamosal bone of skull. Its *dorsal arm* movably articulates with squamosal between the base of its zygomatic process and tympanic cavity. Its *ventral arm* forms a *condyle* for articulation with mandible. Condyle also articulates on the outer side with quadrato-jugal and on the inner side with pterygoid. Its *anterior arm* or *orbital process* runs anteriorly parallel to and above the pterygoid and terminates freely.

Pterygoid. It is a short but stout and rod-shaped bone. It is set somewhat obliquely forming the posterior roof of mouth cavity. Each pterygoid contributes to the middle portion of inner arcade of upper jaw. It articulates behind with inner surface of ventral arm of quadrate, while in front with palatine and parasphenoid rostrum along which it can slide.

Palatine. It is a slender, bony rod which forms most of the anterior portion of inner arcade of upper jaw. Anteriorly it unites with processes of premaxilla and maxilla, while posteriorly it movably articulates with pterygoid. Posterior end also extends inwards into a broad lamellar process which articulates with parasphenoid rostrum on its inner side.

2. Lower jaw or mandible. Lower jaw appears to be a single V-shaped bone, but it is really composed of a pair of long curved and laterally compressed halves or *rami*, firmly united anteriorly and articulating with the quadrates posteriorly. Each ramus is made of five bones : a replacing bone or *articular* and four investing bones-*angular, supra-angular, splenial* and *dentary*-developing around an original cartilaginous bar, the *Meckel's cartilage*. Bones have the same general relations as in lizard, but they are intimately fused together in the adult (Fig. 4).

Articular forms the expanded posterior end of each ramus and is continuous in front with the Meckel's cartilage. It dorsally bears a somewhat concave articular surface, the *mandibular condyle*, for the quadrate, and is produced backwards and inwards into processes. The slender *angular* lies beneath the articular and along the lower and inner borders in posterior third of ramus. *Supra-angular*, bearing a small *coronoid process*, forms the upper border of posterior third of the ramus. *Splenial* is a thin splint-like bone lying along the inner surface in the middle part of mandible. *Dentary* is a large bone, forming the anterior half of ramus. In front it fuses firmly with its fellow of the opposite side at a *symphysis*.

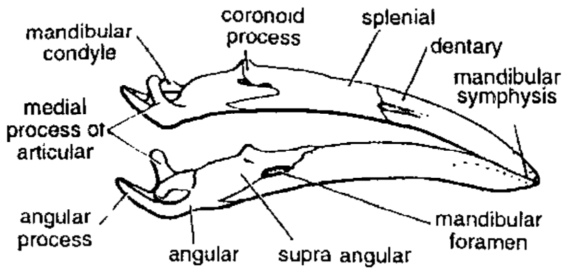


Fig. 4. Fowl. Mandible (complete).

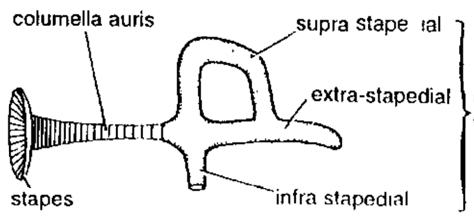


Fig. 5. Fowl. Columella auris

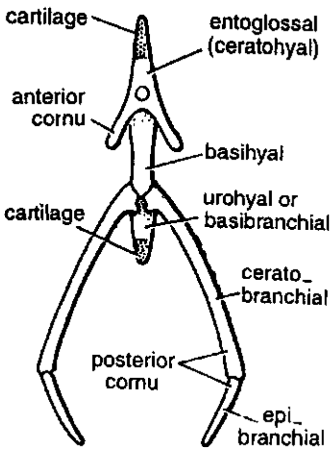


Fig. 6. Fowl. Hyoid apparatus.

Posteriorly, it extends between angular and supra-angular bones up to the articular. It does not bear teeth in birds. A *mandibular foramen* is present between dentary and more posterior bones.

3. Hyoid apparatus. Hyoid apparatus is a framework of bones and cartilages, lying embedded in the floor of mouth and supporting the tongue. Median, arrow-shaped body consists of three bones, an anterior *entoglossal* or *ceratohyal* bearing a cartilaginous process in front, a median bony *basihyal* and a posterior *urohyal* or *basibranchial* having a cartilage behind. Three bones and cartilages are placed end to end. A pair of short *anterior cornua* (singular *cornu*) projects backwards from the entoglossal, representing the free ends of ceratohyals. A pair of long and backwardly directed *posterior cornua* or *thyrohyals* arises from the junction of basihyal and urohyal. Each posterior cornu is made of two rod-like segments, representing the *ceratobranchial* and *epibranchial*, connected by cartilage (Fig. 6).

Vertebral Column

Vertebral column of a bird has many peculiarities. Neck is long and mobile resulting in an increase in the number of cervical vertebrae. Thoracic, lumbar and abdominal region are firmly united to afford rigidity which is of advantage in flight. Tail is short and caudal vertebrae fused to form the pygostyle which supports the large tail feathers. Epiphyses are lacking. Ends of the centra of verterbrae are heterocoelous or saddle-shaped.

Vertebral column of fowl is differentiated into *cervical, thoracic, synsacral* and *caudal* regions.

[I] Cervical vertebrae

Due to long neck, the cervical region is also long and forms nearly the anterior half of vertebral column. It consists of 14 to 16 cervical vertebrae. Special structure and articulation of cervical vertebrae allows greater freedom of movement of the long neck and head.

1. Atlas vertebrae. *First cervical vertebra* or *atlas* is small, ring-like or roughly triangular. Its apex is directed downwards and dorso-lateral surface is convex and smooth. It is characterized by the absence of centrum (greatly reduced) neural spine, ribs, transverse processes, vertebrarterial foramina, and prezygapohyses. It consists of *three elements*, a single *ventral* and two *dorso-lateral*, joining mid-dorsally to form the *neural arch.* Thick ventral portion anteriorly bears a deep cup-like cavity to receive the single occipital condyle of skull, and is *notched* above to receive the *odontoid process* of axis. In live, neural canal is divided by a thin transverse ligament into an upper *spinal canal*, through which spinal cord passes, and a lower *odontoid canal* for the odontoid process of axis. Neural arch posteriorly bears small *post-zygapophyses* for articulation with the prezygapophyses of axis.

2. Axis vertebra. *Axis* or *epistropheus* is the *second cervical vertebra*, slightly bigger than the atlas. It has no transverse processes, no *vertebrarterial canals* and no ribs, but bears a blunt *neural spine* and *pre-*and *postzygapophyses.* Centrum is produced in front into a slender peg-like process, the *odontoid process*, which is really the detached centrum of atlas, but fused with the centrum of axis. Axis forms the pivot on which atlas and head can be turned.

3. Typical cervical. A typical cervical, any one from 6th to 10th, has a long body or *centrum*, a short *neural arch* and a rudimentary *neural spine*. Ends of centrum are *heterocoelous* bearing *saddle-shaped* articular surfaces. Anterior end is

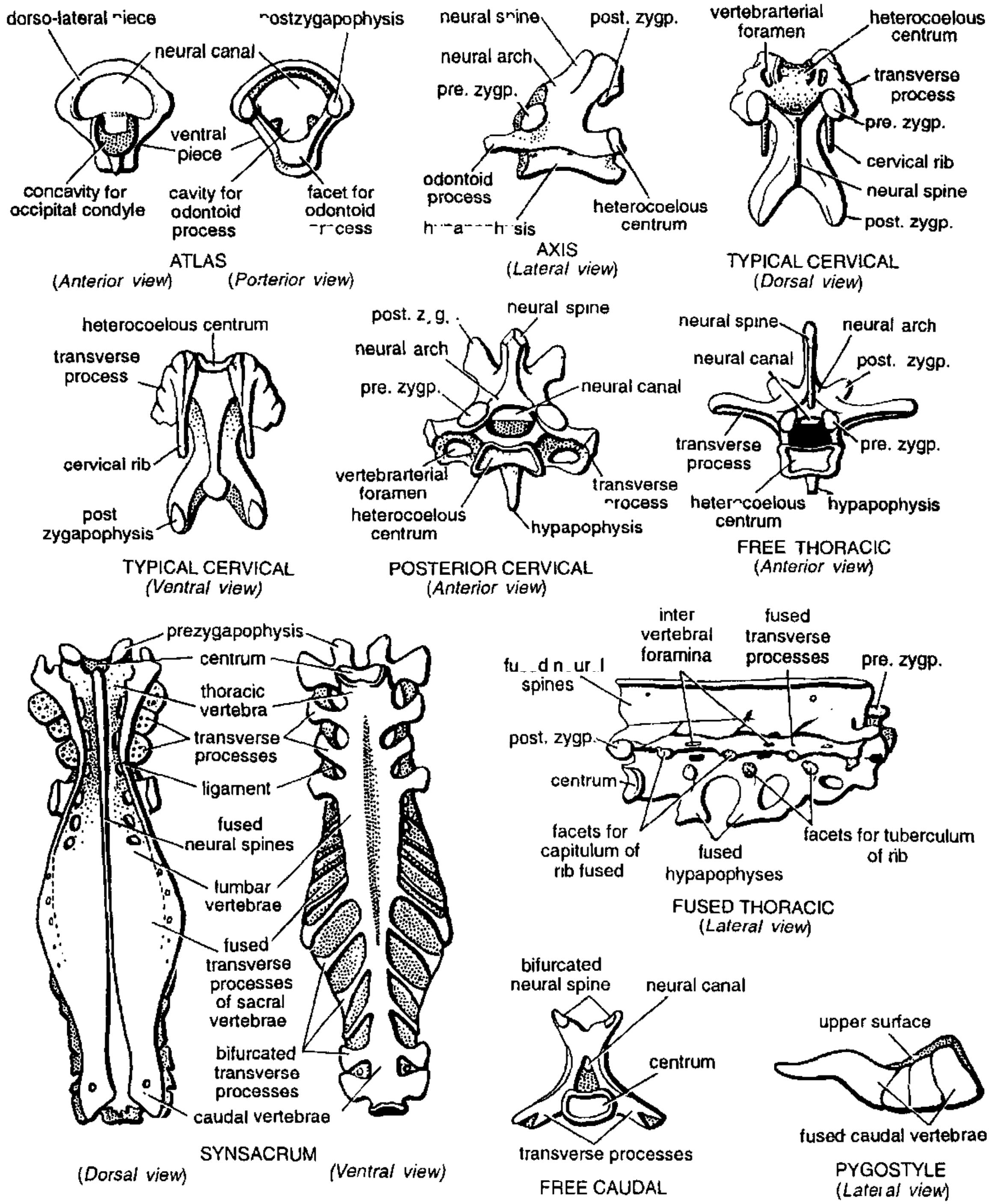


Fig. 7. Fowl. Vertebrae.

convex dorso-ventrally but concave laterally. This condition is reversed at the posterior end. Short and irregular *transverse processes* arise laterally at the anterior end. Each process is fused with a backwardly directed, thin spicular projection, the rudimentary *cervical rib.* Base of each cervical rib is perforated by a characteristic *vertebrarterial foramen*, through which passes the vertebral artery. *Prezygapophyses*, lying anteriorly upon the transverse processes, are flat, oval articular facets, facing upwards and inwards. *Postzygapophyses* or posterior articular facets, projecting backwards, from the hind margin of neural arch, face downwards and outwards. They articulate with the prezygapophyses of the adjacent posterior vertebra.

4. Posterior cervical. Posterior cervical vertebrae, i.e., behind the 10th vertebra, become shorter and more massive. Their centrum bears a ventral spine-like process, called *hypapophysis.* Neural spine is distinct. Last one or two cervical vertebrae bear large, movably articulated and double-headed ribs.

[II] Thoracic vertebrae

Thoracic vertebrae are 7 in number. They are shorter than the cervical vertebrae. 2nd to 5th vertebrae remain free, while the 7th vertebra fuses with synsacrum.

1. Free thoracic vertebra. A free thoracic vertebra (1st or 6th) is slightly smaller than a typical cervical. It has a saddle-shaped centrum, bearing a vertebral process, the *hypapophysis*, for the attachment of flexor muscles of neck. Its neural spine is elongated and pre- and post-zygapophyses are well developed. A pair of double-headed thoracic ribs are carried by each vertebra, the transverse processes and centrum of which bear facets for attachment of the tuberculum and capitulum of rib.

2. Fused thoracic vertebrae. 2nd to 5th thoracic vertebrae are fused together in such a way that their neural spines, transverse processes and hypapophyses become confluent to form prominent plate-like ridges pierced by intervertebral gaps. Fused centra and transverse processes bear on either side facets for articulation with capitula and tubercula of thoracic ribs.

[III] Synsacrum

Thoracic region of vertebral column is followed by a composite bone, called *synsacrum*, which gives support to ilia bones of immense pelvic girdle. It consists of about 16 fused vertebrae of different regions.

Anteriormost vertebra of synsacrum is the last *thoracic vertebra* bearing a pair of free thoracic ribs. It lacks a hypapophysis. Last thoracic and about half a dozen *lumbar vertebrae* are firmly fused together. Their neural spines form a continuous vertical ridge which is fused along its edge with the dorsal margins of ilia. Hypapophyses are lacking. Transverse processes are free and very stout and about against the ilia. Lumber vertebrae are followed by two *sacral vertebrae*, but no distinction can be made between them. Their transverse processes are fused to form bony plates which about against the outer margins of ilia. Sacral ribs are fused with their transverse processes. Remaining seven vertebrae of synsacrum belong to *caudal region.* Their transverse processes, except in the last, are bifurcated into dorsal and ventral processes. Dorsal processes unite to form bony plates continuous with those of vertebrae in front. Free ventral processes represent the ribs, they are rod-like in the first 4 or 5 vertebrae but are smaller in the rest. On either side between the bodies of sacral and caudal vertebrae of ilia are deep hollows in which are embedded the lobes of kidneys.

[IV] Caudal vertebrae

Caudal region is short and includes a few free vertebrae and a pygostyle.

1. Free caudal. Synsacrum is followed by 4 or 5 small free caudal vertebrae of the short tail region. These are rudimentary, with a centrum, transverse processes and bifid neural spines. Free caudal vertebrae make possible the movements of tail and tail feathers.

2. Pygostyle. Last caudal vertebra is called the *pygostyle*. It is actually formed by the fusion of four or more hindermost caudal vertebrae, which are distinct in the embryo. It is a large

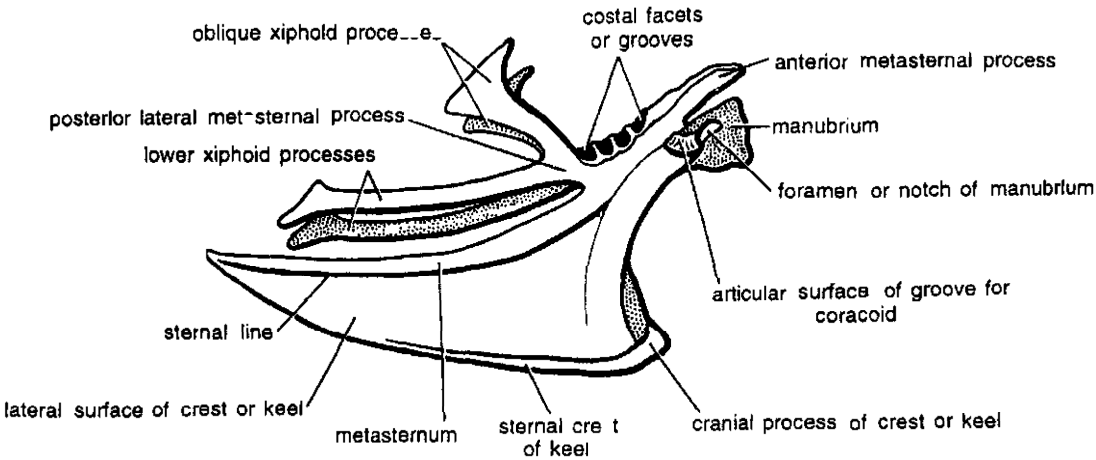


Fig. 8. Fowl. Sternum in lateral view.

vertical ploughshare-like bone, laterally compressed with a straight dorsal border and a convex ventral border. Pygostyle provides attachment to caudal muscles and supports the large tail feathers.

Sternum

The sternum, or *breast bone*, is a broad, flat, unsegmented, irregular or boat-shaped bone, located in the ventral thoracic region. It is one of the most characteristic parts of endoskeleton of birds. Its various components are as follows :

1. Metasternum. It is the body proper or mid-posterior process in the form of a broad plate of bone, which is concave dorsally and convex ventrally. It is broader at the anterior and posterior ends while narrower in the middle. Upper concave surface is perforated by apertures through which air sacs communicate with its cavity.

2. Keel. Ventral convex surface of metasternum is produced mid-ventrally into a median sagittal, triangular ridge, called *sternal crest, carina* or *keel*. It is deepest anteriorly but gradually lowers posteriorly. Its anterior concave border is slightly thicker and ventrally produced into a *cranial process*. It divides the ventral surface of body into two sagittal grooves for the attachment of the great pectoral muscles fused in flight.

3. Manubrium. Anteriorly, the ventral surface of metasternum projects into a small, vertical and plate-like process, the *presternum*, *manubrium* or *rostrum*. It is perforated basically by an aperture called the *notch* or *foramen of manubrium*.

4. Metasternal processes. Metasternum gives out from its anterior region, on either side, a large posterior and a small anterior metasternal process. Anterior metasternal processes are also termed the *costal processes*. Posterior processes are also termed the *metostea* or *xiphoid processes*. Each of the latter soon divides into two flattened branches. Shorter or upper branch is called the *oblique process*, which terminates by a broad end just behind the last sternal rib. Larger or lower xiphoid process runs downwards and backwards to project freely.

5. Costal surfaces. These are four or five cup-like depressions in the dorso-lateral margins of anterior part of metasternum. Each depression serves for the attachment of the lower end of a sternal rib.

6. Coracoid grooves. At the base of manubrium, on either lateral side, the metasternum bears an elongated, saddle-shaped articular surface or groove to receive the lower end of coracoid bone. Two coracoid grooves are continuous through the foramen of manubrium.

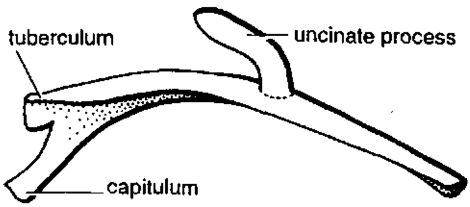


Fig. 9. Fowl. A vertebral thoracic rib.

Ribs

There are seven pairs of thoracic ribs in fowl. One pair of ribs articulates with each thoracic vertebra.

A thoracic rib is made of two distinct portions, a dorsal flat and curved *vertebral* part, attached to the vertebra, and a ventral straight, rod-like *sternal* part, attached to the sternum. Two portions are united in the middle at a right angle. First, second and sometimes the seventh ribs lack a sternal part and do not reach the sternum. P[illegible]xi[illegible]l [illegible] b [illegible] d of each rib is double-headed or *bicephalous*, consisting of a lower *capitulum* attached to centrum, and an upper *tuberculum* attached to transverse process of vertebra. Vertebral portion of each rib, except those of first and the last pairs, carries a backwardly directed bony process, called *uncinate process*, which overlaps the next rib behind, thus increasing the rigidity and strength of the thoracic wall necessary for flight (Fig. 9).

Pectoral Girdle

Shoulder or pectoral girdle, lying at the anterior end of trunk, is made of two similar halves, one on either side. They are firmly connected with the sternum to offer a strong support to the wings needed by flight. Pectoral girdle on each side consists of three bones : a large *coracoid*, a thin narrow *scapula* and a slender *clavicle* (Fig. 10).

1. Coracoid. Stout, straight and rod-like coracoid is the strongest bone of shoulder girdle. It runs as a prop from shoulder joint to sternum. Its lower end is flattened, broad and bears a saddle-shaped surface, articulating with *coracoid groove* on the antero-lateral border of sternum. This end also bears a foramen leading into an air cavity inside the bone. Dorsal end of coracoid is

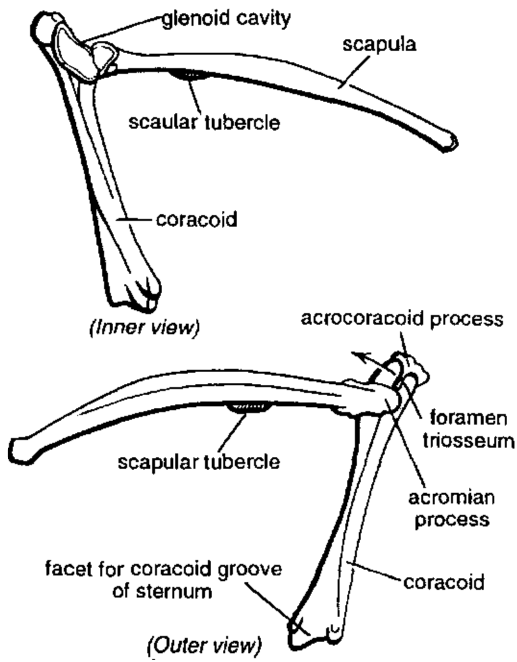


Fig. 10. Fowl. Pectoral girdle. Right half.

produced into a hook-like *acrocoracoid* process which meets the clavicle. Below the acrocoracoid process, the posterior or inner side of coracoid is connected with the scapula, while the outer surface bears a cup-shaped depression which forms the greater part of *glenoid cavity* for the reception of head of humerus. Coraco-scapular angle is less than a right angle.

2. Scapula. Scapula or *shoulder blade* is a long, narrow, slightly curved and more or less sabre-like bone. It extends backwards almost to the pelvis crossing over the thoracic ribs nearly parallel to the vertebral column and is connected with them by muscles. Its anterior end bears on its outer surface a cup-like depression forming part of the glenoid cavity, while the inner surface is produced into an *acromian process*, which meets the clavicle. Thus, coracoid and scapula contribute equally to the formation of glenoid cavity.

3. Clavicles. Each *clavicle* is a slender, slightly curved and delicate rod-like bone. Its dorsal end articulated with the acromian process of scapula and acrocoracoid process of coracoid to enclose a smooth circular gap, called *foramen* *triosseum.* Tendon of the flight muscle, pectoralis minor, that raises the wing, passes through this foramen dorsally to be inserted upon the dorsal aspect of head of humerus.

4. Furcula. Ventrally, the two clavicles are fused to a small interclavicle to form a median laterally compressed disc or *hypocleidium* which is connected by a ligament with the rostrum of the sternum. The V-shaped composite bone, representing fused clavicles and interclavicle, is commonly known in English as *furcula* or *merry thought* or *wishbone*. It works as a spring-like connection between the two halves of shoulder girdle (Fig. 11).

Pelvic Girdle

Noteworthy features of pelvic girdle are as follows :

(1) Absence of a ventral symphysis. This is in accordance with the laying or relatively large eggs.

(2) Firm and extensive fusion of pelvic girdle with synsacrum of vertebral column. It compensates for the weakness which would otherwise result from the absence of a symphysis, and serves for bipedal locomotion.

(3) Incomplete ossification of acetabulum, which is partially membranous at its bottom.

Pelvic girdle is large and consists of two separate halves. Each half is known as *os innominatum* or *innominate bone*, which is composed of the usual three elements : *ilium*, *ischium* and *pubis*. Junction of the three is marked by a deep socket on outer side, the *acetabulum*, which receives the rounded head of femur, forming a typical ball and socket joint (Fig. 12).

1. Ilium. It is an elongated lamellar bone which may conveniently be divided into *preacetabular* and *postacetabular* parts of equal size. Inner border of ilium is firmly united with transverse processes and neural spines of synsacrum. Outer surface of preacetabular ilium is concave while that of postacetabular ilium is convex. Ilium forms the dorsal part of acetabulum, on the posterior border of which it projects into a small process, the *anti-trochanter*, for articulation with the great trochanter of femur. Under surface of ilium shows two depressions for the kidney lobes.

2. Ischium. It is a broad, lamellar almost vertical bone extending behind the acetabulum, of which it forms about a third. It is fused posteriorly with ilium but separated anteriorly from it by a large oval *ilio-ischiatic foramen*.

3. Pubis. Pubis is a thin, slender and curved strip of bone running along the ventral edge of ischium. It forms a small ventral part of acetabulum, in front of which it projects forwards as a small blunt *preacetabular* or *pre-pubic process*. Behind the acetabulum, pubis is separated from ischium by a small, oval *obturator foramen*, behind which the two bones are joined for a short distance only. Free posterior end of pubis extends backwards for some distance beyond the ischium.

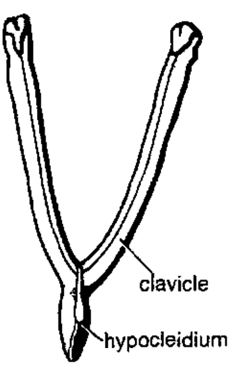


Fig. 11. Fowl. Furcula.

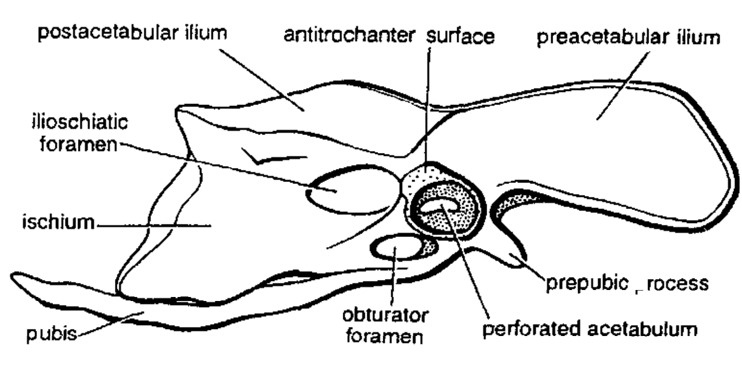


Fig. 12. Fowl. Pelvic girdle. Right os innominatum in outer view.

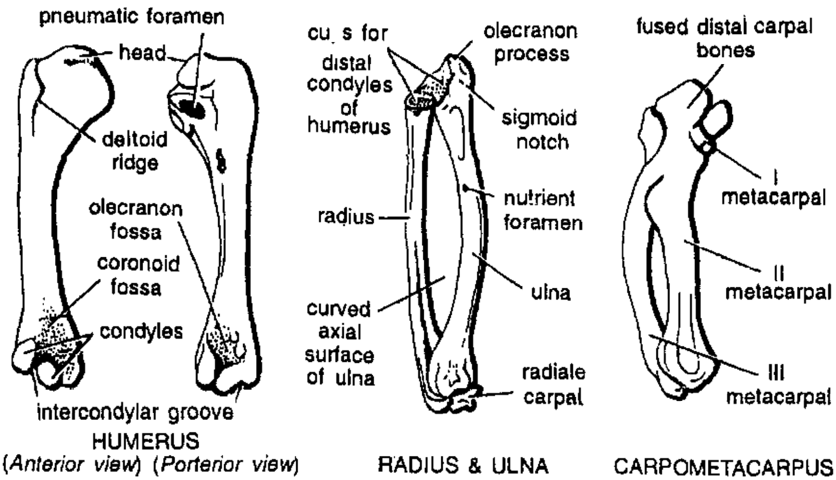


Fig. 13. Fowl. Forelimb bones.

Bones of a Forelimb or Wing

Wing of bird corresponds to the forelimb of a mammal, but it differs from it in many respects.

(1) In adaptation to flight, wing of a bird has much less flexibility of parts than in the forelimb of a mammal.

(2) Radius and ulna do not move upon each other.

(3) Distal carpals fuse with metacarpals to form carpometacarpus.

(4) Only three digits are present.

1. Humerus. Upper arm bone or *humerus* is stout, elongated, slightly curved and expanded at both ends. Proximal end presents a smooth convex surface or *head* which articulates with glenoid cavity, formed by scapula and coracoid bones. It is bordered by two *tuberosities* or *tubercles.* Preaxial or smaller tuberosity shows a prominent crest or *deltoid ridge* for insertion of great pectoral and deltoid muscles. Postaxial or greater tuberosity carries a large *pneumatic foramen*, communicating with an air cavity in the shaft of bone. Distal end of humerus bears a pair of convex trochlear articular surfaces or *condyles* for radius and ulna.

2. Radius and ulna. Forearm has two separate bones, *radius* and *ulna.*

Radius is shorter, slender, straight and preaxial. Its proximal end forms a shallow cup for articulation with the outer or preaxial condyle of trochlea of humerus. Its distal end bears a knob which fits into the radiale carpal.

Ulna is longer, stouter, postaxial and more curved than radius, so that a wide space is enclosed between the two bones. Its proximal end bears an articular facet for the inner or postaxial condyle of trochlea of humerus and is further projected into a small, blunt *olecranon process.* Its distal end articulates with the ulnare carpal and radius.

3. Carpals. Wrist or carpus of adult contains only two irregular bones. Of these, the smaller and preaxial *radiale* articulates with radius while the larger and postaxial *ulnare* articulates with ulna. These represent the proximal row of carpals as in rabbit. The embryo also contains a distal row of carpals but they fuse with the metacarpals in adult.

4. Carpo-metacarpus. Manus or palm in adult contains a single elongated bone, the *carpo-metacarpus.* It is a compound bone formed by the fusion of three *metacarpals* with distal row of carpals. *First metacarpal* is the shortest, represented by a small stumpy projection at the proximal end of composite bone on preaxial side. *Second metacarpal* is by far the strongest and straight bone. *Third metacarpal* is slightly curved outwardly and is more slender than the second with which it is fused at both ends. It is present on the postaxial side.

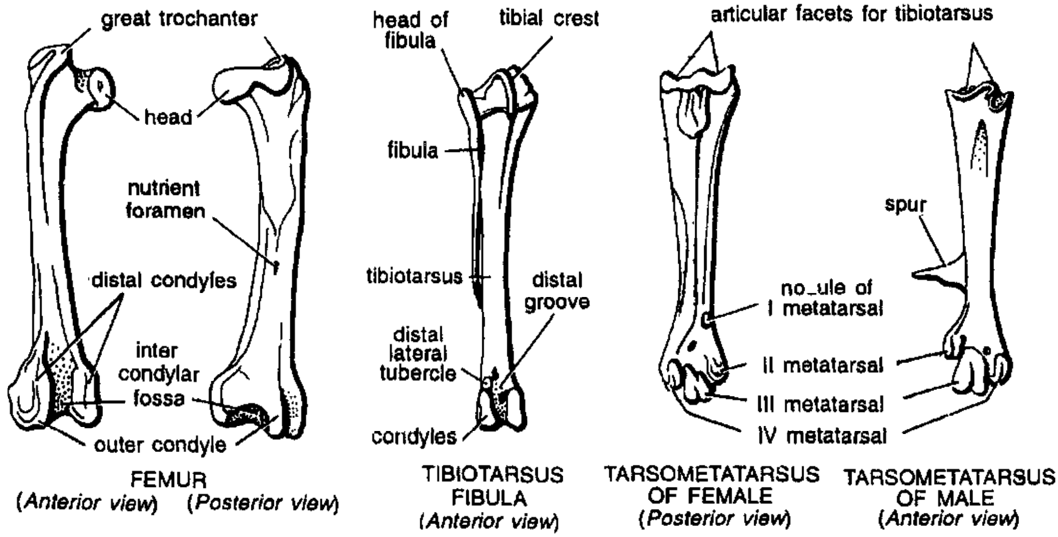


Fig. 14. Fowl. Hind limb bones.

5. Phalanges. There are three clawless digits, or *fingers*, borne by the three metacarpals. They contain small rod-like bones called *phalanges*. Preaxial *first digit*, or *pollex*, consists of a single phalanx, second digit or *index* has two phalanges while the postaxial *third digit* has only a single phalanx.

Hind Limb Bones

Hind limbs of bird, modified for bipedal locomotion, resemble those of rabbit in position and fundamental plan. However, they are characterized by the absence of a tarsus, so that the ankle joint becomes *inter-tarsal* or *meso-tarsal* (Fig. 14).

1. Femur. Thigh contains a single cylindrical, short but stout, and slightly curved bone with flattened ends, called *femur*. Its proximal end bears on inner side a rounded *head* which fits into acetabulum, and, on outer side, a prominent irregular process, the *great trochanter*. Between head and trochanter is an articulating surface for the anti-trochanter of ilium. Distal end of femur carries a pulley-like structure consisting of an anterior deep *intercondylar fossa* or *groove*, bounded laterally by two prominent *condyles* for articulation with the tibiotarsus. Outer condyle is deeply grooved to receive the upper end of fibula.

A sesamoid bone, the *patella*, is found in the tendon in front of the femur-tibiotarsal joint. Sesamoid bones are ossified parts of tendons.

2. Tibio-tarsus and fibula. Shank contains two bones, a *tibio-tarsus* and a *fibula*.

Tibio-tarsus is a stout, nearly straight bone, even longer than femur. It is formed by the fusion of *tibia* with proximal row of tarsals (astragalus and calcaneum). It lies on the preaxial or inner side of shank. Its broad proximal end bears two articular facets for the two condyles of femur, and gives out in front a prominent *cnemial crest*. The distal pulley-like end shows a smooth groove bounded by two articular condyles for the tarso-metatarsus.

Fibula is reduced to a small, slender bone, closely applied to the outer or postaxial surface of tibio-tarsus. Its broad proximal end or head articulates with the outer condyle of femur. Its distal end does not reach the ankle but tapers to a sharp point.

3. Tarsals. Adult has no free tarsals, the proximal row being fused with tibia and distal row with metatarsus, with an *intertarsal ankle-joint* between the two rows.

4. Tarso-metatarsus. Pes or foot contains a single stout, straight and compound bone, the *tarso-metatarsus*. It is formed by the fusion of distal row of tarsals with second, third and fourth *metatarsals*. A reduced, nodule-like, first *metatarsal* bone is attached by ligaments to the inner and posterior surface of tarso-metatarsus near its distal end. Proximally, the tarso-metatarsus bears two cup-like facets for the tibio-tarsus. At its distal end, the three metacarpals become free, each forming a pulley-like articular surface for the corresponding toe. In male, tarso-metatarsus bears on its medial side a stout, conical and slightly curved bony projection, bearing a pointed horny *fighting spur.*

5. Phalanges. Like fingers, the toes also contain small, slender bones, the *phalanges*. Of the four toes carried by the metatarsus, the first or *hallux* is directed backwards, and the remaining three forwards. Number of phalanges is the same as in lizard. Hallux has 2, second toe 3, third toe 4 and the fourth toe 5 phalanges. In each toe the terminal phalanx bears a horny *claw*.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the skull of *Gallus* and compare it with that of *Varanus.*
2. Give a detailed account of appendicular skeleton of fowl.

» *Short Answer Type Questions*

1. Write short notes on — (i) Corpometacarpus, (ii) Furcula, (iii) Pygostyle, (iv) Sternum, (v) Synsacrum, (vi) Tarsometatarsus.
2. Describe briefly the characteristic feature of skull of fowl.
3. Write a short note on visceral skeleton of fowl.

» *Multiple Choice Questions*

1. Bones of fowl are called :
   (a) Cartilaginous (b) Membranous
   (c) Replacing (d) Pneumatic
2. Skull of fowl is :
   (a) Monocondylic (b) Dicondylic
   (c) Acondylic (d) None of these
3. In fowl, cranium does not extend forward into orbital region. This condition of skull is called —
   (a) Edentulus (b) Tropibasic
   (c) Autostylic (d) Craniostylic
4. Jaw suspensorium in *Gallus* is said to be :
   (a) Autostylic (b) Craniostylic
   (c) Monymostylic (d) Hyostylic
5. In fowl the skull palate is with short vomers permitting the palatines to meet. This type of palate is called :
   (a) Palaeognathus (b) Dromaeognathous
   (c) Desmognathous (d) Schizognathous
6. Strongest bone of Pectoral girdle is :
   (a) Clavicle (b) Coracoid
   (c) Scapula (d) Sternum
7. Furcula or Merry thought or Wishbone is a composite bone formed by the fusion of :
   (a) Clavicles and interclavicles
   (b) Coracoid and scapula
   (c) Coracoid and clavicles
   (d) Coracoid and interclavicles
8. One half of Pelvic girdle is called as :
   (a) Osinnominatum or innominate bone
   (b) Ilium
   (c) Synsacrum
   (d) Acetabulum
9. Which of the following is associated with Radius-ulna :
   (a) Obturator foramen (b) Olecranen process
   (c) Pneumatic foramen (d) Acromian process
10. Which of the following is a sesamoid bone :
    (a) Fibula (b) Phalenges (c) Furcula (d) Patella
11. Number of Cervical vertebrae in fowl is :
    (a) 14-16 (b) 7 (c) 10-12 (d) 16
12. Keel is a component of :
    (a) Ribs (b) Pelvic girdle
    (c) Sternum (d) Hyoid apparatus
13. Number of thoracic ribs in fowl is :
    (a) 7 (b) 11 (c) 9 (d) 8
14. The first toe of fowl is called :
    (a) Pollex (b) Hallux (c) Tarsal (d) Phalanges
15. Fighting spur is found in :
    (a) Tarso-metatarsus (b) Carpo metacarpus
    (c) Tibio tarsus (d) Tarsals

ANSWERS

1. (d) 2. (a) 3. (b) 4. (a) 5. (d) 6. (b) 7. (a) 8. (a) 9. (b) 10. (d) 11. (a) 12. (c) 13. (a) 14. (b) 15. (a)

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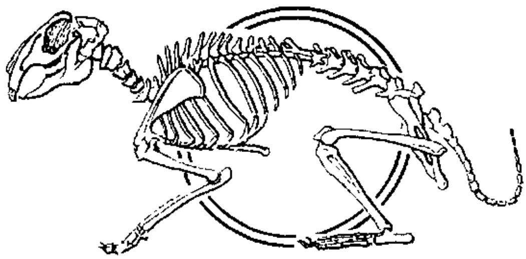

Endoskeleton of Rabbit

Endoskeleton of rabbit is made chiefly of bone with very little cartilage. Bones may be *cartilaginous* or *replacing*, i.e., preformed in cartilage, they may be *membrane* or *dermal, i.e.*, formed by the transformation of connective tissue and some of them, like *patella*, are *sesamoid*, i.e., occurring as ossifications in certain tendons.

As in other vertebrates, endoskeleton of rabbit also falls into two major divisions. (i) Axial skeleton lies along the longitudinal axis of body and includes *skull, vertebral column, ribs* and *sternum*. (ii) Appendicular skeleton is associated with the appendages and consists of *girdles* and *limb bones* (Fig. 1).

Characteristics of Skull

Main characteristic features of skull of rabbit are as follows :

(1) Original chondrocranium is completely ossified.
(2) Sutures between bones are quite distinct.
(3) Cranial part is shorter, while facial part is longer and deflected at an angle of about 60°.
(4) Skull is *dicondylic*, i.e., each exoccipital bears an occipital condyle to articulate with atlas vertebra.
(5) Skull is *tropibasic*, i.e., a vertical interorbital septum lies between two orbits so that cranium does not extend forward into orbital region.
(6) Orbits are quite large.
(7) Temporal fossa is represented by a small depression above the zygomatic process of squamosal.
(8) Certain bones are spongy in texture, e.g., maxilla, etc.
(9) Prefrontal, postfrontal, parasphenoid and quadrato-jugal are absent while pterygoids are much reduced and scale-like.
(10) Turbinal bones are much folded to increase the olfactory of nasal chambers.
(11) Otic bones (prootic, epiotic and opisthotic) are fused into a single compact periotic bone on either side.
(12) Each middle ear-cavity contains three ear-ossicles — *malleus*, *incus* and *stapes*-

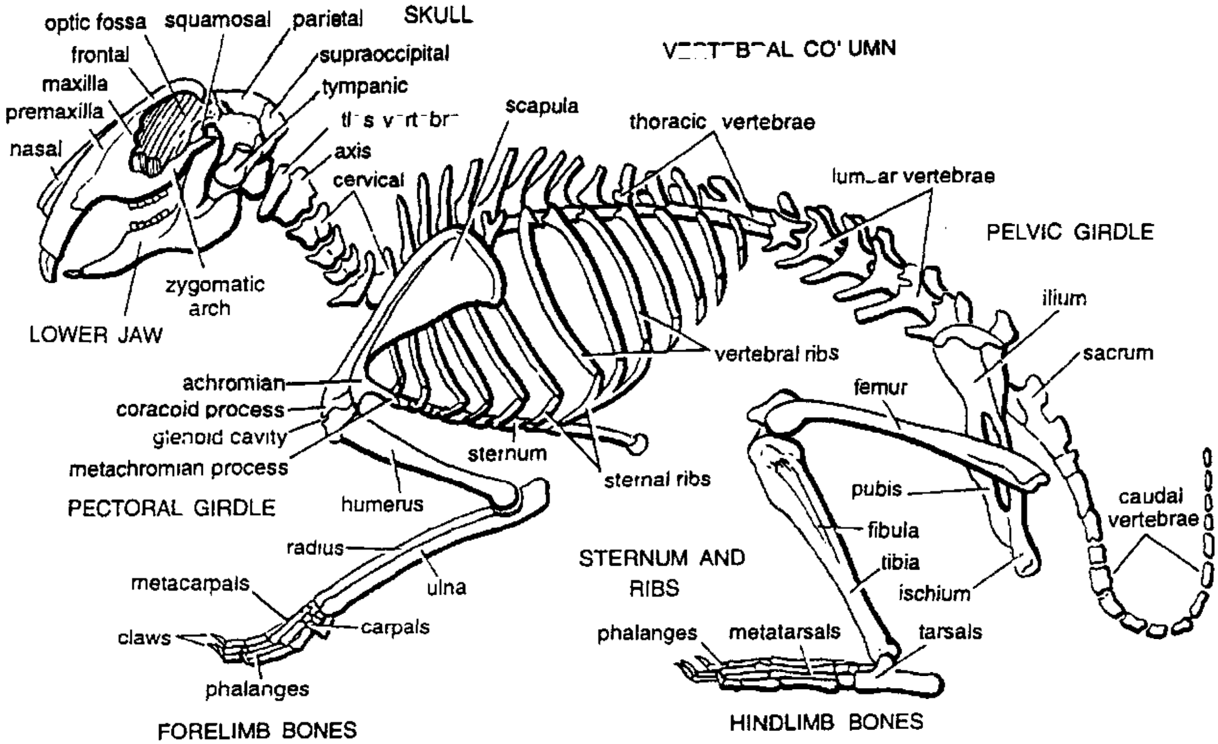

Fig. 1. Rabbit. Complete skeleton in lateral view.

representing the columella, quadrate and articular bones, respectively.

(13) A horizontal bony palate, formed by premaxillae, maxillae and palatines, lies between buccal and nasal cavities.

(14) Tympanic bone forms a flask-shaped tympanic bulla which fuses with periotic.

(15) Premaxillae, maxillae and dentaries bear *thecodont* (embedded in sockets), diphyodont (milk and permanent) and *heterodont* (several types) teeth. Canines are absent with a toothless gap, called *diastema*, between incisors and premolars. Dental formula is $i\ \frac{2}{1}$, $c\ \frac{0}{0}$, $pm\ \frac{3}{2}$, $m\ \frac{3}{3} = 28$.

(16) Lower jaw is made of a single *dentary* bone on either side.

(17) Jaws suspensorium is *craniostylic*, i.e., mandible articulates with squamosal bone of skull.

(18) Hyoid bone is reduced and consists of a transverse bar with two pairs of cornua.

(19) Chondocranium is completely ossified.

(20) Facial part is larger and cranial part is shorter.

Parts of Skull

[I] Cranium

Cranium or brain case encloses the brain and consists of four segments, rings or regions placed one after another. Posteriormost is *occipital ring*, next in front is *parietal ring*, anterior to it is *frontal ring*, whereas the anteriormost is *ethmoidal ring* (Figs. 2 & 3).

1. Occipital segments. It is the rear part of cranium, pierced by the large *foramen magnum* and consisting of four cartilage bones-*supra-occipital* above the foramen, an *exoccipital* on each lateral side, and *basioccipital* on the floor. Each *exoccipital* bears an oval or somewhat elongated *occipital condyle* and also gives off a downwardly directed *paroccipital process* which lies in close contact with the

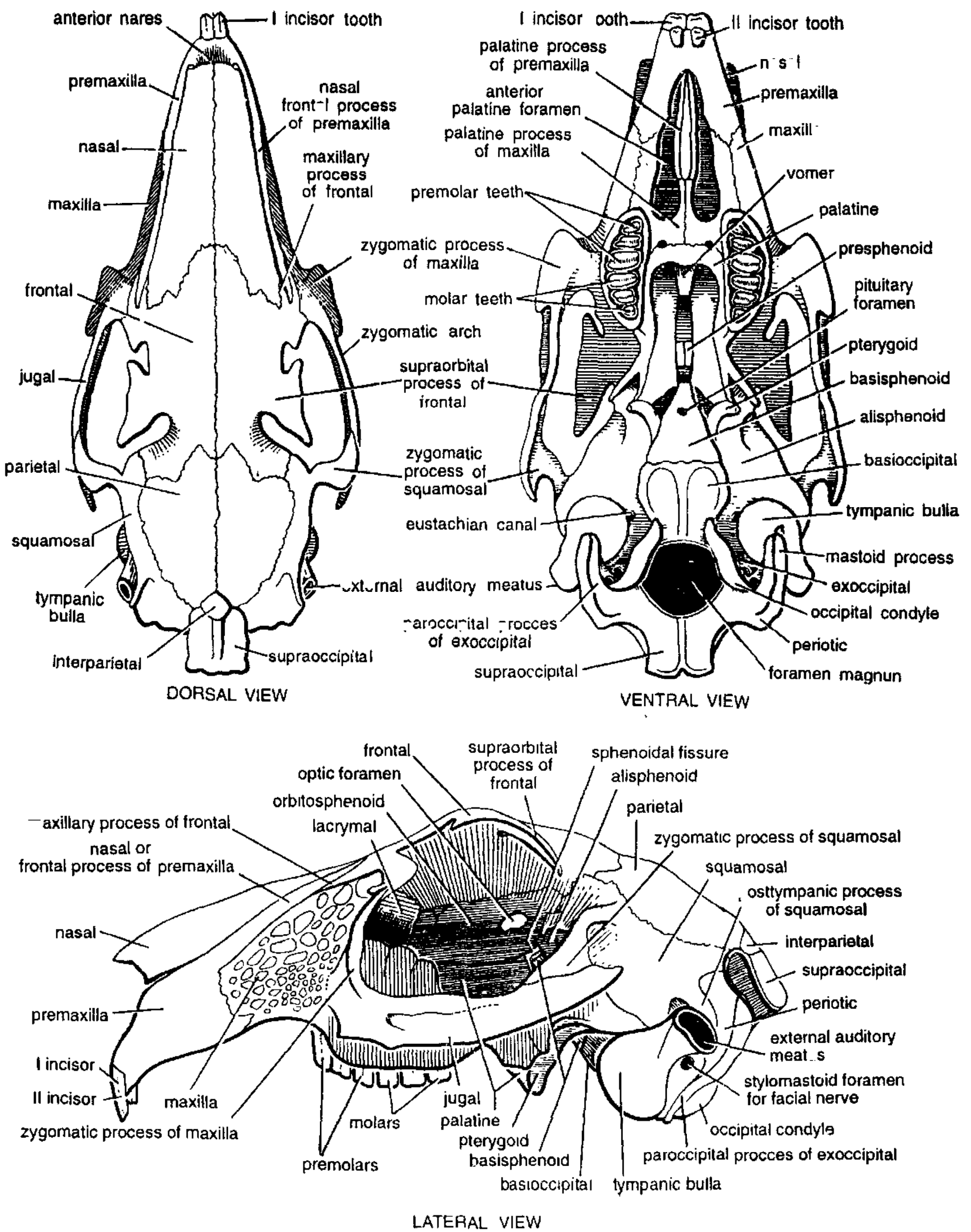

Fig. 2 Rabbit. Skull in dorsal, ventral and lateral views

postero-ventral surface of tympanic bulla. Dorsal part of large *supraoccipital* forms a square, table-like eminence and a process on either side for attachment of muscles. It articulates anteriorly with interparietal and parietals and laterally with squamosals and periotics. *Bcsioccipital* forming the floor is a flat median bone. It articulates in front with basisphenoid and laterally with periotics. Occipital segment can be easily detached from the rest of skull.

2. Parietal ring. It lies just in front of occipital ring. Laterally the two are separated by the interpolation of auditory capsules and squamosal bones. Parietal ring includes ventral *basisphenoid*, lateral *alisphenoids* and dorsal *parietals* and *interparietal*.

Squamosal. Squamosal is a somewhat rectangular membrane bone, lying ventral to parietal on either side. It sends backwards a long narrow *post-tympanic process* over periotic, just above the external auditory meatus. Outer surface of squamosal gives off a prominent *zygomatic process* which contributes to the posterior part of zygomatic arch and on its under surface bears a *glenoid* or *mandibular fossa* for articulation with the condyle of lower jaw.

Parietal. Parietal are a pair of thin and somewhat rectangular membrane bones. They form a large part of the roof and lateral walls of cranium in the posterior region. Both parietals are united mid-dorsally by a prominent suture. They remain separated form alisphenoids by the intervention of squamosals. From its posterior outer border, each parietal gives off a thin *ventral process* which runs beneath the squamosal.

Interparietal. It is a small median, wedge-like, triangular membrane bone which occurs between the two parietals and supra-occipital.

Basisphenoid and alisphenoids. Floor of parietal region is occupied by *basisphenoid*. It is a flat, median and triangular cartilage bone with its apex directed anteriorly to join the presphenoid, while the broad base directed posteriorly to articulate with basioccipital by means of a thin plate of cartilage. Dorsal surface of basisphenoid bears a depression, called *sella turcica*, containing pituitary gland. At about middle of its length, basisphenoid is pierced by a minute *pituitary foramen* which remains covered by a membrane in life. Basisphenoid articulates in front with presphenoid and laterally with alisphenoids.

Sides of parietal region are formed by a pair of large irregular and wing-like bones, the *alisphenoids*, which are attached obliquely one on either side of basisphenoid. Each alisphenoid is differentiated into three parts. Postero-ventral part lying in front of the tympanic bulla is strongly fenestrated. Antero-ventral part forms a smooth plate of bone, including the blunt *external pterygoid process* connected with palatine and bounded infront by a slit-like aperture, the *sphenoidal fissure* or *foramen lacerum anterious*, which opens backwards into cranial cavity. Third part of alisphenoid is a bony plate, forming the floor of orbit. Base of alisphenoid is perforated by foraminae which transmit nerves, veins and arteries. Posteriorly, it bears a deep notch or the *foramen ovale* to transmit a branch of the Vth nerve.

3. Frontal ring. It includes *presphenoid* below, *orbitosphenoids* on sides and *frontals* above.

Presphenoid and orbitosphenoids. Floor of frontal region of cranium if formed by a small, median and laterally compressed cartilage bone, the *presphenoid*, lying anterior to basisphenoid. Connected to it, one on either side, and forming the sides of the frontal region are a pair of relatively large, lamellar bones, the *orbitosphenoids*. In rabbit, they are partially fused to form a thin, vertical median *interorbital septum*, which surrounds the large, conjoined, *optic foramen* for the exit of optic nerve. Orbitosphenoids form the lateral walls of cranium and orbits. They articulate with palatines anteriorly, with frontals dorsally and with squamosals and alisphenoids posteriorly.

Frontal. Roof and sides of frontal region of cranium are formed by a pair of large membrane bones, the *frontals*. They unite with each other mid-dorsally and with parietals posteriorly, by prominent sutures. Outer middle part of each

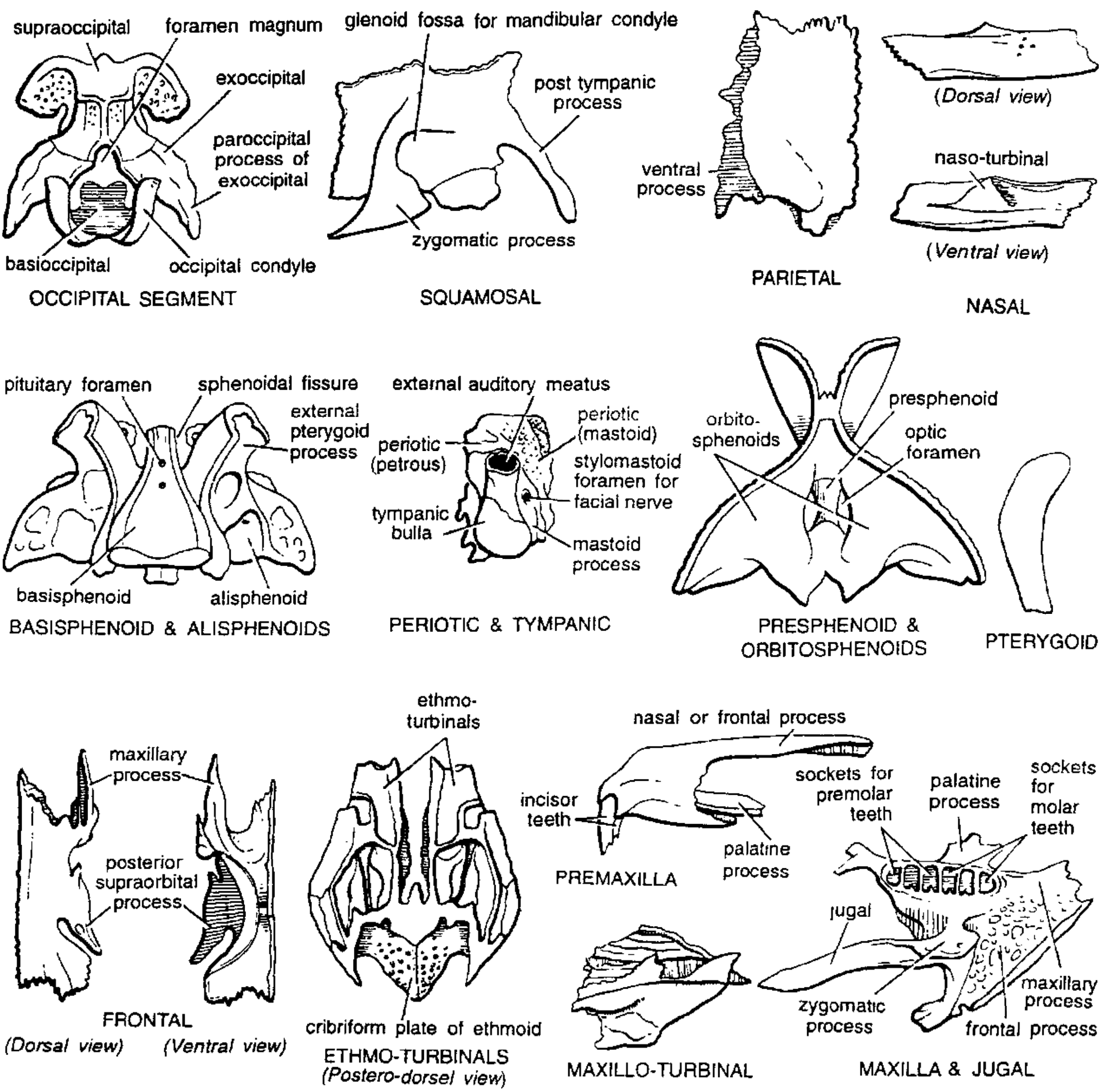

Fig. 3. Rabbit. Disarticulated skull bones.

frontal, forming the dorsal boundary of orbit, bears a prominent and somewhat crescentic *supra-orbital process.* Each frontal articulates anteriorly with nasal bone. It also gives off anteriorly a slender maxillary process which runs infront between the maxilla and premaxilla. Ventrally the frontal articulates with orbitosphenoid.

4. Ethmoid ring. It occupies the part anterior to cranial cavity. It is not well separated from olfactory capsules due to intimate association. It includes only a single *mesethmoid.*

Mesethmoid. It is a median, vertical, plate-like cartilage extending forwards and downwards infront of presphenoid. It is termed *nasal septum* and it separates the two olfactory chambers from each other. Posterior part of masethmoid is transformed into *cribriform plate*, which is laterally expanded. This plate occupies an oblique position in the anterior region of cranial cavity and carries a number of perforations for olfactory nerves.

[II] Sense capsules

There are 3 pairs and intimately attached with cranium. *Olfactory capsules* lodge organs of smell. *Auditory capsules* contain organs of hearing. *Orbits* enclose eyes.

1. Olfactory capsules. ***Nasal.*** Roof of olfactory chambers is formed by the two long, narrow membrane bones, the *nasals*, uniting with each other in the median plane. They extend forwards from frontals and their anterior ends form upper boundaries of external nostrils. On outer side each nasal articulates with premaxilla.

Vomer. Two *vomers* are slender, blade-like bones, present ventral to olfactory capsules. They are fused together and attached to nasal septum.

Turbinals. Each olfactory or nasal chamber encloses an irregular mass of scroll bones comprising of ethmo-turbinal, maxillo-turbinal and naso-turbinal. They are found lined by mucous membrane. These helps in increasing the sensory surface of olfactory chamber.

2. Auditory capsules. These are attached to postero-lateral regions of cranium in nearly completely embedded position. Each auditory capsule encloses the membranous labyrinth of internal ear and includes *periotic* and *tympanic* bones. In embryonic state it is made of three separate bones viz., *prootic, epiotic* and *opisthotic* but in adult they form a composite bone called *periotic*.

Periotic. Each periotic is an irregular cartilage bone formed by the fusion of three ossifications *pro-, epi-*, and *episthotic*. It fits loosely between squamosal and occipital ring and is externally visible forming a prominent bulge. Periotic is differentiated into two portions. Inner dense and stony *petrous portion* encloses the membranous labyrinth while outer, posterior and porous *mastoid portion* is produced downwards into a *mastoid process*, which is closely applied to posterior aspect of tympanic. On removal of tympanic, petrous portion is seen to bear two apertures, a prominent anterior *fenestra ovalis* and an irregular posterior *fenestra rotunda*, and a ventral rounded swelling, the *promontary*, containing cochlea.

Inner surface of periotic bears two prominent depressions. Upper and larger depression contains the *floccular lobe* of cerebellum. Lower and smaller depression is further divided by a bony ridge into an anterior *stylomastoid foramen* for facial nerve and a posterior *internal auditory meatus* for auditory nerve.

Tympanic. A membrane bone, called *tympanic*, is closely applied to outer surface of each periotic. Its lower, flask-shaped swollen part is called *tympanic bulla*, enclosing the tympanic cavity of middle ear, which contains 3 ear ossicles-*malleus, incus* and *stapes*. Tympanic bulla is continued upwards as a tubular neck, enclosing the *external auditory meatus*, which is closed at the base by a tympanic membrane in life. On the posterior side of tympanic opens the *stylomastoid foramen* for the exit of facial nerve from skull.

[III] Visceral skeleton

It includes upper and lower *jaws* and *hyoid apparatus*.

1. Upper jaw. Snout roof is constituted by upper jaw. Bones related with upper jaw are intimately associated with cranium and olfactory capsules. These are *premaxillae, maxillae, jugals, pterygoids* and *palatines*.

Premaxillae. Two premaxillae form the anteriormost part of upper jaw. They are relatively longer in rabbit and united with each other in the median plane in front. Anteriorly, each premaxilla bears two *sockets* on ventral side for two *incisor* teeth which have sharp chisel edge and are used for biting off pieces of food. Posteriorly, each premaxilla gives off two processes. Dorsal or *nasal process*, extends back right up to frontal, wedged between nasal and maxilla. Ventral or palatine process meets the fellow of other side along mid-ventral line and both reach up to palatine processes of maxillae, thus dividing the large *anterior palatine foramen* in o wo la eral halves. Premaxillae contribute to anterior half of diastemas or toothless gaps between incisors and premolars.

Maxilla. Two maxillae are large irregular bones forming the greater part of upper jaw and sides of face. They contribute to posterior part of diastemas and also project into anterior part of orbits. Ventral surface of alveolar part of each maxilla bears six sockets or alveoli for cheek teeth. Each maxilla also gives off several processes. Anteriorly, it gives off a *maxillary process* to join premaxilla. A large antero-dorsal *frontal plate* forms most of the side of facial part or olfactory chamber where it remains greatly fenestrated. It articulates with premaxilla and frontal. A medial horizontal *palatine* or *palatal process* given off from middle part meets the fellow of opposite side midventrall to form anterior part of hard palate. A stout *zygomatic process* from outer surface runs behind to meet *jugal* and contributes to zygomatic arch which bounds the orbit below.

Jugal. A laterally compressed bone, *malar* or *jugal*, extends between zygomatic processes of maxilla and squamosal forming the greater part of zygomatic arch.

Pterygoid. A small scale-like pterygoid attaches vertically at the union of palatine, alisphenoid and basisphenoid on either side.

Palatine. Two palatines are irregular-shaped bones on mid-ventral aspect of skull. Anteriorly, they become firmly united medially to form the posterior part of hard palate. Posteriorly, each palatine meets alisphenoid and pterygoid of its side and also encloses a pterygoid fossa between it and basisphenoid.

2. Lower jaw or mandible. Lower jaw or mandible consists on either side of a single membrane bone, the *dentary*. Both dentaries remain united anteriorly at a *mandibular symphysis*. Each dentary is somewhat triangular vertical bony plate bearing along its upper edge sockets for teeth. There is a long *diastema* between incisor and first premolar. It corresponds with that of upper jaw. A large depression, called

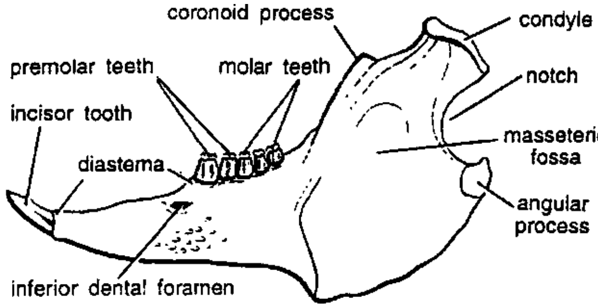

Fig. 4. Rabbit. Mandible. Left half.

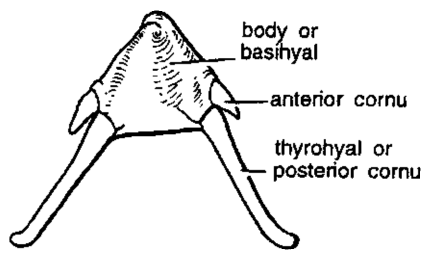

Fig. 5. Rabbit. Hyoid apparatus.

masseteric fossa, on the posterolateral surface serves for attachment of large masseter muscle. A deep notch on posterior side separates dorsal *condyle* from ventral *angle*. Angular process is rounded and inflected. Condyle is thick, elongated longitudinally and set much higher well above the level of teeth. It articulates with glenoid fossa of squamosal just below the base of its zygomatic process. Rabbits grind up their food by moving their mandibles forward and backward and not crosswise. *Coronoid process* infront of condyle is much less prominent and provides attachment to temporal muscle. Outer anterior face of dentary bears a prominent *mental* or *inferior dental foramen*, while a *mandibular foramen* is present on the inner face. These allow passage to nerves and blood vessels (Fig. 4).

3. Hyoid apparatus. Hyoid apparatus is buried in the floor of mouth cavity to give support to tongue and larynx. Body of hyoid or *basihyal* is a small plate, lying transversely between the two rami of mandible, and bearing anterior and posterior pairs of cornua. Each anterior cornu is made of a series of four short rods-*ceratohyal, epihyal, stylohyal* and *tympanohyal*. Of these the

Table 1. **Showing some important foramina of rabbit skull.**

	Name	Location	Structure passing through
1.	Optic foramen	Orbitosphenoid	Optic nerves
2.	Superior orbital fissure	Between orbito and alisphenoid	III, IV ophthalamic and maxillary branches of V and VI cranial nerve
3.	Foramen Lacerum	At front of periotic	Internal carotid artery and mandibular branch of V cranial nerve
4.	Stylomastoid foramen	In periotic bone between tympanic and mastoid part	VII cranial nerve
5.	External auditory meatus	Opening of bulla	Ear
6.	Jugal foramen	Between periotic and exooccipital	Internal jugular vein and IX, X and XI cranial nerve
7.	Condyler foramen	On occipital below condyle	XII cranial nerve
8.	Lacrymal foramen	Over lachrymal	Lachrymal duct
9.	Infraorbital foramen	Outer surface of maxilla above	V cranial nerve mandibular branch
10.	Pituitary foramen	Over basisphenoid	Pituitary body
11.	Foramen magnum	Between occipitals	Spinal cord
12.	External carotid foramen	Over periotic on ventral surface	External carotid artery

distal one or the last named fuses with tympanic and periotic bones, so that it may be absent from prepared specimens. Each posterior cornu is a short bony rod called *thyrohyal* (Fig. 5).

Some of the important foramina of rabbit skull are shown in the Table 1.

Vertebral Column

Vertebral column of a mammal differs from that of other vertebrates in several respects (Fig. 6) :

(1) A bony plate, called *epiphysis*, is present at each end of centrum of vertebra, so that articular surfaces of centra are more or less flat (*acoelous* or *amphiplatyan*). However, in the embryonic state a thin *epiphysial cartilage* separates centrum and epiphysis but at later stages of development it fuses with centrum.

(2) Cartilaginous *intervertebral discs* are present between centra of adjacent vertebrae.

(3) Vertebral column of rabbit includes about 46 vertebrae and is differentiated into five regions : *cervical, thoracic, lumbar, sacral* and *caudal*. Vertebral formula of rabbit is $C_7, T_{12-13}, L_{6-7}, S_4, Cd_{16}$ where C = Cervical, T = thoracic, L = lumber, S = sacral and Cd = caudal.

Atlas. Neck contains 7 cervical vertebrae. Of these first cervical vertebra is called *atlas*. It is a bony circle, like a signet ring, formed practically by the neural arch, without a *centrum* and *zygapophyses*, but bearing a rudimentary *neural spine*. In life, the large neural canal is divided horizontally by a ligament into a dorsal part for spinal cord and a ventral part for odontoid process of second vertebra. Projecting from sides are the much enlarged, flattened, *cervical ribs* in the form of horizontal wing-like processes, often termed as *transverse processes*. These are perforated basally by the *vertebrarterial canals*. Anteriorly, atlas bears a pair of large, shallow concave facets for occipital condyles of skull. Posteriorly, it bears two stout lateral facets and a small mid-ventral facet for odontoid process of axis.

Axis. Second cervical vertebra is called *axis* or *epistropheus*. *Neural spine* is high, ridge-like, laterally flattened and elongated antero-posteriorly. The so-called transverse processes or *cervical ribs* are small, posteriorly directed and basally perforated by *vertebarterial canals*. *Prezygapophyses* are absent but a pair of *postzygapophyses* are present. Anteriorly, centrum bears a long, pointed, peg-like *odontoid process*

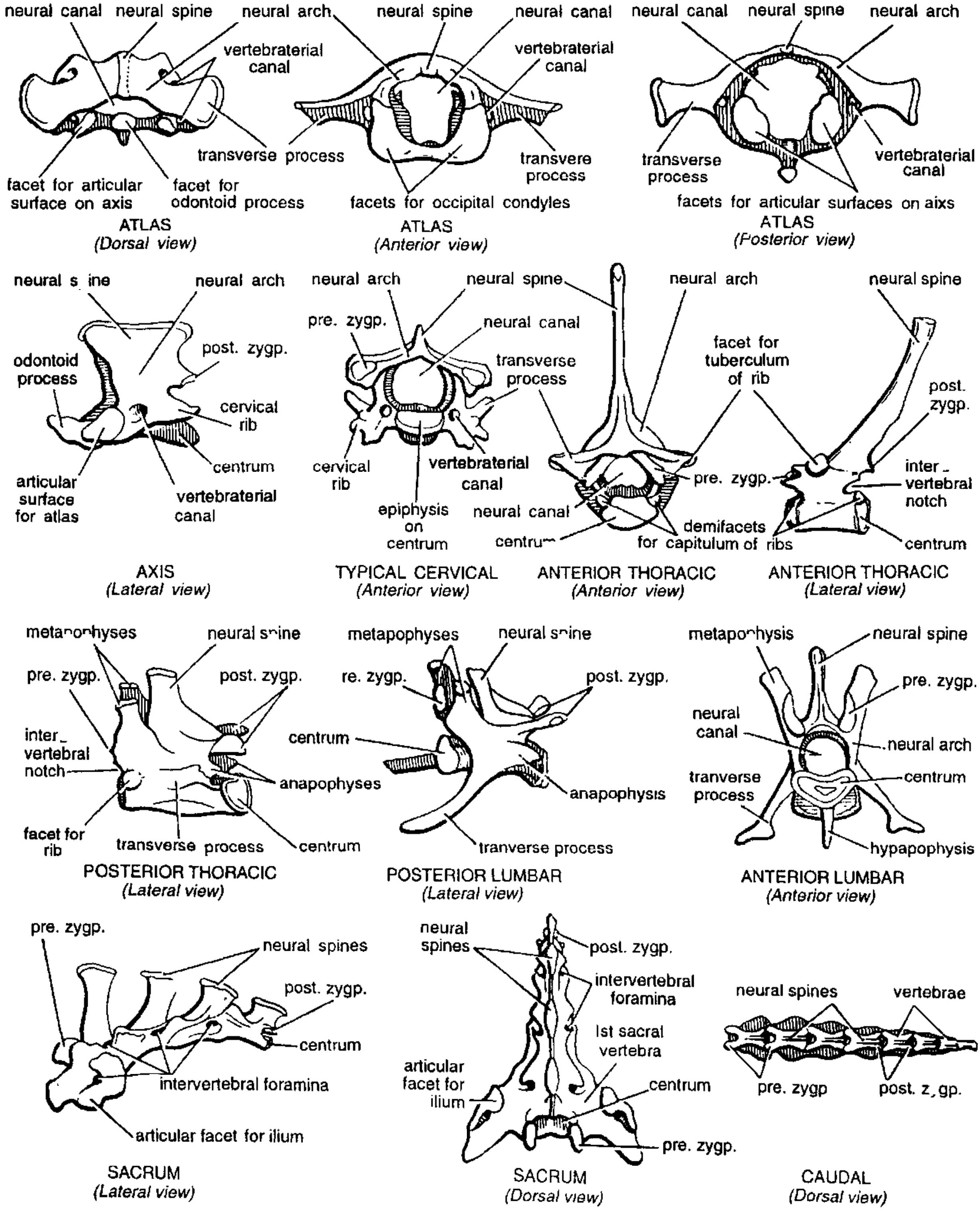

Fig. 6. Rabbit. Vertebrae.

which is developmentally the centrum of atlas vertebra. It is lodged in the ventral part of neural canal of atlas. Head and atlas can freely rotate on the odontoid process which serves as a horizontal pivot.

Typical cervical. Any cervical vertebra from 3rd to 7th is typical in structure. It has a large *neural arch*, a small neural spine, a short flattened *centrum* and broad sides. *Pre-* and *post-zygapophyses* are present. On each side of neural arch is present a bifurcated *transverse process*, pierced basally by a *vertebraterial canal*, formed by the fusion of a *cervical rib* with the vertebra. Cervical ribs are significantly reduced. Transverse processes and reduced cervical ribs provide site for the attachment of neck muscles. The 7th cervical vertebra differs slightly from others in having more elongated neural spine, in presence of a small concave facet at the posterior edge of centrum for the articulation of thoracic ribs and in absence of *foramen transversia* (= vertebraterial canal).

Anterior thoracic (typical). First 6 or 7 thoracic vertebrae are typical in structure. Each bears a tall slender *neural spine* slopping backwards. *Neural arch* bears *pre-zygapophyses* facing outwards and upwards, and *post-zygapophyses* facing inwards and downwards. *Transverse processes* are short, stout and horizontal and each bears ventrally a facet for the tuberculum of a rib. Short and thick *centrum* bears on each side at each end a small concave *demi-facet*, which, with the corresponding demi-facet of adjacent vertebra, articulates with the capitulum of a rib.

Posterior thoracic. Posterior 4 or 5 thoracic vertebrae are somewhat different from the anterior ones. They have longer and stouter *centra*, shorter *neural spines*, more prominent *zygapophyses* and reduced *transverse processes* without tubercular facets. Each bears a complete *capitular facet* for rib, one on either side near the anterior end of centrum. In the form and shape of neural spines, in the presence of *metapophyses* and *anapophyses*, and in the orientation of zygapophyses, the posterior thoracic vertebrae present a backwardly increasing resemblance to the lumbar vertebrae succeeding them.

Anterior lumbar. There are usually 7 lumbar vertebrae of which the first 2 may be recognized as *anterior lumbar*. Each of them bears a median ventral process of centrum called *hypapophysis*. *Neural spine* is crest-like and slopes anteriorly. *Transverse processes* are large, expanded distally and directed downwards and forwards. Anterior end of neural arch gives off on either side a large forward sloping process, the *metapophysis*, bearing a *pre-zygapophysis* on its medial aspect. Similarly, a pair of small backwardly directed processes, the *anapophyses*, arise form the posterior end of neural arch, below *post-zygapophyses*.

Posterior lumbar. Any lumbar vertebra from 3rd to 7th may be called as *posterior lumbar*. It resembles anterior lumbar in all the essential parts, but *hypapophysis* below centrum is absent, being replaced by a short ridge.

Sacrum. Lumbar region is followed by a single compound bone, the *sacrum*, which supports the pelvis. It is formed by the fusion of 3 or 4 sacral vertebrae, which can be marked out easily by their neural spines, zygapophyses and intervertebral foramina for the passage of *sacral spinal nerves*. First or true sacral vertebra is the largest of all and bears strong transverse processes, probably fused sacral ribs, which are attached with ilia bones of pelvic girdle. Articular surface of sacrum and ilium are covered by cartilage which is rough for the attachment of a strong ligament called, *interosseus sacroiliac ligament*. Through them, the push of hindlegs against ground is transmitted to vertebral column. Its neural spine is upright, metapophyses are reduced and anapophyses absent. Remaining vertebrae of sacrum become gradually smaller behind and their neural spines slope backwards. The lateral tubercles borne by them represent fused pre-and post-zygapophyses, while other processes are reduced.

Caudal. There are nearly 16 caudal vertebrae in rabbit. They progressively decrease in size backward. Their processes also become gradually shorter and finally the terminal vertebrae are merely rod-like centra alone.

Ribs

Rabbit has 12 or 13 pairs of thoracic ribs. A typical rib is a curved, rod-like bone. It is divisible into a longer, dorsal bony part, the *vertebral rib*, and a smaller, ventral cartilaginous part, the *sternal rib*. Vertebral rib is *bicephalous*, i.e. articulated to a thoracic vertebra by two heads. Upper head, or ***tuberculum***, articulates with a facet on transverse process of vertebra, while lower head or ***capitulum*** articulates with demi-facets on the centra of two adjacent vertebrae. Part of rib between these two heads is termed *neck*, while the rest is *body*. Immediately behind the tuberculum, a little process serves for the attachment of tendons. Sternal rib articulates with sternum. On the basis of attachment of ribs, ribs are classified into two type, except last 5 all thoracic ribs meet with the sternum below through their sternal parts are called *true ribs*. But the last 4-5 ribs are not provided with sternal parts and do not get connected with the sternum are called *floating ribs* (Fig. 7).

Sternum

Sternum lies embedded midventrally in the thoracic wall. It is elongated, laterally compressed, transversely segmented, and made of series of 6 small bony segments, called *sternebrae*. First or anteriormost sternebra is the longest and called *manubrium* (= *presternum*). It is produced ventrally into a *keel* and first pair of sternal ribs articulate with about half way along its length. Sixth sternebra is the smallest of all. Last or seventh sternebra is called *xiphisternum*. It is long and slender and terminates in an expanded plate of cartilage, the *xiphisternal* or *xiphoid cartilage* (Fig. 8).

Pectoral Girdle

Pectoral girdle consists of two separate halves, each comprising of two bones—a small membrane bone or *clavicle*, and a large replacing bone called shoulder blade or *scapula-coracoid* (Fig. 9).

Scapula-coracoid is a large, flat and triangular bone. Its apex is directed downwards and forwards and terminates below into a concave *glenoid cavity* which receives the head of humerus. Overhanging

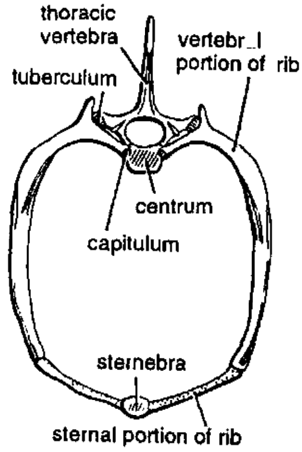

Fig. 7. Rabbit. A thoracic vertebra with its ribs.

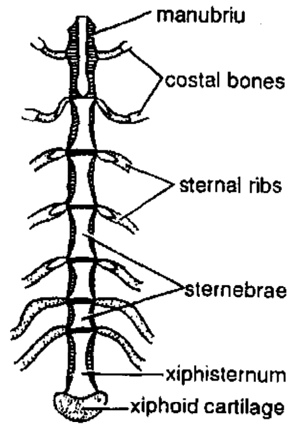

Fig. 8. Rabbit. Sternum in ventral view.

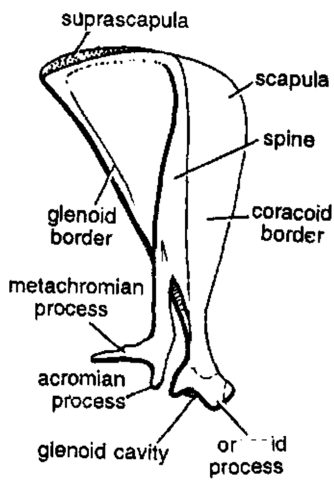

Fig. 9. Rabbit. Pectoral girdle. Right half in outer view.

glenoid cavity is a small hook-like *coracoid process*, the vestigial coracoid bone. Outer surface of scapula is divided by a prominent vertical ridge or *spine*, into antero-dorsal and postero-ventral portions to which, as well as to the spine, muscles are attached. Spine terminates below into a pointed *acromian process* which posteriorly gives off a large *metacromian process*. Dorsal or vertebral edge of scapula is made of a thin strip of cartilage, the *suprascapula*.

Clavicle is a slender, slightly curved bony rod. On one end it articulates with manubrium of sternum while at the other with acromian process of scapula.

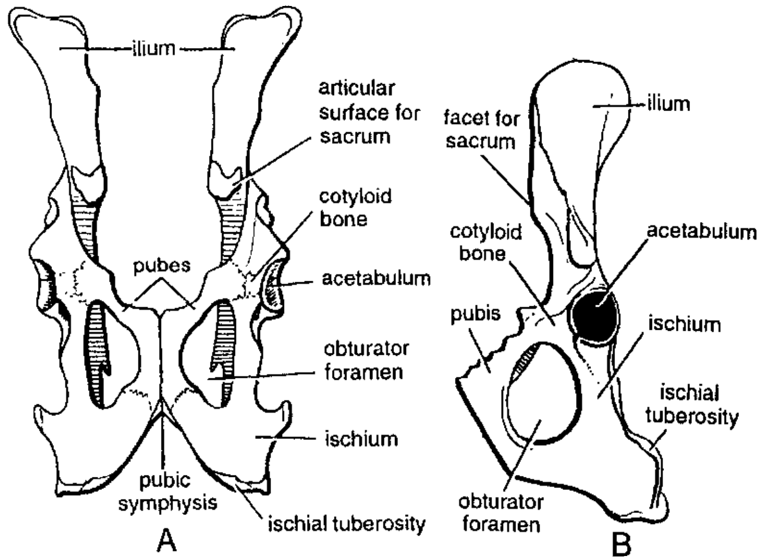

Fig. 10. Rabbit. Pelvic girdle. A—Complete girdle in ventral view. B—Left half.

Pelvic Girdle

Pelvic girdle of rabbit is composed of two halves, united mid-ventrally at a *pubic symphysis*. Anteriorly they are intimately connected to sacrum. Each half of pelvic girdle, or *os innominatum*, comprises of the usual three bones-*ilium*, *ischium* and *pubis*-which are fused together into a single innominate or *hip bone* (Fig. 10).

On outer middle side of innominate bone lies a deep cup-like cavity or *acetabulum*, which articulates with the head of femur. Ilium and ischium participate in the formation of acetabulum but a small *cotyloid bone* prevents pubis from reaching up to acetabulum.

Ilium is the large antero-dorsal and blade-like bone, joined to sacrum at about the middle of its length by a prominent crescentic articular surface. Towards acetabulum it becomes narrower. *Ischium* forms the postero-dorsal part of innominate bone. Its posteriormost thickened portion, called *ischial tuberosity*, is produced outwards and forwards into a hook-like process. *Pubis* is a small, slender bone forming the ventro-median portion of innominate bone. It is separated from ischium by a large oval space, the *obturator foramen*. Pubes of two sides unite mid-ventrally at a *pubic symphysis*.

Forelimb Bones

Humerus. It is a relatively short but stout rod-like bone of upper arm. Proximally, it bears a large rounded *head* articulating with glenoid cavity of scapula. Close to head are a *greater tuberosity* on outer, and a *lesser tuberosity* on inner side. Between these two tuberosities is a *bicipital groove*. In upper or proximal part, humerus bears a slight *deltoid ridge* on the preaxial or anterior side. It serves for attachment of muscles. Distally, humerus bears a pulley-like *trochlea* for articulation with ulna. Just above trochlea are present two depressions or *supra-fossae*, communicating with each other through a *supra-trochlear foramen*. Anterior or *coracoid fossa* is smaller while posterior or *olecranon fossa* is larger into which fits the olecranon process of ulna (Fig. 11).

Radius and ulna. Forearm contains two separate bones, *radius* and *ulna*, but they are tightly bound together at the two ends. *Radius* is small and somewhat curved so that proximally it lies in front of ulna, but distally on its inner side. *Ulna* is continued proximally into a prominent *olecranon process* to articulate with *olecranon fossa* of humerus. Basally this process is notched

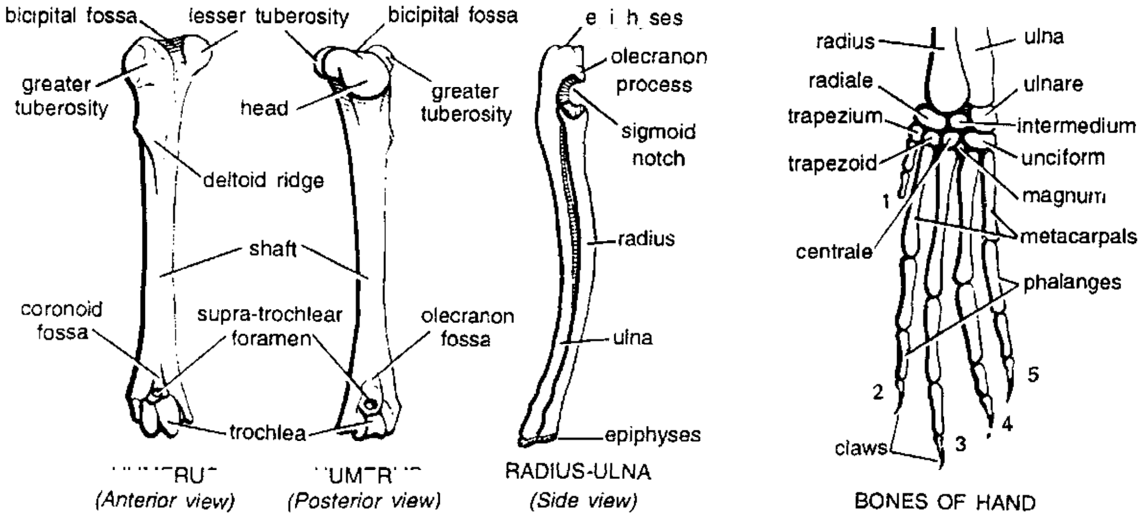

Fig. 11. Rabbit. Forelimb bones.

by the *sigmoid notch* into which fits the trochlea of humerus. Distally the two bones bear epiphyses and articulate with carpals.

Bones of forefoot or hand. Wrist or carpus contains 9 small *carpal bones* arranged in two rows. These are *radiale*, *intermedium* and *ulnare* in proximal row, one *centrale*, and *trapezium*, *trapezoid*, *magnum* and *unciform* in distal row. Unciform represents the fusion of two carpals. In addition, a sesamoid bone, *pisciform*, is present on the ventral side of carpus. There are five elongated *metacarpals* supporting the manus and five digits with 2, 3, 3, 3, 3, *phalanges*, respectively. The terminal phalanx bears a horny *claw*.

Hind-limb Bones

Femur. It is the bone of thigh region. It is the longest and the stoutest bone of body. It has a long cylindrical shaft with expanded extremities. Proximal end bears on the inner side a prominent

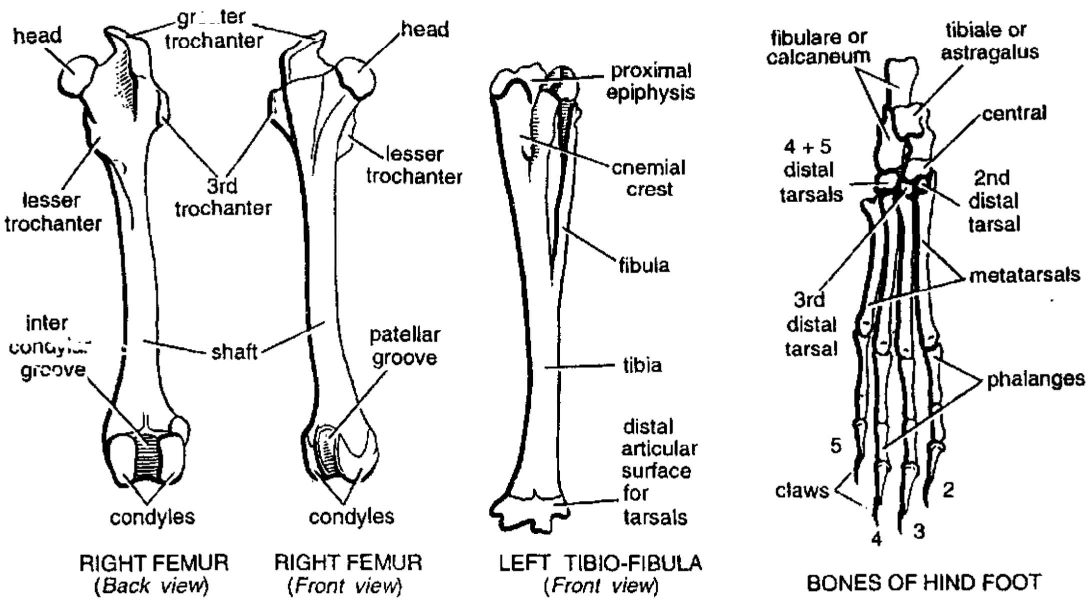

Fig. 12. Rabbit. Hind limb bones.

rounded head for articulation with acetabulum of pelvic girdle. It also bears a rough eminence, the *greater trochanter* above the head, a *lesser trochanter* below the head, and a *third trochanter* below the greater trochanter. The trochanters serve for muscle attachment. The deep groove bordered by head and greater trochanter is called *digital fossa*. Distally, the femur bears a pulley-like structure made of two lateral *condyles* enclosing an *intercondylar groove*, for articulation with tibio-fibula. Anteriorly this groove is termed the *patellar groove*, because in it slides a tendon containing the sesamoid bone, *patella* or knee cap.

Tibio-fibula. Shank contains two bones— a large, stout and straight *tibia*, and a small, slender *fibula*. The two bones are free proximally but fused distally, hence the name *tibio-fibula*. Its proximal end bears anteriorly a small but sharp ridge, the *cnemial crest* and articulates by two depressions with the two femoral condyles. Fibula lies on the postaxial side.

Bones of hindfoot. Ankle or tarsus contains 6 *tarsal* bones arranged in two rows. *Tibiale* and *intermedium* of proximal row are fused to form *astragalus* lying on the preaxial side. Other bone of proximal row, called *calcaneum*, is the largest tarsal bone, produced into a spur or process behind its articulation with tibio-fibula. It occupies the post-axial side. A single *centrale* lies just in front of astragalus. Distal row includes three bones— *mesocuneiform, ectocuneiform* and *cuboid.*

There are 4 long slender, *metatarsal* bones supporting the sole or pes, the first being absent. First toe or *hallux* is also absent so that there are only four toes, each composed of three *phalanges*, the terminal one of which bears a claw.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give an account of the skull of rabbit.
2. What is the basic structure of a vertebra ? Describe various types of vertebrae found in rabbit.

» *Short Answer Type Questions*

1. Write short notes on the following bones of rabbit— (i) Atlas vertebra, (ii) Lower jaw, (iii) Pectoral girdle, (iv) Pelvic girdle, (v) Periotic bone.

» *Multiple Choice Questions*

1. The skull of rabbit is :
   (a) Dicondylic (b) Tripobasic
   (c) Both (a) and (b) (d) None
2. The jaw suspensorium in rabbit is :
   (a) Craniostylic (b) Autostylic
   (c) Platibasic (d) All of the above
3. The floor of the brain-box is made by :
   (a) Supra-occipital (b) Basi-occipital
   (c) Exoccipital (d) Paroccipital process
4. A deep notch present posteriorly in alisphenoid :
   (a) Foramen magnum (b) Foramen ovale
   (c) Foramen lacerum anterious
   (d) Pituitary foramen
5. Lower jaw of rabbit is made up of :
   (a) Dentary only
   (b) Premaxillae, Maxillae and Dentaries
   (c) Premaxillae only
   (d) Maxillae only
6. Toothless gap present in the jaws of rabbit is :
   (a) Dentary (b) Diastema
   (c) Thecodont (d) Maxillae
7. Vomer and turbinals are parts of :
   (a) Auditory capsule (b) Olfactory capsules
   (c) Orbits (d) Ossicles
8. Ear ossicles in the correct order of their appearance in the tympanic cavity :
   (a) Malleus, incus, stapes (b) Incus, stapes, malleus
   (c) Stapes, incus, malleus (d) Malleus, stapes, incus
9. Zygomatic arch is made up of :
   (a) Maxilla, squamosal and jugal
   (b) Pterygoid, squamosal and jugal
   (c) Maxilla, palatine and jugal
   (d) Maxilla, palatine, pterygoid
10. Half of the jaw is known as :
   (a) Ramus (b) Os-innominatum
   (c) Ceratohyal (d) Hyoid

11. Signet ring like cervical vertebra of rabbit is :
    (a) First cervical vertebra (atlas)
    (b) Second cervical vertebra (axis)
    (c) First cervical vertebra (axis)
    (d) Second cervical vertebra (atlas)
12. The vertebrae of rabbit is :
    (a) Amphicoelous (b) Acoelous
    (c) Procoelous (d) Heterocoelous
13. Last sternebra is known as :
    (a) Xiphisternum (b) Manubrium
    (c) Capitulum
    (d) Tuberculum
14. Structure present in pectoral girdle which receives the head of the humerus :
    (a) Glenoid cavity (b) Coracoid process
    (c) Metacromian process (d) Suprascapula
15. The two halves of the pelvic girdle of rabbit is united mid-ventrally at :
    (a) Ilium (b) Cotyloid bone
    (c) Pubic symphysis (d) Acetabulum
16. Pubis is separated from ischium by a foramen :
    (a) Foramen magnum (b) Foramen ovale
    (c) Obturator foramen (d) Pubic symphysis
17. Deltoid ridge is found in :
    (a) Humerus of frog (b) Humerus of rabbit
    (c) Femur of frog (d) Femur of rabbit
18. Olecranon process is formed by :
    (a) Proximal end of ulna (b) Distal end of ulna
    (c) Proximal end of radius (d) Distal end of radius
19. Longest bone in the body of rabbit is :
    (a) Humerus (b) Femur
    (c) Tibia (d) Ulna
20. Shortest bone in the body of rabbit is :
    (a) Tibia (b) Ulna
    (c) Stapes
    (d) Fibula

ANSWERS

1. (c) 2. (a) 3. (b) 4. (b) 5. (a) 6. (b) 7. (b) 8. (a) 9. (a) 10. (a) 11. (a) 12. (b) 13. (a) 14. (a) 15. (c) 16. (c) 17. (b) 18. (a) 19. (b) 20. (c).

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Introduction to Vertebrate Embryology

Embryogenesis and Embryology

Embryogenesis or *embryogeny* may be defined as the formation and development of embryos. In fact it includes all the changes by which a fertilized ovum or zygote is transformed into an adult. So long as the developing individual remains in the egg, it is called an *embryo*. In some lower animals the amount of yolk is less in egg, so that the embryo hatches in an earlier stage of development, called a *larva*. Usually, it is very different in form and structure from the adult. Examples are *caterpillars* of insects and *tadpoles* of frogs. The larva undergoes transformation into the adult by the process of *metamorphosis*. In higher vertebrates like reptiles, birds and mammals, the eggs are richly supplied with yolk. Their embryos continue development until they attain a form resembling the adult. Examples are *chicks* of birds and *foetuses* of mammals.

Embryology is that branch of Zoology which deals with the development of animals. It is a much broader term, including generalizations and details not implied by the term embryogeny. Embryology contributes a great deal to an understanding of adult anatomy, and therefore to comparative morphology.

Historical review

Aristotle 384-322 B.C. was the first Greek philosopher who described the ontogenic development of chick and many other forms. This doctrines about the development were accepted for a very long time. Harvey (1651) and Malpighi (1672) contributed information on the various stages of the development of chick on the basis of their studies with the help of the simple lens. With the discovery of the microscope, Leuwenhock (1677) described the sperm of man and other mammals. Von Baer (1827) identified the mammalian egg.

The earlier embryologists did not have a clear idea about the functions of the sperm and the ovum. They conceived that the sex cells contain preformed miniatures of the adult. Casper Friedrich Wolff (1759) offered on experimental evidence that no preformed embryo existed in the egg of chick. He suggested that during embryonic development, the organs formed successively in an epigenetic manner. He advocated that the future embryonic regions of an egg first consists of granules or globules, lacking in any arrangement that can be related directly to the form or structure of the future embryo. Later, these globules were arranged into rudiments which can be called the germinal layers. This method of progressive development from simpler to more complex through the utilization or building units (globules) is called epigenesis. Today this theory is accepted in a modified form.

Von Baer (1792-1876) the father of modern biology made many outstanding investigations. He established the Baer's law which states. "More general features that are common to all the members of a group of animals, developed earlier than the more special features which distinguish the various members of the group."

In 1824 Prevost and Duman described cleavage or segmentation of the egg. Hertwig in 1875 observed the main events taking plane in fertilization of an egg by a sperm. Von Bender (1883) proved that the male and the female sex cells contribute the equal number of chromosomes to the fertilized egg. During the last days of Nineteenth and early days of Twentieth century, embryologists like Weismann (1883), Endnes (1885), Spermann (1901 and 1903) and Morgan (1908) made experimental and analytical investigations and thus a new branch of embryology way the experimental embryology was initiated. Weisman suggested convincingly that a child in no way inherits its characters from the bodies of the parents but from the sex cells alone. There germ cells in turn, acquired their characters directly from the preexisting germ cells of the same kind.

Wilhelm Roux in 1888 performed an important experiment on frogs. At the two celled stage of development, he destroyed one of the cells by hot needle and observed that the remaining cell had its own potentialities as it developed into one half blastula and one half gastrula. He described that the material of the egg is differentially distributed in the animal pole and the vegetal pole. In the frog egg, the animal pole had pigmented material and developed into head region while the vegetal pole had yolky cytoplasm this region developed into posterior region of the embryo.

Whole gastrula and finally whole larva but of reduced size on the basis of his experiment Driesh (1891) suggested that early cleavages of the egg are equational and have a "quantitative division of homogeneous material therefore the blastomeres have equal potentialities and their fate is determined by their position. Child (1940) showed that there exist differences in the rate of general metabolism in the ooplasm of animal and vegetal hemispheres of oocytes and cleaving eggs of sea urchin and starfish. It is a fact that the cytoplasm of the animal pole of egg divides with high frequency and this frequency gradually becomes progressively low towards the vegetal pole. Ooplasm of the animal pole has high metabolic rate which gradually decreases towards vegetal pole and this a metabolic axial gradient exists along the animal-vegetal axis.

Horstadius (1955) and Runns strom (1967) modified the gradient theory of Child. According to them there is a double gradient system (animal gradients and vegetal gradient) to control morphogeneus and differentiation in the early development of sea urchin eggs. Horstadius and Josefsson (1969) identified specific animalizing and vegetalizing substances, one contaning tryptophane and the other a nucleotide respectively in the mature unfertilized eggs.

Spermann and Hilde Mangold (1927) had suggested that there are interactions between the parts of the developing embryos. These interactions assure that the parts will develop in them proper positions as well regulate their relative sizes. This is true even when the parts are experimentally disarranged. They postulated the concept of induction as a basic mechanism in the embryonic development. According to them one of your tissue may transmit a stimulus that influences another tissue to produce a structure that otherwise would not come into being. The former tissue is called inductor or organizer and its morphogenetic effect is called induction.

Modern Embryology

With the discovery of the chromosomes, genes and genetic code, its has become evidents that all the properties of any organism are determined by the sequence of the triplets in the DNA molecule. The sequence of the base triplets can directly determine what kind of proteins can be produced by an organism. All the morphological and physiological manifestations of an organism depend on the assortment of proteins, coded for by the hereditary DNA. The modern embryology is heading towards analytical embryology on the basis of the analysis through molecular biology techniques.

Scope of Embryology

Embryology is the most important biological science today. It explains the details of the ontogenic development of an animal from a single fertilized cell. It gives basic information about the physiology, genetics, sex determination, various diseases and organic evolution. It also explains many facts that can be used in the repair of the tissue injury. In medical science, it explains the causes of pathological conditions, infantile disorders and unusual patterns of development. With the success in cloning experiments of Ian Wilmut (1996) a new concept of cloning without involving germ cells has originated which hit open new dimensions for the economic use of the biological resources.

Gametogenesis

Sexual reproduction is the most common method of reproduction in Metazoa, in which a male gamete, the *sperm,* fuses with a female gamete, the *ovum,* in a process called *fertilization.* Formation of sex cells or gametes is termed *gametogenesis.* It is accompanied by a special type of nuclear division, called *meiosis.* As a result, the nuclei of gametes formed contain only half or *haploid* number of chromosomes. When male and female sex cells unite at the time of fertilization, the resulting cell or *zygote* again has the full or *diploid* number of chromosomes.

Production of male germ cells, the *sperms* or *spermatozoa,* occurs in the male gonads, the *testes,* by a process called *spermatogenesis.* Each sperm consists of a head, middle piece and tail. The term 'spermatozoa' perpetuates an error. It literally means 'sperm animals' and was proposed when these cells were themselves considered to be animals living in the bodies of higher animals. It is preferable to call them sperm cells or simply sperms.

Production of female germ cells, the *ova,* takes place in the female gonads, the *ovaries,* and the process is termed *oogenesis.* The word 'egg' is often loosely used for ova or secondary oocytes. It may be reserved for more complex structures such as the hen's egg which may even contain early embryonic stages.

Processes of *meiosis* and *gametogenesis* are described in full details in all texts of Cytology, Genetics and Histology, so that it is not necessary to describe them in this textbook.

Fertilization or Zygote Formation

Fertilization may be defined as the union of ovum and sperm to form the zygote.

Process of fertilization. Details of the process of fertilization are variable in different animals, but the essential facts remain the same. Usually the entire sperm cell enters the cytoplasm of the ovum. In some cases the tail of sperm is left outside and only its nucleus, centriole and very little cytoplasm enter. Entry of sperm may take place before or after the completion of second maturation division of ovum. Nucleus of ovum is known as *female pronucleus* and that of sperm, *male pronucleus.* Fertilization may be said to be completed when the two pronuclei merge or fuse to form the *zygote nucleus.*

Effects and significance. Fertilization has several important effects. Main results may be summarised as follows :

(1) Union of haploid nuclei of two gametes restores the *diploid* number of chromosomes in zygote.
(2) Rapid chemical changes in cytoplasm of zygote render it incapable of penetration by other sperms. If *polyspermy* (entrance of several sperms) occurs, nucleus of one sperm only fuses with that of ovum, while other sperms soon degenerate.
(3) With slight decrease in volume of zygote, a fluid-filled space appears between it and the vitelline membrane, called *perivitelline space* and dense granular materials (derivatives of cortical granules) get deposited on the inner side of the membrane which now becomes the *fertilization membrane* and permits movements of zygote inside.
(4) It provides stimulus for ovum to complete its *maturation.* Formation of second polar body

(mammals) or both polar bodies occurs only after entry of sperm into ovum.

(5) It introduces *centrosome* which is lacking in mature ovum.

(6) Entry of sperm *activates* ovum to undergo cleavage or further development. However, there are notable exceptions. In honey-bee, unfertilized ova develop into male bees (drones). Similarly, in aphids, several successive generations in life cycle arise from unfertilized ova. These are cases of *natural parthenogenesis* which means development without fertilization. On the other hand, successful experiments have been carried out in which unfertilized ova of starfish, sea urchins, certain fish, frog, rabbit, etc. were caused to develop without the aid of sperms but by some artificial stimulation—mechanical, thermal or chemical. These are cases of *artificial parthenogenesis.* These prove that activation is not a result due to union of two gametic nuclei.

Types of fertilization. Time, place and modes of fertilization also vary depending upon the habitats and egg-laying habits of different animals. Most animals, specially the higher ones, are *unisexual* (dioecious). They are either males producing sperms, or females producing ova (e.g. rabbit, man). When male and female gametes from two different individuals fuse, this is called *cross-fertilization.* Some animals, specially the lower one, are *bisexual* (monoecious or hermaphrodite). They are capable of producing both ova and sperms, but majority of them cross-fertilize (e.g. *Hydra).* However, in some bisexual animals (e.g. tapeworms), ova and sperms within the same individual are capable of fertilization. This is known as *self-fertilization.*

Fertilization necessitates discharge of ova and sperms in close proximity. This may be accomplished in water in aquatic animals, or in special cavities of the female, more commonly in land animals. In most *aquatic animals,* such as echinoderms (starfish, urchins), many fish and amphibians (frogs), both ova and sperms are laid directly into water where they fertilize. This is called *external fertilization* taking place outside the body of parents. In other aquatic animals (e.g. crayfish, cephalopods) and in most *terrestrial animals,* the male deposits sperms, during *copulation,* either into the oviduct of female (e.g. vertebrates) or into special receptacles called *spermathecae* (e.g. earthworms, insects, spiders), so that fertilization takes place inside the body of female. This is called *internal fertilization.*

Animals that lay eggs are called *oviparous.* In echinoderms, fish, frogs, etc. eggs are laid before fertilization. In insects, spiders, reptiles, birds and monotremes, the eggs are laid after internal fertilization. In certain animals such as sharks and viper snakes, fertilized eggs are large, shelled and heavily yolked. They are incubated and hatched within the mother's body so that young are produced which are not nourished by the mother. These are called *ovoviviparous animals.* Higher mammals (Metatheria and Eutheria) and some others (e.g. *Peripatus*) also give birth to living young ones. They produce small almost yolkless eggs, which develop within the body of the mother and nourished from her blood stream through a special embryonic organ called placenta, until the fully developed young are born.

Types of Eggs

Eggs are of three general types according to the amount and distribution of yolk. Yolk concentration *(lecithality)* is important in determining the size of egg and the type of cleavage and early embryonic development.

1. Homolecithal or isolecithal. Eggs are small with a small quantity of yolk, fine grained and evenly distributed throughout the cytoplasm. Ova of placental mammals (including man) and many invertebrates are *alecithal,* without or with a very little amount of yolk. Ova of *Herdmania* and *Branchiostoma* are *microlecithal,* containing a small amount of yolk.

2. Telolecithal. Telolecithal eggs contain relatively more yolk, concentrated at the vegetative (or vegetal) pole. The animal pole is practically without yolk. *Mesolecithal* eggs are typical of cyclostomes, fish and amphibians. They are fairly

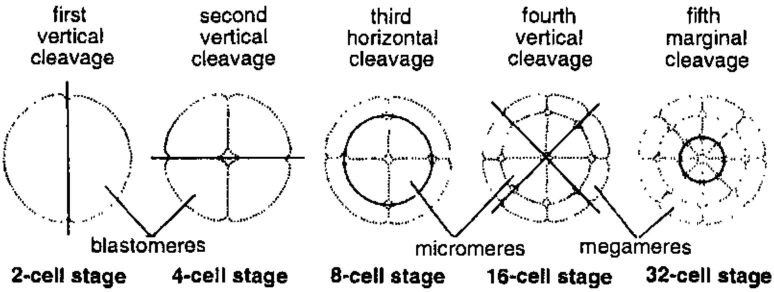

Fig. 1. Planes of early cleavage of zygote.

large in size and contain a moderate amount of yolk. In contrast, the *macrolecithal* or *polylecithal* eggs of bony fishes, reptiles, birds and egg-laying mammals (monotremes) are very large containing enormous amount of yolk leaving cytoplasm as a small germinal disc at the upper or animal pole.

3. Centrolecithal. In insects and other arthropods, eggs are centrolecithal. Size is relatively small, containing a fair amount of yolk concentrated centrally and surrounded by a peripheral layer of cytoplasm. No chordate has centrolecithal eggs.

Types of Cleavage or Segmentation

The term *cleavage* or *segmentation* is applied to the early repeated mitotic divisions of the fertilized egg or zygote, resulting in 2, 4, 8, 16 and more daughter cells called *blastomeres*. The daughter cells do not separate but remain attached with one another forming embryonic stages (Fig. 1).

Several types of cleavage patterns are recognized. According to *potentialities* of early blastomeres, cleavage may be determinate or indeterminate.

1. Determinate. In determinate cleavage, each early blastomere is destined to become a particular portion of embryo. Ex. *Ascaris*, some tunicates.

2. Indeterminate. In contrast, early blastomeres are equivalent in their potentialities. If separated, each will give rise to a complete normal embryo. Ex. All chordates.

According to furrows, cleavage is of two types : radial and spiral.

1. Radial. In radial cleavage, the furrows line up in successive tiers.

2. Spiral. In spiral cleavage, the furrows are at right angles to each other.

The type of egg according to the amount of yolk (lecithality) also determines the type of cleavage and the method of blastulation, gastrulation and further development. Accordingly, 3 main types of cleavage are recognized.

1. Holoblastic. Alecithal, homolecithal and mesolecithal eggs show rapid and complete division of zygote, called *total* or *holoblastic cleavage*. Resulting 8 blastomeres after the third cleavage may be equal or unequal to each other. Accordingly there are two variations. If blastomeres are approximately equal, it is total but *equal holoblastic cleavage*, as in echinoderms, amphioxus and placental mammals. If the upper 4 blastomeres are smaller (micromeres) than the lower 4 yolk-laden larger blastomeres (macromeres), it is total but *unequal holoblastic cleavage*, as in fish and amphibians.

2. Meroblastic and discoidal. It is characteristic of large polylecithal eggs as in most fishes, reptiles, birds and egg-laying mammals. The cleavage furrow can not cut through the enormous yolk present so that the entire egg is not divided into cells. Thus cleavage is incomplete or partial, termed *meroblastic*. Cleavages are restricted only to the small cytoplasmic cap at the animal pole resulting in a rounded embryonic or germinal disc. Accordingly, the cleavage is termed *discoidal.*

3. Superficial. It is characteristic of centrolecithal eggs of arthropods. Cell division is restricted to a superficial peripheral layer of cytoplasm around yolk, hence the term *superficial cleavage.*

A distinct geometric relationship exists between blastomeres in early cleavage divisions. These planes of divisions are of following types (Fig. 1) :

1. Meridional plane of cleavage. When cleavage furrow bisects both the poles passing through centre of the egg it is called meridional plane of cleavage. The median axis runs between centres of animal pole and vegetal pole.

2. Vertical plane of cleavage. When cleavage furrow passes any axis but not the median axis from animal pole towards opposite pole it is called vertical plane of cleavage.

3. Equatorial plane of cleavage. This type of cleavage plane divides the egg halfway between the animal and vegetal poles and the line of division runs at right angle to median axis.

4. Latitudinal plane of cleavage. This is almost similar to the equatorial plane of cleavage, but furrows runs through the cytoplasm on either side of equatorial plane.

Steps in Embryogeny

Morulation. In a typical case of embryogeny, that of a homolecithal egg (e.g. starfish, amphioxus), cleavage results in a compact mass at the stage of 16 or more cells. Due to its general resemblance to a mulberry fruit, it is called the mulberry *stage* or *morula.*

Blastulation. As cell division continues, a cavity forms within the cell mass. The cells also become smaller and arranged in the form of a single-layered *(monoblastic)* hollow ball or sphere called *blastula.* The process is called *blastulation,* the central cavity the *segmentation cavity* or *blastocoel,* and the single layer of cells the *blastoderm.*

Gastrulation. Cells on one side of blastula may begin to invaginate (infold) or move into its interior. As invagination increases, blastocoel is gradually obliterated. A new cavity is formed, called *gastrocoel* or *archenteron,* bounded by the invaginated cells and opening to outside through a *blastopore.* Thus, monoblastic blastula is converted into a *diploblastic* embryo, the *gastrula.* The process of its formation is called *gastrulation* whereby presumptive (future) endoderm and notochordal tissue of blastula migrate to the interior of gastrula. In the two-layered gastrula, outer layer is *epiblast* and the inner invaginated layer, the *hypoblast.* Soon a third layer, the *mesoderm,* is established between them. Thus, the embryo becomes *triploblastic.* The actual process of gastrulation differs in different vertebrates as described later in the development of individual types.

Organogeny. Ectoderm, endoderm and mesoderm are called the three *primary germ layers* (or *germinal layers).* These are formed in different ways in various animal groups depending on the types of eggs and their yolk content. The germ layers form all the tissues and organs of the body, step by step, until the adult stage is reached. This process is termed *organogenesis.* Organ-formation is accomplished by several methods, such as folding of layers, cell migration and cell differentiation after reaching destination. A detailed purview is out of scope of the present text. However, formation of nervous system *(neurulation),* notochord *(notogenesis),* mesoderm and coelom has been described briefly in the development of individual types *(Balanoglossus, Herdmania, Branchiostoma,* frog, fowl and rabbit) in subsequent chapters.

Fate of germ layers. Each of the three germ layers gives rise to definite tissues, organs and systems of the body. Their fate in embryo and adult has been listed in Table 1.

Table 1. **Chart showing Fate of Germ Layers in Vertebrates.**

Layer	Embryo			Adult
ECTODERM	Somatic ectoderm		→	Epidermis, skin derivatives, olfactory organ, lense of eye, inner ear, anterior pituitary, mouth
	Neural crest		→	Branchial skeleton, ganglia, sensory nerves, adrenal medulla
	Neural tube		→	Brain, spinal cord, motor nerves, retina, optic nerve, posterior pituitary
ENDODERM	Archenteron (primitive gut)		→	Digestive tract lining, liver, pancreas, respiratory system, bladder, thyroid, parathyroid, thymus
MESODERM	Notochord		——→	Reduced or obliterated
	Epimere	Dermatome	→	Dermis
		Sclerotome	→	Vertebral column
		Myotome	→	Skeletal muscles, appendicular skeleton
	Mesomere		——→	Excretory system, gonoducts
	Hypomere →	Somatic layer	→	Parietal peritoneum
		Splanchnic layer	→	Visceral peritoneum, mesenteries, circulatory system, gonads, visceral muscles
	Coelom		——→	Body cavities

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe various types of eggs and cleavage in chordates.
2. Define the term cleavage, blastulation and gastrulation. Give examples of different types of these.
3. Describe the process of blastulation in chordates and comment upon the importance of blastula.

» *Short Answer Type Questions*

1. Write short notes on following — (i) Blastopore, (ii) Blastula, (iii) Fertilization, (iv) Oogenesis, (v) Parthenogenesis (vi) Types of cleavage, (vii) Planes of cleavage, (viii) Scope of embryology, (ix) Germ layers and their fate.

» *Multiple Choice Questions*

1. Concept of induction was forwarded by :
   (a) Spemann and H. Mangold
   (b) Horstadius and Josefsson
   (c) Von Baer
   (d) Endnes
2. Process of sperm formation is called :
   (a) Oogenesis (b) Spermetogenesis
   (c) Gametogenesis (d) Meiosis
3. Union of sperm and ovum is called .
   (a) Parthenogenesis (b) Polyspermy
   (c) Fertilization
   (d) Karyokinesis
4. Which of the following produce centrolecithal egg :
   (a) Mammals (b) Fishes
   (c) Amphibians (d) Insects
5. Cleavage in which furrows are at right angle to each other is called :
   (a) Radial (b) Spiral
   (c) Determinate (d) Indeterminate
6. Meroblastic and discoidal cleavage is characteristic of :
   (a) Centrolecithal eggs (b) polylecithal egg
   (c) Mesolecithal egg (d) Alecithal egg
7. Formation of archenteron occurs in which of the following stage of development :
   (a) Blastulation (b) Organogeny
   (c) Gastrulation (d) Cleavage

8. Coelome is formed from which of the following germ layer :
   (a) Ectoderm (b) Mesoderm
   (c) Endoderm (d) All the three
9. Which of the following is mesodermal in origin :
   (a) Neural tube (b) Archenteron
   (c) Notochord (d) None of these
10. Brain is formed from :
    (a) Embryonic neural tube (b) Coelome
    (c) Neural crest (d) None of these
11. In honey bee domes are formed by :
    (a) Parthenogenesis (b) Fertilization
    (c) Oogenesis (d) All these
12. In the two layered gastrula the inner invaginative layer is :
    (a) Ectoderm (b) Mesoderm
    (c) Endoderm (d) All three
13. Embryo becomes triploblastic during :
    (a) Blastulation (b) Gastrulation
    (c) Cleavage (d) Organogeny
14. Mass of cells formed after cleavage is known as :
    (a) Blastulla (b) Morula
    (c) Gastrula (d) Both a and b
15. Superficial cleavage is found in :
    (a) Star fish (b) Frog
    (c) Man (d) Cockroach
16. Which of the following layer is formed at last during gastrulation :
    (a) Ectoderm (b) Mesoderm
    (c) Endoderm (d) None of these
17. Mesoderm is derived from :
    (a) Ectoderm (b) Endoderm
    (c) Both these (d) None of these
18. When cleavage furrow bisects both the poles passing through centre of the egg and median axis runs between centers of animal pole and vegetal pole. It is called :
    (a) Meridional plane of cleavage
    (b) Vertical plane of cleavage
    (c) Equatorial plane of cleavage
    (d) Latitudinal plane of cleavage

ANSWERS

1. (a) 2. (b) 3. (c) 4. (d) 5. (b) 6. (b) 7. (c) 8. (b) 9. (c) 10. (a) 11. (a) 12. (c) 13. (b) 14. (b) 15. (d) 16. (b) 17. (c) 18. (a).

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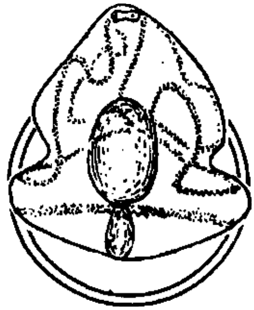

Development of *Balanoglossus*

Asexual reproduction is rare phenomenon in hemichordates but Gilchrist (1923) reported asexual reproduction in *Balanoglossus capensis*. In summer months isolated parts of tail of *juvenile phase* develop completely into adult in subsequent winters. During sexual reproduction *zygote* of *Balanoglossus* develops either *directly* or *indirectly* depending on its size. The small fertilized eggs develop indirectly but large fertilized eggs develop directly. The indirect development is through a larval form called *tornaria larva*. In both the cases early phases of the development are same.

Fertilization

During breeding season (May to June), mature sperms and ova escape into the surrounding sea water where fertilization takes place. Thus, fertilization is external.

Indirect Development

Indirect type of development is studied in *Balanoglossus clavigerus* by workers like Heider (1909), Stiansy (1914) and Payne (1937).

Embryonic or prelarval development

The prelarval development is similar to that of *Branchiostoma*. The zygote, produced as a result of fertilization, undergoes *cleavage* which is *holoblastic*, almost *equal* and of *radial* type (Fig. 1). It results into a sphere of blastomeres, the *morula*. First *cleavage* is vertical. The second is also vertical but at right angle to the former. Third cleavage is horizontal and results into 8 *blastomeres* of unequal sizes, upper ones are smaller *micromeres* and lower ones are larger the *macromeres*. The morula undergoes reorganization

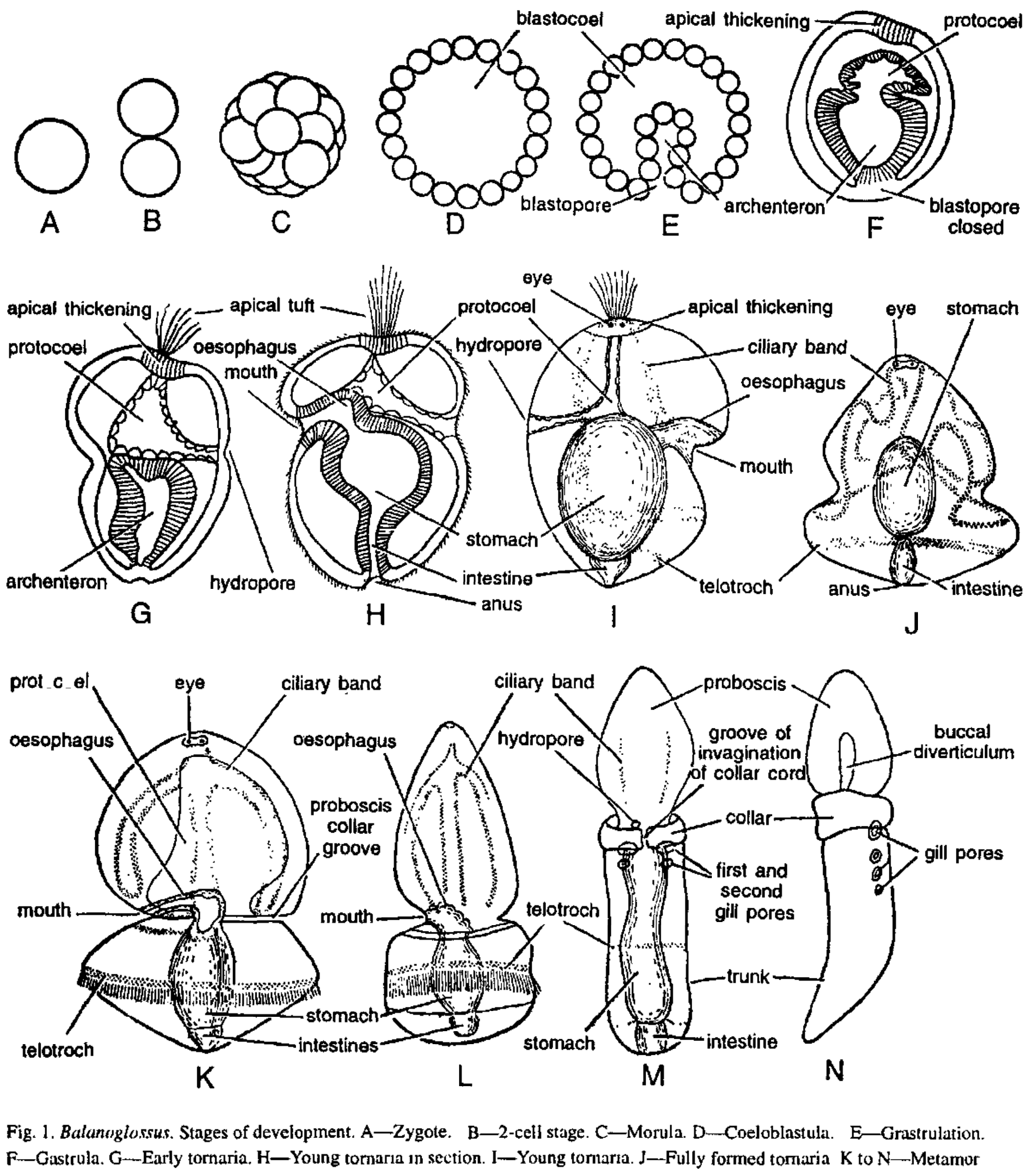

Fig. 1. *Balanoglossus*. Stages of development. A—Zygote. B—2-cell stage. C—Morula. D—Coeloblastula. E—Grastrulation. F—Gastrula. G—Early tornaria. H—Young tornaria in section. I—Young tornaria. J—Fully formed tornaria K to N—Metamorphosis of tornaria into a young worm.

of its blastomeres and takes the form of a single-layered, hollow and spherical embryo, the *blastula* or *coeloblastula*. Its central fluid-filled cavity is called the *blastocoel*. Blastula results in about 6-15 hours after fertilization. Within 12 to 24 hours, an invagination starts in the blastula which deepens to form the *archenteron* that opens to outside through a *blastopore*. Soon the blastopore closes and the embryo, now called *gastrula*, lengthens along the anteroposterior axis. Now the tip of the archenteron is pinched off as a coelomic vesicle called the *protocoel*. Thus origin of coelom is *enterocoelic*. The remaining portion marks the future *gut*. The protocoel becomes triangular in shape. Its one end gets attached to the underside of the apical thickening and another end opens to outside through an aperture, the *hydropore*, towards the dorsal side of the embryo. The protocoel and hydropore are the future *proboscis coelom* and *proboscis pore*, respectively. The collar and trunk coelom arise as solid invaginations of the hindgut, independent of the formation of protocoel (Fig. 1).

Larval development

With the formation of the protocoel, the inner end of the early gut moves towards the ventral surface and opens to outside through a *mouth*. The gut is now regionated into the oesophagus, stomach and intestine. The intestine opens to outside through an *anus*, formed at the side of the closed blastopore. By this time the embryo becomes uniformly *ciliated* and escapes from the egg membrane on 7th day to lead a free swimming larval life. It is called *tornaria*.

Tornaria larva

Tornaria larva was first described by J. Muller in 1850 who suspected it to be the larva of some starfish. Later on it was known to belong to *Balanoglossus clavigerus*. It is so called because of its habit of rotating in circles. It is clear, glossy in appearance with an oval body ranging upto 3 mm in size. It has a ventral mouth near the equatorial plane of the body, a posterior terminal anus and gut differentiated into an oesophagus, stomach and intestine. The cilia form two bands on the body surface. The anterior *ciliary band* or *circumoral band* takes up a winding course over the preoral surface and forms a postoral loop, its cilia are short and serve to collect food. The posterior ciliated band or *telotroch*, occurs as a ring in front of the anus, its cilia are long and serve as locomotor organs. At the anterior end is an *apical plate* of thickened epidermal cells, which bears a pair of eye spots or *ocelli* and a tuft of sensory cilia called *apical tuft* or *ciliary organ* eyes are cup shaped, cavity of the cup is filled with clear material constituting the *lens*. Cells of the cup are provided with pigment granules. The *protocoel* (proboscis coelom) in the form of a thin-walled sàc, is present and opens to the exterior through a *hydropore* (proboscis pore). To the right of the hydropore lies a pulsating *heart vesicle*. The collar and trunk coeloms appear in the older larva.

Metamorphosis

The larva swims freely, leads a planktonic life, feeding on minute organisms, and metamorphoses into an adult worm. During metamorphosis, the size is reduced probably due to loss of water. Transparency, ciliary bands, sensory cilia and eye spots are lost. Body becomes differentiated into proboscis, collar and trunk by the appearance of two constrictions, and the trunk region is elongated. The hydropore persists as proboscis pore, and the buccal diverticulum and gill-slits appear as outgrowths of the alimentary canal. Reproductive organs mark their presence, probably they develop from mesoderm. Tongue bar grows. An adhesive post anal tail is formed which helps in anchoring the young worms and later resorbed. The animal now sinks to the bottom to lead a benthonic life as an adult.

Direct Development

Direct development is found mostly in the genus *Saccoglossus*. It is found in the large eggs provided with good amount of yolk. In this case *tornaria larva* is not formed. *Blastopore* of the *gastrula* narrows down and finally closes. *Cilia* develops on the general surface of the gastrula stage of the embryo. Later embryo becomes free and swims in water for about 24-26 hrs. The embryo elongates and becomes more worm like. A *transverse groove* appears and mouth develops by *invagination* on the position of groove. The *anus* develops at the position earlier occupied by blastopore. Before formation of mouth, a *diverticulum* is separated off in the anterior region from the *archenteron*. The cavity of this forms the *proboscis coelome*. Paired *collar trunk coelome* is formed as outgrowth from the posterior wall of the proboscis cavity directly from the walls of archenteron. At this stage structures elongate and get differentiated into *proboscis*, *collar*, *trunk* etc.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the development of *Balanoglossus* and point out its affinities.
2. Give an account of structure and metamorphosis of tornaria larva of *Balanoglossus*.

» *Short Answer Type Questions*

1. Write notes on— (i) Tornaria larva. (ii) Direct development of hemichordates, (iii) Indirect development of hemichordates, (iv) Asexual reproduction in *Balanoglossus*.

» *Multiple Choice Questions*

1. *Balanoglossus* reproduce :
   (a) Asexually (b) Sexually
   (c) Parthenogenetically (d) Both a and b
2. Development in Hemichordate is :
   (a) Direct (b) Indirect
   (c) Both direct and indirect (c) None of these
3. In *Balanoglossus* cleavage is :
   (a) Radial (b) Superficial
   (c) Discoidal (d) None of these
4. Coelome in *Balanoglossus* is :
   (a) Protocoelic (b) Enterocoelic
   (c) Schizocoelic
   (d) Acoelic
5. Larval form of *Balanoglossus* is called :
   (a) Tornaria larva (b) Trochophore larva
   (c) Tadpole larva
   (b) Pluteus larva

ANSWERS

1 (d) 2. (c) 3. (a) 4. (a) 5. (a)

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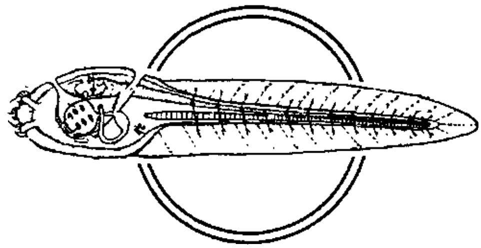

Development of *Herdmania*

Development of *Herdmania* has been described by Sebastian (1953) and Das (1957). Development is *indirect* involving a free-swimming *tadpole larva.* Tunicates (e.g. *Herdmania*) furnish one of the best examples of *retrogressive metamorphosis* in which the highly developed tadpole larva undergoes retrogressive changes to become the most degenerated and sedentary adult. Though common in some nonchordates this phenomenon of retrogressive metamorphosis is peculiar to urochordates and provides a clue to their chordate nature.

Fertilization

Fertilization is external. Although *Herdmania* is hermaphrodite, self- fertilization does not occur due to *protogyny* as female gametes become mature and discharged earlier than the male gametes of the same individual. Therefore, mature sperms of older individuals and mature ova of younger individuals, liberated in their cloaca, pass out through their atrial apertures into the surrounding sea water where *cross-fertilization* takes place.

Presumptive Areas

Entry of sperm into ovum results in movements of ovum's cytoplasm (ooplasm), so that the fertilized egg or zygote is mosaic, i.e., it shows *presumptive areas* with predictable future.

Embryonic or Prelarval Development

Cleavage or *segmentation* begins about half an hour after fertilization. It is holoblastic (complete), somewhat unequal and determinate, i.e., the fate of blastomeres is predetermined. The first cleavage is vertical, meridional and divides the gray crescent into two equal parts. Second cleavage is also vertical but at right angle to the first. The resultant four blastomeres are different. Two smaller blastomeres are at posterior side and two larger blastomeres are at front. Only two of these four contain parts of gray crescent. The third cleavage is horizontal and passes little above the equator which divides the blastomeres into 8 cells arranged in two tiers. Fourth cleavage results into 16 blastomeres. Subsequently, cleavage becomes irregular and finally result into a solid ball of cells

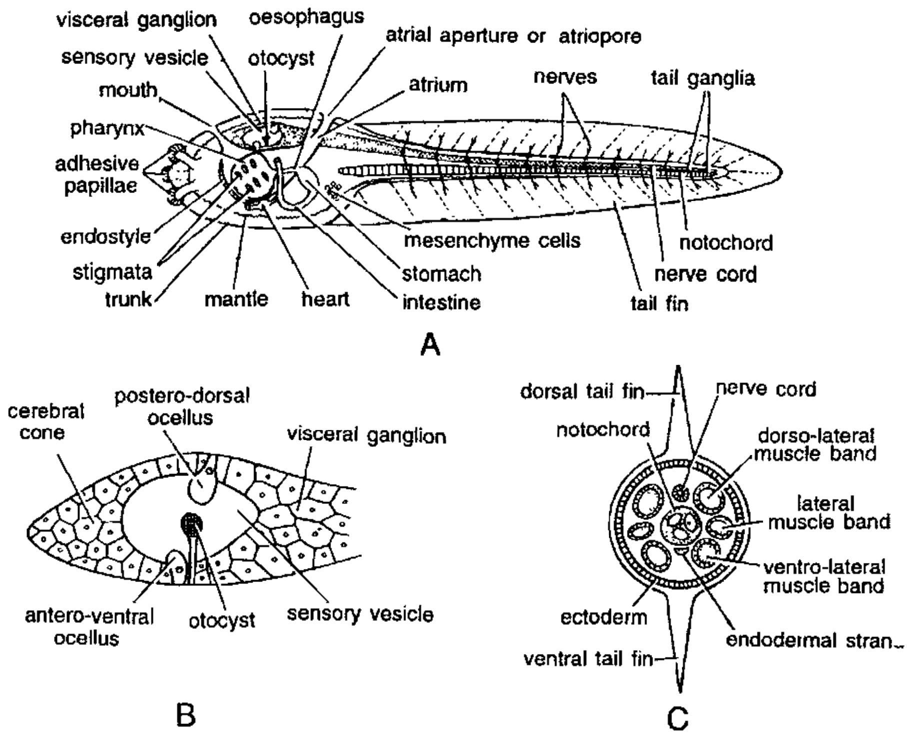

Fig. 1. *Herdmania*. A—Tadpole in left lateral view. B—Sensory vesicle enlarged. C—Tail of tadpole in T.S.

called *morula*. A single-layered flat *coeloblastula* with an internal fluid filled segmentation cavity or *blastocoel* is formed at 64-cell stage. In all it takes about 110 minutes. *Gastrulation* follows by emboly or invagination forming *archenteron* opening by *blastopore*.

Larval Development

The blastopore closes and develops a rudiment of tail. The embryo elongates and forms a tailed larva. The presumptive notochordal cells separated from roof of archenteron, occupy the central core of larval tail. Archenteron produces presumptive mesoderm as solid bands and not as hollow coelomic sacs as in *Balanoglossus* or *Branchiostoma*. About 8 hours after fertilization, the chorions rupture, probably dissolved by an enzyme secreted by the inner follicle cells, and the fully formed larva hatches out to become free-swimming.

Tadpole larva

The ascidian larva is called *tadpole larva* because of its resemblance to a small tadpole. Formation of tadpole larva takes about 10-12 hrs, after the egg is fertilized. It is transparent, minute, about 1.2 mm long, 02-0.3 mm wide and highly motile. The entire body is covered by a thin *tunic* or *test* secreted by ectoderm and shows two distinct divisions—a short oval anterior *trunk* or *head* and a long posterior *tail* (Fig. 1).

1. Head or trunk. The trunk is about 0.3 mm long and cylindrical. Its anterior end has three stalked *adhesive papillae*, two dorso-lateral and one ventro-median. These are made of secretory ectodermal cells and serve for attachment during metamorphosis. Situated in the dorsal part of the trunk is an oval, hollow *sensory vesicle* or *brain*. Its wall is made of a single layer of cells. It encloses the larval sensory organs, two *ocelli*

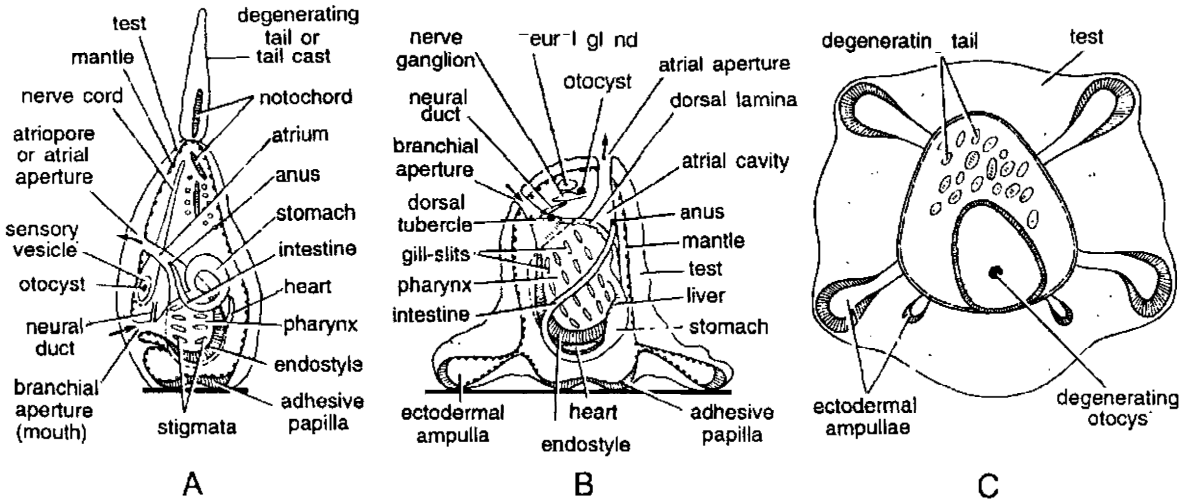

Fig. 2. *Herdmania*. Stages showing retrogressive metamorphosis. A—Recently attached larva showing degeneration of tail. B—Young adult in side view. C—Young adult in dorsal view.

which are photoreceptors, and a single *otocyst* or *otolith* which serves to maintain equilibrium. In front of sensory vesicle is a conical solid mass of nerve cells, called *cerebral cone*. Behind the vesicle is a thickened solid mass of nerve cells, called *visceral ganglion*, which is continued into the tubular *nerve cord* upto the tip of the tail. *Mouth* is situated antero-dorsally leading into a rudimentary *alimentary canal*, comprising a narrow branchial siphon, a large sac-like pharynx, a short narrow oesophagus, a swollen stomach, a slender intestine and a small rectum. The *anus* opens into the left side of atrium. The *pharynx* has a well developed *endostyle* and initially one pair of large gill-slits which split to form six stigmata on either side. The *atrium* surrounds the pharynx laterally and dorsally and leads outsides by a posterior mid-dorsal *atrial aperture*. The pericardium containing heart lies below the posterior end of pharynx. *Mesenchyme cells* occur scattered all over the body beneath the ectoderm and also in a mass in the posterior region of trunk.

2. Tail. The locomotory organ of tadpole larva is its powerful transparent *tail*. It is about 0.9 mm long, laterally compressed and pointed terminally. It is fringed with a continuous vertical *tail fin* formed by the test and marked with oblique striations looking like fin-rays. *Notochord* forms the supporting axial skeletal rod restricted to the tail. It is formed by a single row of turgid vacuolated cells. The anterior end of notochord slightly projects into the trunk. Above the notochord is present the hollow *nerve cord* bearing tail *ganglia* from which fine *nerves* arise. A strand of endoderm cells lies below the notochord. Tail also contains strong *muscle bands* which show a superficial segmentation similar to vertebrate myotomes.

Habits and Habitat of Larva

Just after hatching, the larva is photopositive and geonegative. It can not feed because its mouth is still closed by test. After a short active free-swimming existence lasting 3 to 4 hours, the larva becomes geo-positive, photonegative and sluggish. It sinks to the bottom, attaches itself upside down to a suitable hard substratum by adhesive papillae and undergoes rapid degeneration or *retrogressive metamorphosis* to attain adulthood. According to Berrill (1955) the selection of a suitable habitat is essential as the larva may not survive on any other habitat or may get suffocated by the bottom mud and detritus.

Retrogressive Metamorphosis

Metamorphosis of the ascidian larva is unique. It involves transformation of an active, free swimming larva with advanced characters such as axial notochord, dorsal neural tube and special sense organs, into an inert, sedentary and simple adult with only a pharynx, with stigmata and endostyle to indicate its chordate nature. This type of metamorphosis which shows retrogression or degeneration from larva to adult is referred to as *retrogressive metamorphosis* (Fig. 2). It is probably due to the sedentary mode of life of the adult. Similar strange phenomenon showing drastic changes from a complex and well organized larval stage to a simpler and extremely degenerated adult stage is seen among invertebrates in the parasitic crustacean *Sacculina*. In contrast, the common type of metamorphosis in which a less developed larva changes into a more advanced adult is called *progressive metamorphosis* as seen in *Balanoglossus*, frog, fowl, etc.

Retrogressive metamorphosis of the tadpole of *Herdmania* involves two types of changes : (i) *retrogressive* and (ii) *progressive*.

1. Retrogressive changes. It involves *degeneration*, that is, destruction of larval tissues and disappearance of some structures as follows :

(1) Long tail of larva with caudal fin shortens and finally disappears, partly absorbed and partly cast off.

(2) Caudal muscles, nerve cord and notochord disappear as they break down and are consumed by phagocytes.

(3) Adhesive papillae disappear completely.

(4) Larval sense organs (ocelli and otocyst) and sensory vesicle break down and disappear.

(5) Anterior region between point of attachment (adhesive papillae) and mouth shows rapid growth, while original dorsal side with atriopore stops growth. This causes shifting of mouth through 90°. Therefore, the final positions of branchial and atrial apertures in the adult represent the original anterior and dorsal sides of the larva.

2. Progressive changes. Some larval structures necessary for survival become more elaborated and specialized in the adult, such as :

(1) Due to loss of tail, the trunk becomes pear-shaped and four *larger ectodermal ampullae* grow out of its four corners. These firmly anchor the metamorphosing tadpole to substratum and also serve for respiration as a blood-like fluid keeps circulating through them. Soon two more *smaller ectodermal ampullae* appear dorso-laterally.

(2) Adult *neural gland* and *nerve ganglion* formed by neural tube and trunk ganglion come to lie middorsally between mouth and atriopore. The trunk ganglion itself persists as *visceral nerve*.

(3) With absorption of its test, covering mouth becomes functional and feeding begins by incoming ciliary water current.

(4) Pharynx greatly enlarges, develops blood vessels and stigmata multiply rapidly, forming *branchial sac*.

(5) Stomach enlarges, intestine elongates and gets curved, and liver develops.

(6) *Atrial cavity* becomes more extensive.

(7) *Circulatory system* with heart and pericardium develops and the gonads and gonoducts appear from larval mesodermal cells.

(8) *Test* or *tunic* spreads to cover entire animal, becomes thick, tough and vascular and attaches the animal by forming a foot if necessary.

The foregoing changes mark the beginning of a sedentary, actively feeding adult life which soon starts producing gametes, first ova and later sperms.

3. Molecular changes. Manket and Cowden (1965) studied the molecular changes taking place during metamorphosis. They studied the metabolism of protein and nucleic acid and pointed out that some protein synthesis occurs throughout the development but with the outset of metamorphosis, extensive degradation of proteins begins followed by rapid synthesis of new proteins.

Significance of ascidian tadpole

The presence of a tadpole larva in the life history of *Herdmania* and other ascidians is significant in the following ways :

1. Taxonomic significance. The larva possesses true chordate characters, such as notochord and dorsal tubular nerve cord, which are lacking in the adult. Thus, the ascidian larva provides the clue for including the ascidian under the phylum Chordata. Without larva, the true nature and taxonomic position of degenerate sedentary adult ascidians would have remained uncertain.

2. Phylogenetic significance. On the basis of recapitulation theory, the tadpole larva is considered a relic of the free-swimming ancestral vertebrates. According to one view the larva, possessing all the basic chordate characters, evolved into ancestral vertebrate by the suppression of metamorphosis and precociously developing gonads. However, this hypothesis is discarded now-a-days.

3. Dispersal. The adult being sedentary, the free-swimming habit of the larva provides the only means of dispersal of the species. It also provides chances of selecting better sites regarding food and protection thus ensuring survival of the race.

4. Embryological significance. Study of the development of *Herdmania* provides best example of mosaic eggs with a well organized, prepatterned and well differentiated ooplasm and highly determinate type of development. Moreover, ascidians are the only chordates exhibiting true retrogressive metamorphosis. The egg cortex in case of ascidians is site of morphogenetic patterning related to polar, bilateral and general organization of developing egg. Besides this, cleavage in ascidians tends to segregate cytoplasmic territories, having different biological, histochemical and biochemical properties.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Describe the development of tadpole larva of *Herdmania.*
2. What is retrogressive metamorphosis ? Discuss with special reference to the life history of an Ascidian.

» ***Short Answer Type Questions***

1. Draw labelled diagrams of— (i) Ascidian tadpole, (ii) Section of Ascidian larva.
2. Write notes on— (i) Ascidian tadpole, (ii) Retrogressive metamorphosis.

» ***Multiple Choice Questions***

1. Development of *Herdmania* is :
   (a) Direct (b) Indirect
   (c) Partly indirect (d) Both a and b
2. Fertilization in *Herdmania* is :
   (a) Internal (b) External
   (c) Both (d) None of the above
3. In *Herdmania* metamorphosis is :
   (a) Retrogressive (b) Progressive
   (c) No metamorphosis (d) Incomplete metamorphosis
4. Number of adhesive papillae on trunk of *Herdmania* larva is :
   (a) 5 (b) 8 (c) 3 (d) 2
5. The function of otocyst or otolith in tadpole of *Herdmania* is :
   (a) Photoreceptor
   (b) Touch receptor
   (c) Maintenance of equilibrium
   (d) All these
6. Just after hatching larva of *Herdmania* is :
   (a) Photopositive and geopositive
   (b) Photopositive and geonegative
   (c) Photopositive and geopositive
   (d) Photonegative and geonegative

7. The larva of *Herdmania* shows :
   (a) True chordate character
   (b) True nonchordate character
   (c) Echinodermate character
   (d) Hemochordate character
8. Fertilized eggs of *Herdmania* are :
   (a) Mosaic showing presumptive areas
   (b) Nonmosaic
   (c) Some times mosaic
   (d) All these
9. Opening of archenteron in *Herdmania* is called :
   (a) Gastropore (b) Blastopore
   (c) Archentopore (d) Coelopore
10. Archenteron in *Herdmania* produces :
   (a) Presumptive mesoderm (b) Coelomic sacs
   (c) Presumptive ectoderm (d) Tail

ANSWERS

1. (b) 2. (b) 3. (a) 4. (c) 5. (c) 6. (b) 7. (a) 8. (a) 9. (b) 10. (a)

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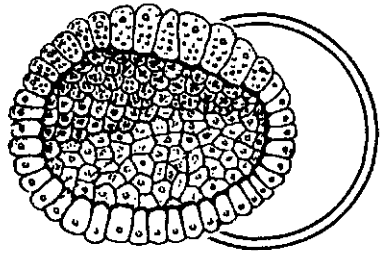

Development of *Branchiostoma*

Development is *indirect* involving a larval stage. The early embryology of *Branchiostoma* is simple and straightforward. Therefore, the transformation of egg, uncluttered by much yolk, into a complex and differentiated animal is far easier to follow than in any other vertebrate. The early development of *Amphioxus* is of great phylogenetic significance because it resembles with those of invertebrates like Echinodermates on one hand and vertebrates on the other. Development of *Amphioxus* was described by many scientists viz., Hatscheck (1882, 1888), Wilson (1883), Cerfontaine (1906) and Conklin (1932). The work of Conklin is the most recent and accepted one.

Fertilization

Fertilization is external, taking place in the surrounding sea water where eggs and spermatozoa become shed. Before fertilization, the ovum has an outer thin *vitelline membrane*, enclosing a *peripheral cytoplasmic layer*, central *yolky cytoplasm* mainly towards the vegetal pole, and a fluid-filled *germinal sac* or *nucleus* towards the animal pole. During fertilization, the sperm enters the egg near the vegetal pole (Fig. 1).

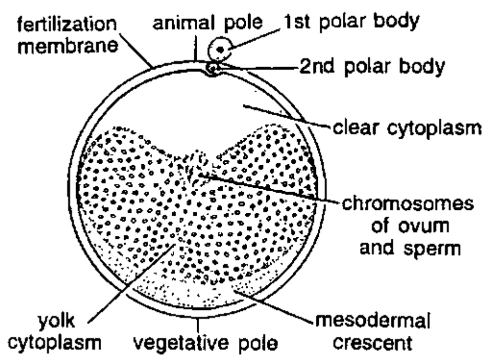

Fig. 1. *Branchiostoma*. Fertilized egg or zygote in dorsal view.

Presumptive Area

The fertilized egg or zygote is *mosaic*, diploid and has 24 chromosomes. It immediately gives out a second polar body and its cytoplasm becomes rearranged to form *presumptive areas* that form definite future organs of the animal. Clear cytoplasm of anterior half forms ectoderm, yolky

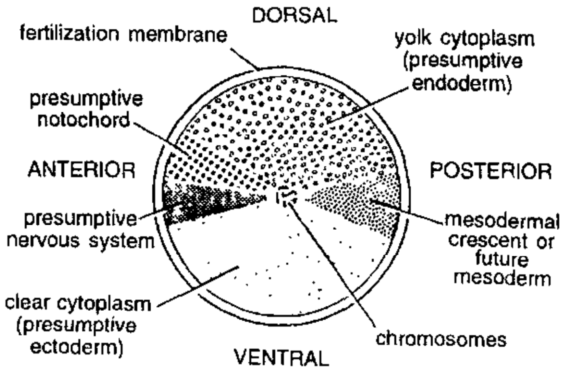

Fig. 2. *Branchiostoma* Presumptive areas of zygote in side view

cytoplasm develops into endoderm, whereas a crescent shaped granular area gives rise to mesoderm. At the animal pole, area of clear cytoplasm developed by rupture of germinal vesicle. Granular cytoplasm located in peripheral region flows downwardly towards vegetal pole and condenses to form *gray crescent* (Fig. 2).

Early Embryonic Development

1. Cleavage. Cleavage is quick process, starts soon after fertilization. Roughly it begins at sunset and completed upto morning. Before the outset of cleavage, *vitelline membrane* get separated from ooplasm and a wide cavity appears around ooplasm. Zygote of *Branchiostoma* contains very little amount of yolk so that its segmentation or division is total or complete, called *holoblastic cleavage*. The first and second cleavage are *meridional* or vertical and at right angles to each other resulting in 4 equal cells or *blastomeres*. Third cleavage is *equatorial* passing horizontally a little above the middle line producing 8 blastomeres of which upper 4 are smaller and called *micromeres*, and the lower 4 are larger called *megameres*. After sixth cleavage the embryo forms a ball-like mass of 64 cells, called *morula* (Fig. 3).

2. Blastula. Further cleavages result in a hollow ball, the *blastula*. It has a fluid-filled internal space, the *segmentation cavity* or *blastocoel*. Blastula is not spherical but somewhat pear-shaped, the posterior end slightly pointed. Its wall is thin, only one-cell thick and the cells destined to produce specific structures. Smaller,

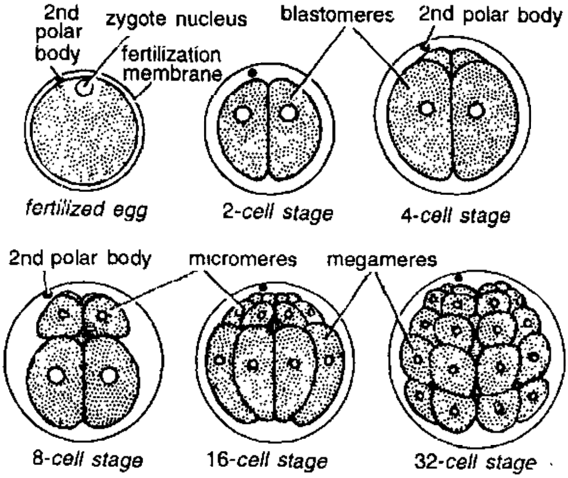

Fig. 3. *Branchiostoma*. Cleavage upto 32-cell stage.

columnar micromeres on the ventral side form the future *ectoderm*. Larger yolky macromeres on the dorsal side form the future *endoderm*. Granular cells on its postero-lateral sides are the potential *mesodermal cells*. A small antero-dorsal area contains small ectodermal potential *notochord* or

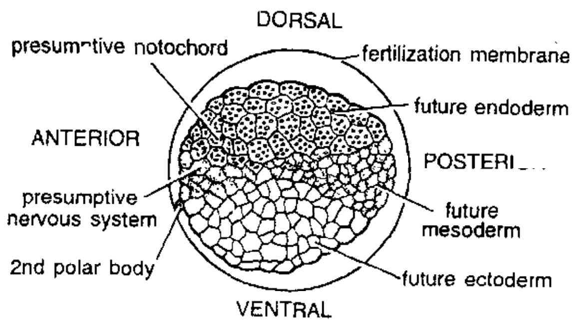

Fig. 4. *Branchiostoma*. Side view of complete blastula showing presumptive areas.

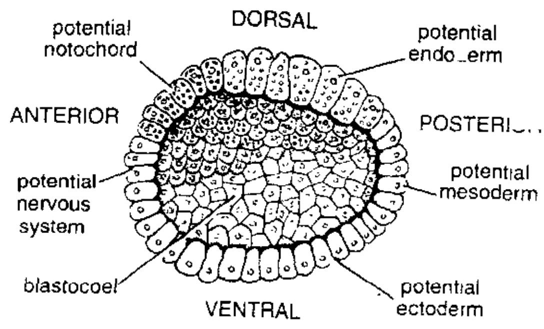

Fig. 5 *Branchiostoma*. Right sagittal half of blastula.

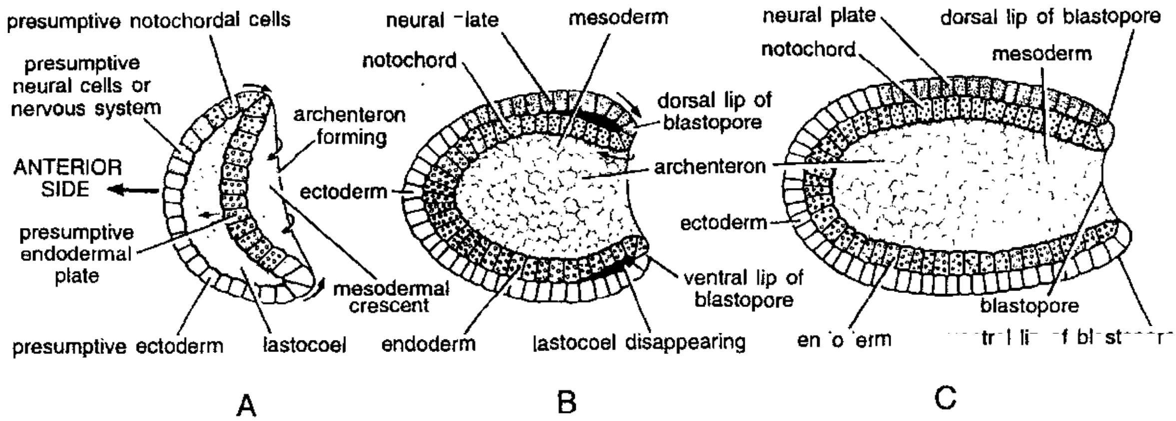

Fig. 6. *Branchiostoma*. Stages in gastrulation. A—Early gastrula. B—Mid gastrula. C—Completed gastrula.

chorda cells, and below it a small antero-ventral area includes ectodermal potential *neural plate* cells (Figs. 4 & 5).

3. Gastrula. The changes which convert the single-layered blastula into a two-layered gastrula, constitute *gastrulation.* It starts with the rapid proliferation of smaller ventral micromeres or ectodermal cells. As a result, the larger dorsal yolky megameres or endodermal cells first become flattened, then concave and gradually pushed into the blastocoel. This process is called *invagination* or *emboly.* It proceeds till the original blastocoel is completely obliterated and a secondary cavity, called *archenteron,* forms which opens to the exterior through a wide opening, the *blastopore.* The embryo now becomes bowl or cup-shaped and double-layered *gastrula.* Simultaneously, the presumptive notochordal cells roll inwards along the dorsal edge or lip of blastopore followed by the presumptive mesodermal cells rolling inwards along the lateral and ventral lips of blastopore. This process is called *involution.* At the same time, the lips of blastopore grow backwards so that the larva elongates along its antero-posterior axis with a flat dorsal surface. The dorsal lip grows faster so that blastopore shifts from dorsal to posterior end, becomes reduced to a small opening and persists as anus. The ectodermal cells forming the outer surface acquire cilia which help in the rotation of embryo inside its vitelline or fertilization membrane (Fig. 6).

Organogenesis

Synchronized with gastrulation are the process of formation of neural tube *(neuralization)*, formation of notochord *(notogenesis)*, and formation of

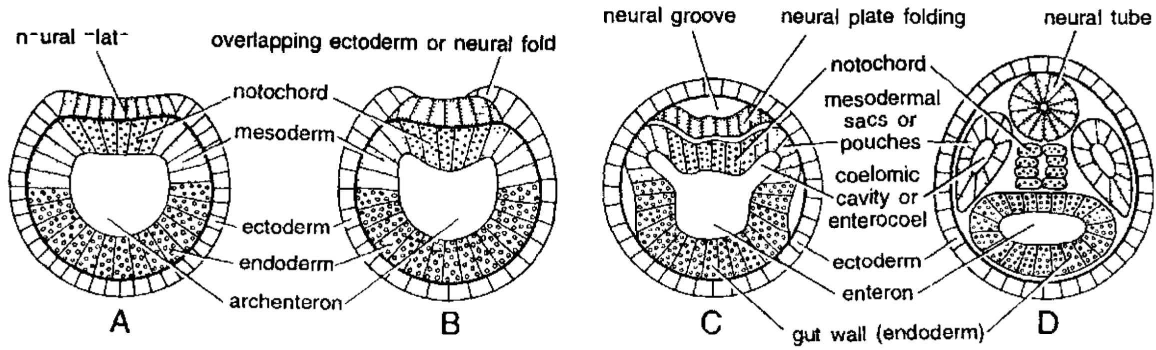

Fig. 7. *Branchiostoma*. Successive stages in the formation of central nervous system, notochord and mesodermal sacs, as seen in transverse sections. A—Completed gastrula B—Early neurula C—Mid neurula. D—Late neurula.

mesoderm *(mesogenesis)* and *coelom.* For convenience of study, the formation of each organ will be described separately (Fig. 7).

1. Formation of neural tube. The mid-dorsal ectoderm cells of gastrula become thick and large to form a *neural plate.* The centre of the plate is depressed to form a *neural groove.* Due to faster growth the cells along its two sides rise up to form longitudinal ridges called *neural folds.* The two folds meet each other and fuse over the groove forming a closed longitudinal hollow *neural tube.* The cavity of neural tube, or *neurocoel,* anteriorly opens to outside by a minute aperture, the *neuropore,* which closes in the adult forming the olfactory or Kolliker's pit. Posteriorly, the neurocoel encloses the blastopore and opens into archenteron by a small *neurenteric canal* which closes somewhat later.

2. Formation of notochord. The chorda cells situated middorsally in the roof of archenteron form the *notochordal plate.* It bulges up, towards the neural plate and finally pinched off from the archenteron to become the notochord. It elongates with the embryo, forming a solid mid-dorsal skeletal rod consisting of a linear row of *vacuolated cells.* Afterwards, it is surrounded by a *notochordal sheath* and also extends into the rostrum.

3. Formation of mesoderm, myotomes and coelom. At the time of notogenesis, the presumptive mesodermal cells in the dorso-lateral roof of archenteron also become deeply folded

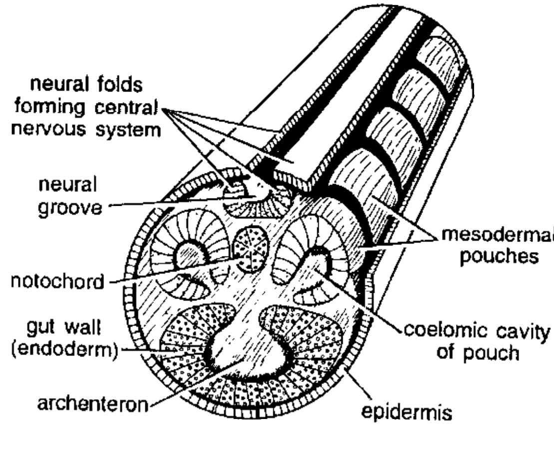

Fig. 8. Branchiostoma. Stereogram of a post-gastrular stage to show arrangement of mesodermal pouches.

forming a longitudinal fold or groove on either side. Transverse partitions appear to divide each *mesodermal groove* into a linear series of *mesodermal* or *coelomic pouches* which are in continuation with the archenteron. The mesodermal pouches represent the beginning of metameric segmentation in *Branchiostoma.* The pouches subsequently cut off from the archenteron forming closed *mesodermal sacs* or *coelomic cavities.* Thus the coelom is enterocoelic in origin. After separation of notochord and coelomic sacs, the archenteron is reduced to *enteron* and develops the midgut diverticulum of the anteriormost or first pair of sacs, the left one remains small and opens into the oral hood forming the *Hatschek's pit* and *wheel organ.* The right sac enlarges to form the

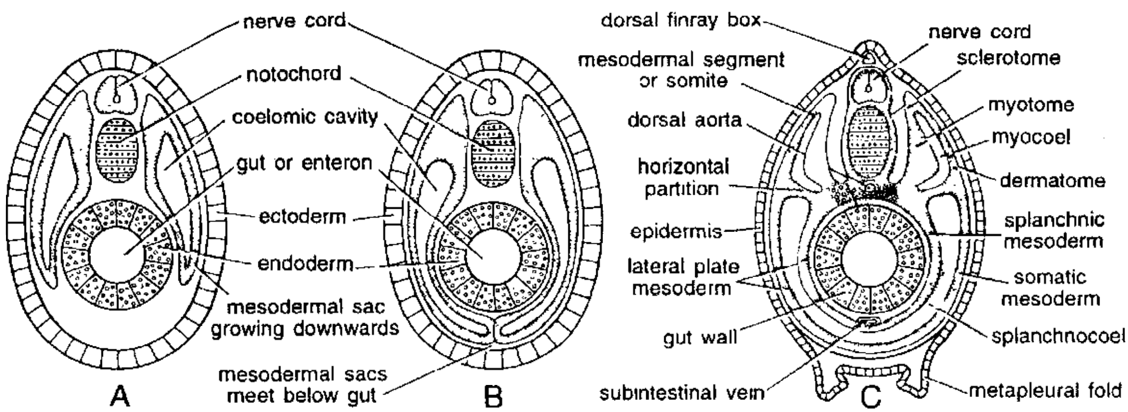

Fig. 9. *Branchiostoma.* Further stages in T.S. to show development of mesodermal somites and coelom

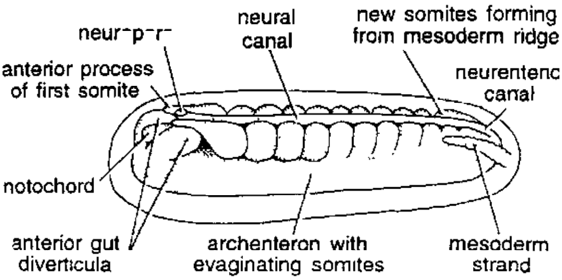

Fig. 10. *Branchiostoma*. Late neurula.

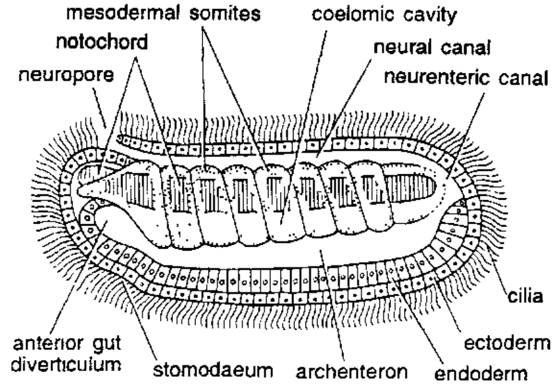

Fig 11 *Branchiostoma*. Neurula in V.L.S.

cavity of rostrum in front of the myotomes. The other mesodermal sacs on either side become each segmented into a small dorsal *somite* and a large *lateral plate mesoderm*. The dorsal somites remain distinct as *myotomes* and their cavities are called *myocoels*. The lateral plate mesoderms, flanking the enteron, grow ventrally pushing between the ectoderm (bodywall) and the endoderm (gut), and meet underneath the gut forming a temporary *ventral mesentery*. The cavity of each lateral mesodermal sac is called *splanchnocoel*. Its outer wall, attached to body wall is called *somatic mesoderm*, while the inner wall attached to the gut is called *splanchnic mesoderm*. With the rupture of partitions and ventral mesentery, all the cavities of the right and left sides become confluent forming a *perivisceral coelom* continuous underneath the gut (Figs. 8 & 9).

Neurula

The embryonic stage is now termed a *neurula*. An identical neurala is formed in all vertebrates although its manner of attainment differs widely (Figs. 10 & 11). The neurula has the following typical parts :

(1) Booly elongated, fish-like.
(2) Outer single layered ciliated ectoderm.
(3) Endoderm forming an enteron or gut.
(4) Rod-like skeletal notochord above gut.
(5) Dorsal hollow neural tube above notochord.
(6) Segmented dorso-lateral mesodermal somites or myotomes.
(7) Pervisceral coelom, lined by somatic and splanchnic layers of mesoderm.

Hatching

The neurula hatches out by rupturing its fertilization (vitelline) membrane when only two pairs of mesodermal somites have formed. Its surface is ciliated and it swims in the surface water layers of the sea as a free-swimming larva. As the newly hatched larva has no mouth and anus, it can not feed at once.

Larval Development

The larva elongates rapidly, becomes laterally compressed and pointed at both ends. Mouth appears as a circular aperture to the left of mid-ventral line and bears cilia. Neurenteric canal closes and *anus* develops mid-ventrally near the hind end. *Tail* forms behind the anus. First pair of pharyngeal *gill slits* form ventrally but soon shift to the right side. The larva having eight pairs of gill slits remains unchanged for a long time and later become fourteen pairs. Gill slits open directly to outside through ectoderm. *Endostyle* forms gradually on the floor of pharynx. The larva starts feeding on planktonic food by ciliary method. A larval club-shaped organ develops. Two longitudinal ventro-lateral *metapleural folds* appear. On their inner sides grow horizontally *epipleures* which meet and fuse together ventrally enclosing a large *atrial cavity* (Fig. 12). It gradually reduces the coelomic cavity and opens to outside though atriopore. The gill-slits now open into the atrium instead of opening directly to the exterior. The

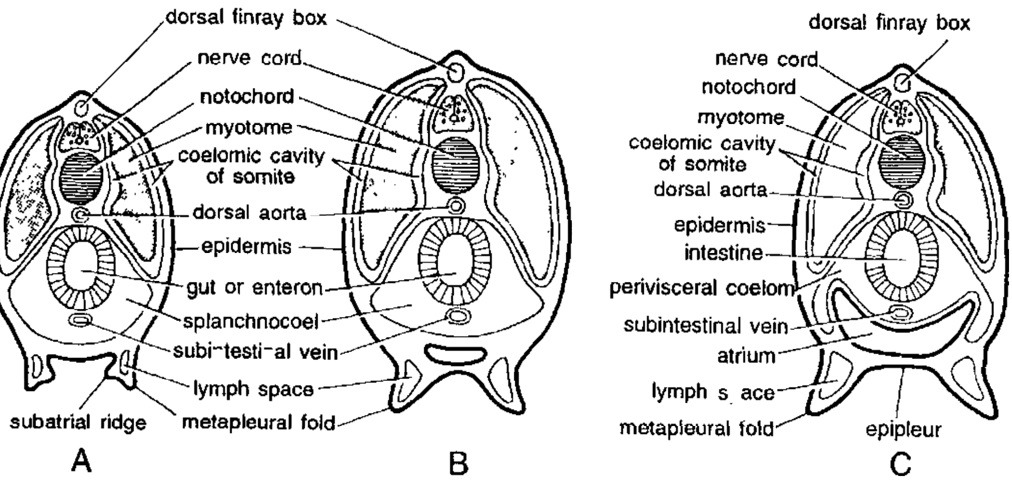

Fig. 12. *Branchiostoma.* Three stages in T.S. showing successive development of atrium.

larva of *Branchiostoma* exhibit asymmetry unlike adult in the arrangement of various body organs like :

(1) Mouth appears first on left side.
(2) *Diverticula* which originates from the anterior part of the gut also shows asymmetry. The left diverticulum remains smaller.
(3) Development of gill slits also show asymmetry. Both set of gills first appear on right side.

Metamorphosis

The larva, after passing three months pelagic life, now sinks down to the bottom, takes a burrowing life and gradually metamorphoses into the adult in several years. During metamorphosis, ectodermal cilia and larval club-shaped organs disappear and mouth becomes anterior. Oral hood with cirri, wheel organ and velum develop. Number of gill-slits increases due to subdivision of primary gill slits by tongue bars. Nephridia form, tail region elongates and notochord extends into rostrum. Sooner, the metamerically situated gonads develop and the adult lancelet starts breeding.

Significance

Study of the development of *Branchiostoma* is significant from following point of view :

(1) Study of embryology offers an insight into evolutionary history of chordates.
(2) Position and way of the formation of blastopore in developing embryos divide bilaterally symmetrical animal into 2 groups viz., *Protostomia* (where blastopore marks the area of mouth) and *Deuterostomia* (where blastopore marks the anus). The *Branchiostoma* falls in the later together with other chordates and Echinodermates.
(3) Way of formation of coelome in *Amphioxus* brings it closer to Echinodermates.

Based on fate of blastopore, manner of mesoderm formation, muscle chemistry and similarity in sera proteins, it is believed that Coelenterates onwards two stock of invertebrates evolved. *Branchiostoma,* supposed to be a representative of primitive chordate and links chordates with invertebrates and shows the evolutionary steps followed by vertebrates.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give a detailed account of development of *Amphioxus.*
2. Describe the development of *Branchiostoma* upto the formation of three germinal layers.
3. Describe the development of coelom in *Amphioxus* and show how it is affected by the developing atrium.
4. Describe the structure of larva of *Amphioxus* and its metamorphosis to reach the adult stage.
5. Draw diagrams of T.S. of the larval *Amphioxus* showing development of atrium.

» *Short Answer Type Questions*

1. Write short notes on — (i) Cleavage in *Amphioxus,* (ii) Gastrula in *Amphioxus,* (iii) Organogenesis in *Amphioxus,* (iv) Orgenogenesis in *Amphioxus,* (v) Formation of mesoderm and coelome in *Amphioxus.*

» *Multiple Choice Questions*

1. Development of *Amphioxus* resembles with those of :
   (a) Coelenterates (b) Annelids
   (c) Echinodermates (d) All these
2. Number of chromosomes in the fertilized eggs of *Branchiostoma* are :
   (a) 24 (b) 12 (c) 20 (d) 21
3. Yolky cytoplasm in *Amphioxus* develops into :
   (a) Ectoderm (b) Endoderm
   (c) Mesoderm (d) Both b and c
4. Cleavage in *Amphioxus* is :
   (a) Holoblastic (b) Meroblastic
   (c) Superficial (d) Discoidal
5. Emboly occurs in *Amphioxus* development during :
   (a) Cleavage (b) Blastulation
   (c) Organogenesis (d) Gastrulation
6. Which amongst the following is olfactory pit in *Amphioxus* :
   (a) Hatschek's pit (b) Kolliker's pit
   (c) Larval pit (d) Hasel's pit
7. At the time of hatching of *Amphioxus* larva the number of formed mesodermal somites are :
   (a) 5 pairs
   (b) 4 pairs
   (c) 2 pairs (d) one pair

ANSWERS

1. (c) 2. (a) 3. (b) 4. (a) 5. (d) 6. (b) 7. (c)

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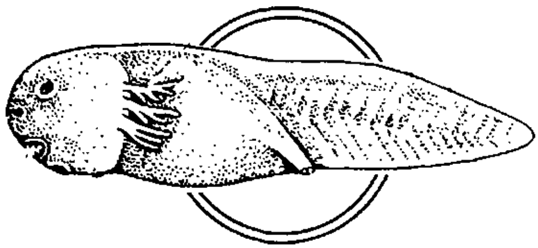

Development of Frog

Frogs lay t e r eggs n water n early spr ng. During *copulation* or *mating*, the male firmly clasps the body of the female by his forelegs and enlarged thumb pads *(nuptial pads)*. Smaller thickenings are also present below the joints of all digits of hand and foot, which are called *articular pads*. These also help in clasping the body of female. This sexual embrace is called *amplexus*, as already described in chapter 19. As the eggs are extruded through the cloaca of female *(oviposition)*, the male deposits sperm cells over t em *(insemination)*. T us *ferti izat on* s *externa*, taking place in water. Each female lays several hundred eggs in a mass called *spawn*. The jelly that surrounds and protects the eggs, soon swells up by absorbing water, causing the eggs to stick to one another, so that the entire mass of spawn is held together. *Development* is *indirect*, the zygote forming a well-known aquatic larval form, called *tadpole*, which undergoes *metamorphosis* to become the terrestrial adult frog (Fig. 1).

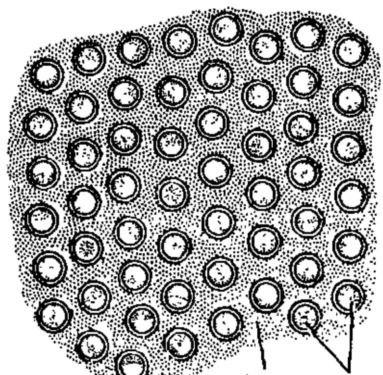

Fig. 1. Frog. Spawn.

Process of Fertilization

Eggs are laid in the form of *secondary oocytes*, each containing the *1st polar body* beneath the vitelline membrane near animal pole. Fertilization takes place before the jelly of egg swells up in water. During fertilization, the sperm always enters the animal hemisphere of egg just above the

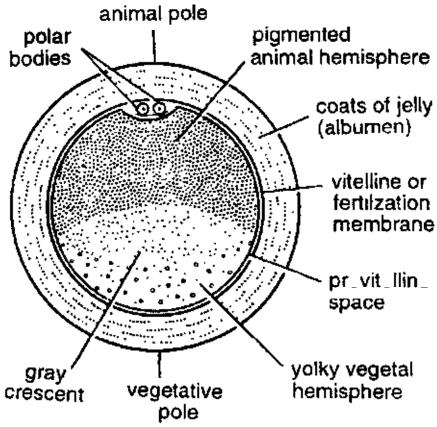

Fig. 2. Frog. Fertilized ovum or zygote in dorsal view.

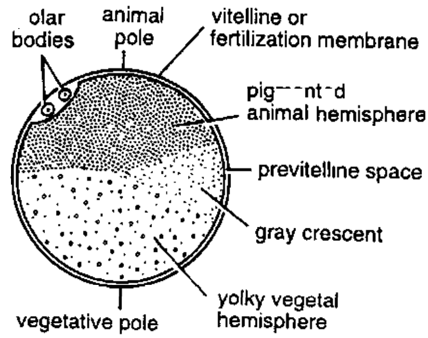

Fig 3. Frog. Zygote without jelly in lateral view.

equator, losing its tail in the process. At the point of entry, the egg surface is raised into a small papilla or the *cone of reception*. After entry of sperm, some *cortical reaction* takes place due to which vitelline membrane get separated from the plasma membrane of the egg and a space called *perivitelline* space is established between the two. This space is subsequently filled with a liquid substance released by exocytosis of cortical granules which finally adhere to the inner surface of vitelline membrane. The vitelline membrane of egg becomes the *fertilization membrane*. Wolf *et al.*, (1976) was of opinion that this membrane checks the *polyspermy*. Passage of sperm head (now *male pronucleus*) towards egg nucleus (now *female pronucleus)* is marked by a dark streak, consisting of a preliminary straight *penetration* or *sperm path* and a subsequently inclined *copulation path*. This dark streak is formed because some pigment granules from surface are carried deeper into cytoplasm along with the sperm head. The male and female pronuclei are *haploid*. Their fusion results in the formation of zygote nucleus restoring *diploid* chromosome number which is 26 in frog (Figs. 2–4).

Effects of Fertilization

Entry of sperm brings about rearrangement of cytoplasmic materials of egg. The following changes are visible :

(1) Even before the actual fusion of male and female pronuclei, the second maturation division of ovum occurs with the formation of a *second polar body*.

(2) Cytoplasm of zygote contracts, expelling a small quantity of fluid. As a result, the vitelline membrane separates from egg surface, becomes more obvious and known as

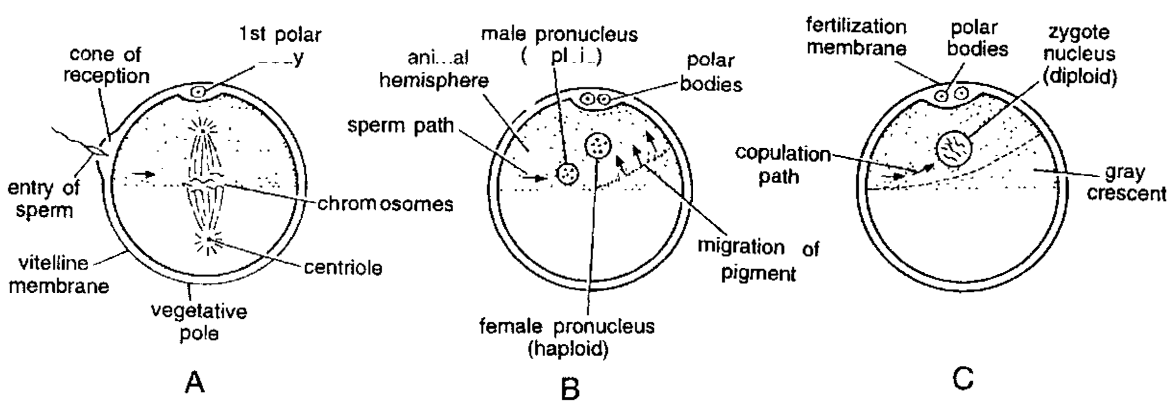

Fig. 4. Frog. Stages in fertilization of ovum.

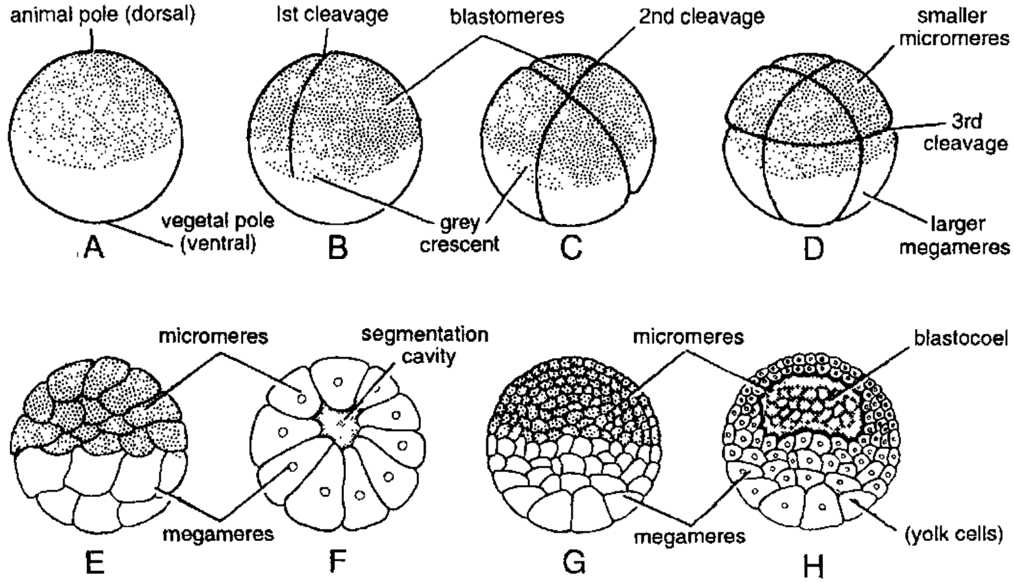

Fig. 5. Frog. Cleavage and blastulation. A—Zygote. B—2-cell stage. C—4-cell stage. D—8-cell stage. E—Early blastula. F—V.S. early blastula. G—Late blastula. H—V.S. late blastula.

fertilization membrane. This also enables the egg to rotate freely.

(3) In the side opposite that of sperm entry, there is an inward influx or movement of superficial pigment. This results in the formation of a crescentic surface area in the animal hemisphere near the equator. As this region becomes intermediate or grayish in pigmentation instead of the normal dark, it is known as the *grey crescent* which forms an important *landmark*. It marks the position of *dorsal lip of future blastopore* and the region from which *mesoderm* and *notochord* will later develop. Before fertilization, the egg was radially symmetrical. With the appearance of grey crescent, it becomes *bilaterally symmetrical*. With respect to the future embryo and adult, the grey crescent marks the future dorsal surface, the animal pole marks the anterior end, and the vegetative pole the posterior end.

Early Embryonic Development

Cleavage

Jelly present around the egg imbibes water and swells up as a result of which eggs get separated from each other which provides favourable environment for eggs. All the subsequent developments and divisions take place within this vitelline membrane and jelly. Fertilization is followed by *cleavage* or *segmentation* of zygote, which is *holoblastic* but *unequal* due to large quantity of yolk present. *First cleavage* is meridional, passing vertically from animal to vegetative pole. It divides the grey crescent and zygote into two similar and symmetrical cells, called *blastomeres*, which represent the right and left sides of future embryo and adult. *Second cleavage* starts at the time when the first cleavage furrow is in process of cleaving the yolky cytoplasm of the vegetal hemisphere is also meridional (vertical), passing through the poles, but at right angles to the first cleavage plane, producing four equal blastomeres. *Third cleavage* is latitudinal (horizontal) but well above the equator toward the animal pole, producing eight blastomeres of two distinct types. The upper four smaller pigmented cells at the animal pole are called *micromeres*. The lower four larger yolk-containing cells at vegetative pole are called *megameres* or *macromeres*. Further cleavages become less regular and difficult to follow. However, the smaller micromeres in the animal hemisphere divide much faster than the larger macromeres because of large quantity of non-living inert yolk present in the vegetative hemisphere (Fig. 5).

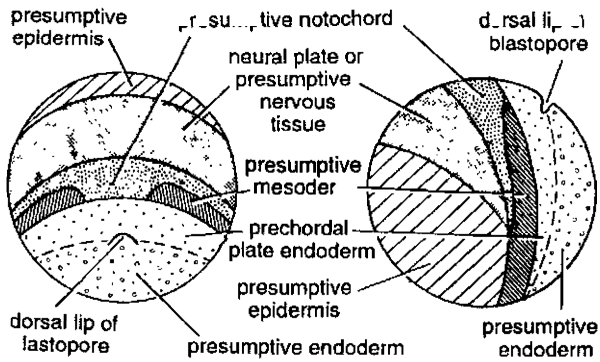

Fig. 6. Frog. Presumptive areas on zygote or blastula. A—Postero-dorsal view. B—Side view.

Blastula formation

A solid ball-like *morula* stage does not occur in frog. Instead, a hollow ball-like *blastula* stage is formed. As early as the 8-cell stage, a small central fluid-filled space, called *segmentation cavity* or *blastocoel*, appears within the embryo which is now termed a *blastula*. The blastocoel probably serves two major functions— firstly it is the cavity that permits migration of cells during gastrulation, secondly it prevents interaction of cells of vegetal half with animal half. In a fully formed blastula, blastocoel is a large hemispherical cavity entirely in the upper or animal half. Its dome-like roof is formed by numerous small, pigmented, black micromeres, while its floor is composed of large, yolk-laden, white macromeres. The blastula wall, or *blastoderm*, is one-cell thick in *Branchiostoma*, but many cells thick in frog.

Gastrulation

A series of changes, converting the single-layered blastula into a two-layered embryo or *gastrula*, are collectively known as *gastrulation*. It involves mass migrations *(formative movements)* and rearrangement of cells (or presumptive areas) of blastula. Several changes or processes taking place simultaneously during gastrulation are as described below.

1. Epiboly. A fold of rapidly dividing pigmented cells of micromeres of animal pole gradually grows over the light-coloured yolky cells or megameres of vegetative pole. It completely encloses the megameres except in the region of yolk plug. This process of overgrowth is called *epiboly*.

2. Formation of blastopore. In the beginning of epiboly, a small crescentic groove appears postero-dorsally on blastula a little behind the edge of grey crescent in the presumptive endoderm. Its anterior pigmented margin is called the *dorsal lip of blastopore*. Its backwardly projecting lateral horns are called the *lateral lips*. As epiboly progresses, the lateral lips finally meet below forming the *ventral lip*. Thus, the crescentic groove becomes a complete circle, or *blastopore*, through which is visible a tiny white spot of yolky endodermal cells, called *yolk plug*. It is present ventrally slightly in front of vegetative pole.

3. Invagination of endoderm. As the prospective ectoderm cells or micromeres advance, the future endoderm cells or megameres gradually migrate towards blastopore and gradually sink inside. With the completion of blastopore, the whole of yolky megameres or future endoderm becomes internal.

4. Formation of archenteron. With the inturning of tissues the earlier crescentic groove gradually grows inward into a new cavity, the *archenteron* or primitive gut, which opens to outside through blastopore. As a result of inwardly rotating endodermal cells, the blastocoel becomes gradually reduced and finally obliterated.

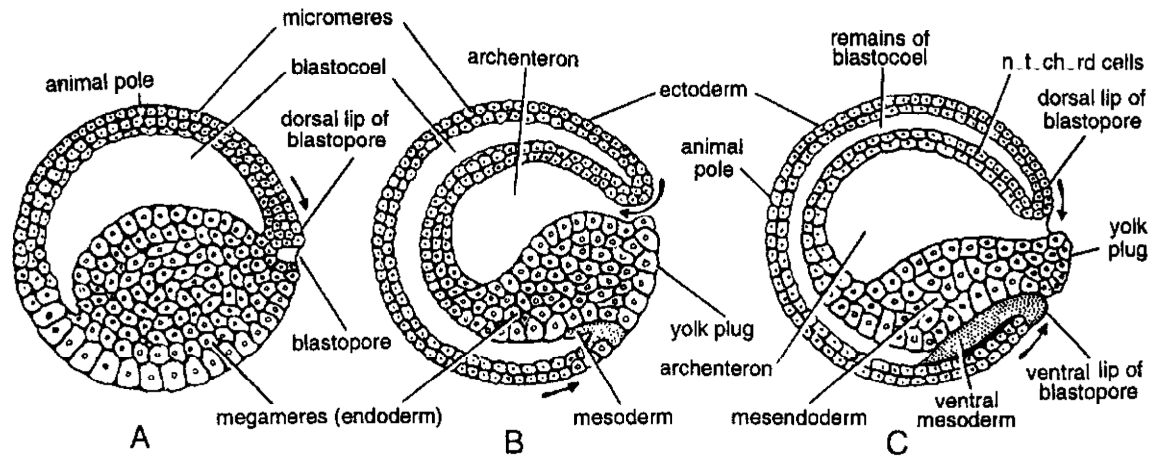

Fig. 7. Frog. Stages of gastrulation in median sagittal sections. A—Early gastrula. B—Mid gastrula. C—Completed gastrula (yolk-plug stage).

5. Involution. In the beginning of epiboly, the advancing future notochord cells, or *chorda cells*, become inflected or turned inside round the dorsal lip of blastopore. They extend beneath the neural plate cells which however remain on the surface. With the formation of lateral lips of blastopore, the future mesoderm cells also roll inside over the lateral lips. Internally they occupy positions on either side of chorda cells between the surface epidermis and endoderm. Mesoderm of ventral side also rolls over the ventral lip of blastopore.

In a completed gastrula, blastocoel is obliterated. Archenteron is well developed and opens to outside through blastopore later reduced to a slit (*proctodaeum*). Roof of archenteron is made by notochord cells and sides of mesoderm cells. Floor of archenteron contains a mass of yolky endoderm cells visible through blastopore as yolk plug. The outer layer of pigmented cells consists of ectoderm and neural plate. Formation of gastrula is now complete.

Fate maps in frog. The entire surface of the blastula may be divided into three regions —

(1) A large area on and around the animal pole.

(2) Marginal zone which spreads all around the equator of the blastula.

(3) The area on and around the vegetal pole.

These areas can be differentiated on the basis of their pigmentation. Whole of the animal region is deeply pigmented. The marginal zone is much

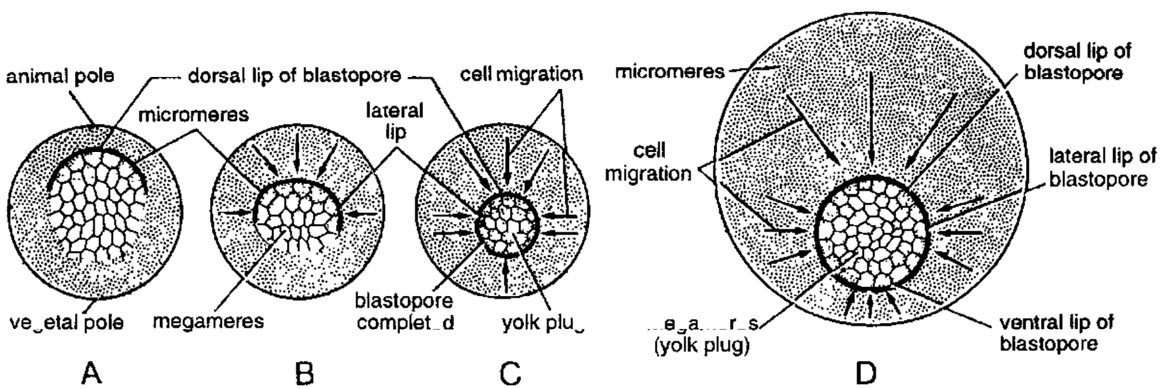

Fig. 8. Frog. Successive stages in the formation of blastopore as seen from vegetative pole (posterior view).

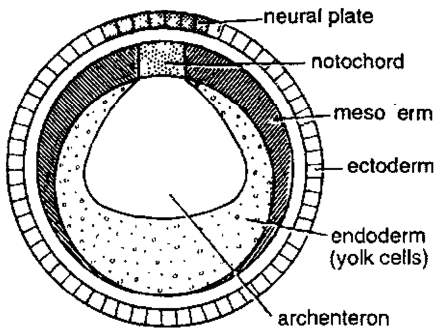

Fig. 9. Frog. Gastrula in T.S. showing three primary germinal layers.

broader on one side of the embryo and is lightly pigmented, while the vegetal pole has very little pigmentation. Each of the above regions corresponds to the future organs of the animal. On the basis of the vital staining the cells of these areas can be differentiated which in future will form the various organs of the embryo. The animal region has two areas, one of which has to develop into the nervous system of the embryo and the other area becomes the skin of the embryo. The material for the sense organs is also present in these areas. Inside the nervous system area, a small area may be localized which takes part in the formation of the eyes of the embryo. Similarly in the epidermis area the material for the nose, ears and the foregut may be found. In the marginal zone the material for the notochord occupying a large area on the dorsal side of the blastula may be found. The area lying near the vegetal pole contains the material for prechordal connective tissue. Towards the vegeted pole but still inside the marginal zone lies the material for the alimentary canal, the endodermal lining of mouth, gill region and pharynx. On both sides of th. n.tochord .r.. th. m.rgin.l zon. .r..s .r. taken up by the material for the segmental muscles of the bod.. The lateral and ventral .arts of the marginal zone give rise to the mesodermal lining o t e body cavity, the kidney etc. T e cells o. t.. v.g.t.. r.gion tak. part in t.e ..rmati.n .. midgut and hindgut.

Formation of neurula stage (organogenesis)

Neurogenesis

Towards the end of gastrulation, the presumptive neural plate area, running forwards from the blastopore, becomes thickened forming a mid-dorsal pear-shaped *medullary* or *neural plate*. Running throughout its length is an open midline depression or *neural groove*. This is the early neurula stage of embryo. The edges of lateral sides of neural plate rise up as a pair of ridges or *neural folds*. These folds grow to meet and fuse with each other in the midline so that the open neural groove is changed into a close *neural tube*, with its cavity called *neurocoel*. Its anterior wider end forms the brain and narrower posterior end the *spinal cord*. Anterior end opens outside for a short time by a *neuropore*. But it soon closes, and the anterior end of neural tube enlarges to form the *primary cerebral vesicle*, which is constricted to form fore-, mid- and hind brain vesicles. At the posterior end of embryo, the blastopore becomes drawn out as a longitudinal slit. Its lateral margins fuse in the middle of the slit forming the *primitive streak* and *groove*. However the blastoporal slit remains open at the upper and lower ends by *neurenteric canal* and *proctodaeum*, both opening

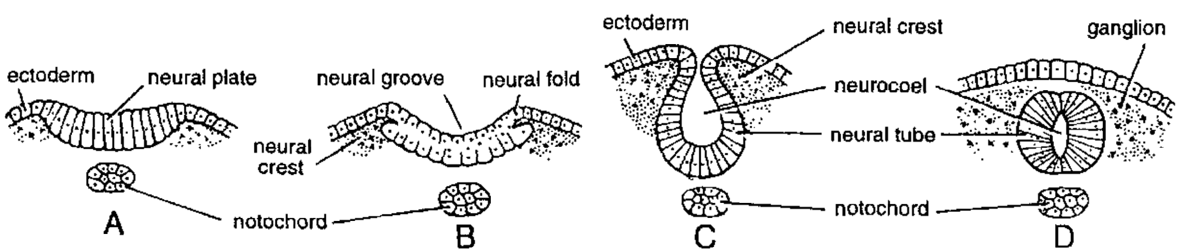

Fig. 10. Frog. Stages in formation of neural tube (neurogenesis).

into the archenteron. Posteriorly, the neural folds close over the neurenteric canal through which the neural tube opens into archenteron. Later, the neurenteric canal closes so that there is no connection between neural tube (spinal cord) and gut. The proctodaeum marks the site of future *anus* or *cloaca*.

Certain ectoderm cells at the lateral margins of neural plate do not become incorporated in the neural tube. They remain separate forming linear bands called *neural crests*. They give rise to parts of autonomic nervous system, dorsal root ganglia of cranial and spinal nerves, and certain other tissues such as trabeculae of skull and elements of visceral arches (Fig. 10).

Notogenesis

The chorda cells lying in mid-dorsal region of roof of archenteron, separate from adjacent mesoderm cells. They form a cylindrical rod-like notochord made of characteristic vacuolated cells. It becomes the axial skeleton of embryo. A notochordal sheath develops around the notochord.

Formation of mesodermal somites

The presumptive mesoderm cells, inturning at the lateral margins of blastopore, become arranged on either side of notochord in two solid blocks or sheets without any cavity. This is unlike *Branchiostoma* in which mesoderm first appears as hollow mesodermal sacs. Mesodermal sheet on either side is differentiated into three fairly distinct zones. The most dorsal and thicker zone, close to notochord, is called *epimere*. The most lateral and thinner zone is *hypomere* or *lateral plate mesoderm*. The intermediate cell mass is called *mesomere* or *nephrotome*. The hypomere extends laterally and ventrally around the yolk cells, so that mesoderm forms a continuous layer beneath the archenteron which is now lined wholly by endoderm. Mesoderm now constitutes the third *germ layer*, lying between the other two, that is, endoderm and ectoderm. At this stage, the embryo becomes *triploblastic*.

The epimere mesoderm of each side thickens and segmented transversely into blocks of cells, the *somites*. Formation of somites begins in front of the middle of embryo and proceeds backwards. Nephrostome and lateral plate mesoderm remain undivided.

Formation of coelom

A split occurs in the hypomere of lateral plate mesoderm separating an outer *somatic* or *parietal layer* and an inner *splanchnic* or *visceral layer*. The cavity thus formed between the two layers is *splanchnocoel* which marks the beginning of coelom. It extends downwards to become continuous with that of the outer side below get to appear U-shaped in a section. Thus coelom in frog is a *schizocoel* formed by the splitting of mesoderm, in contrast to the *enterocoel* of *Branchiostoma* which is derived from the archenteron. Somatic layer unites with ectoderm to form the *somatopleure* or bodywall, while visceral layer unites with endoderm to form the gut wall or *splanchnopleure*.

A narrow cavity, called *myocoel*, appears in each mesodermal somite which itself differentiates into 3 parts. Outer thin *dermatome* becomes the dermis of skin. Middle thick *myotome* forms the body muscles. Inner *sclerotome* contributes to vertebral portions of skeleton. Myocoels shortly disappear without contributing to the coelom of the adult. Myomeres lead to the formation of kidneys, and their cavities, the *nephrocoels*, persist as excretory tubules and their ducts which are therefore coelomic in origin. The splanchnocoles of hypomeres become the general body cavity or *perivisceral coelom* lined with peritoneum.

Formation of eye

After the differentiation of the three primary brain regions from the neural tube, the rudiments of the eye start appearing in the region of future diencephalon. The presumptive retinal plate which at lateral sides of forebrain begin to evaginate as protsuding sacs. They are called primary optic vesicles. Each optic vesicle continues to grow towards the epidermis. By the pressure so developed the intervening mesenchyma is displaced and ultimately comes in contact with the

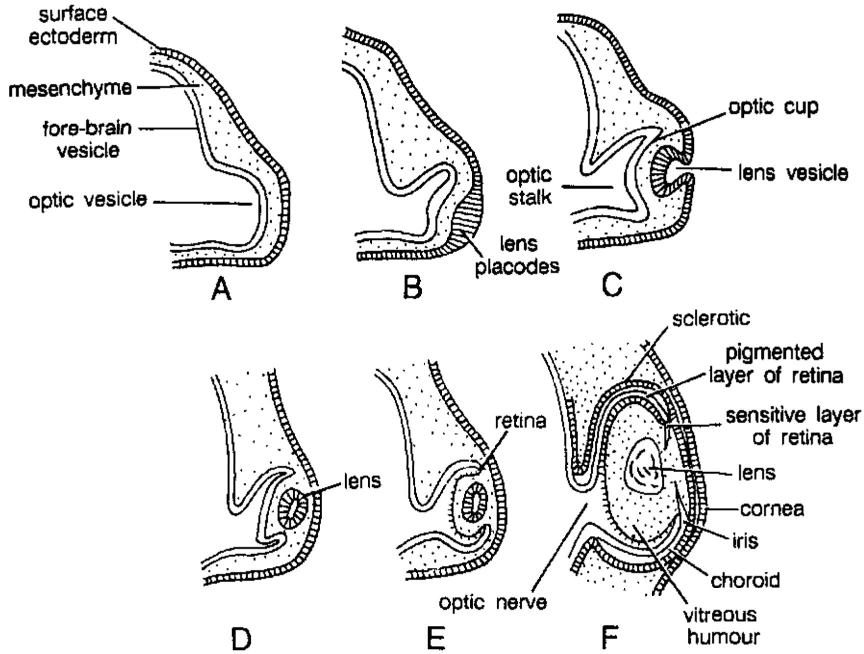

Fig. 11. Stages of development of eye of frog.

epidermis. The wall of the optic vesicle undergoes invagination to form a double walled optic cup-enclosing a space which is the future posterior chamber of the eye. The cup is two walled structure. Pigment granules develop in the external thin layer which forms the pigmented coat of retina. In the invaginated thicker layer sensory and conducting cells differentiate to form the neurosensory layer of retina. There two layers are continuous with one another at the rin of the optic cup which forms the edges of the pupil. In the beginning the pupil is quite wide but lateron its edges bend inward and converge so that the opening of the pupil is reduced. Edges surrounding the pipil, become considerably thin to form the iris. Later ciliary body and retina is developed.

Epidermis of the head opposite to the optic vesicle thickness to form the lens-placodes which invaginates to form the lens cup which gradually deepens and puiches off from the epidermis and forms a closed lens vesicle. The lens vesicle gradually comes to lie in the secondary optic vesicle. Cells of the lens vesicle undergo cytodifferentiation and ultimately develop into a refracting body (Fig. 11).

Cornea is formed by the skin epidermis and mesenchyma of the head region. In larval stage the epidermis forms the external cornea which remains continuous with the skin while the mesenchyma forms the internal cornea which is continuous. During metamorphosis these layers fuse and become transparent.

The choroid coat and the sclera of the eye develop from the mesenchyma cells accumulating around the eye-ball. The inner layer of mesenchyma gives rise to a network of blood vessels surrounding the pigmented retinal epithelium and is called choroid coat. The outer layer of the mesenchyma forms a fibrous capsule, the sclerotia coat or sclera around the eye which has protective function.

Formation of heart

Embryonic development of the heart initiates from the lateral mesoderm plate in the pharyngeal region. After the formation of the nerve chord, the

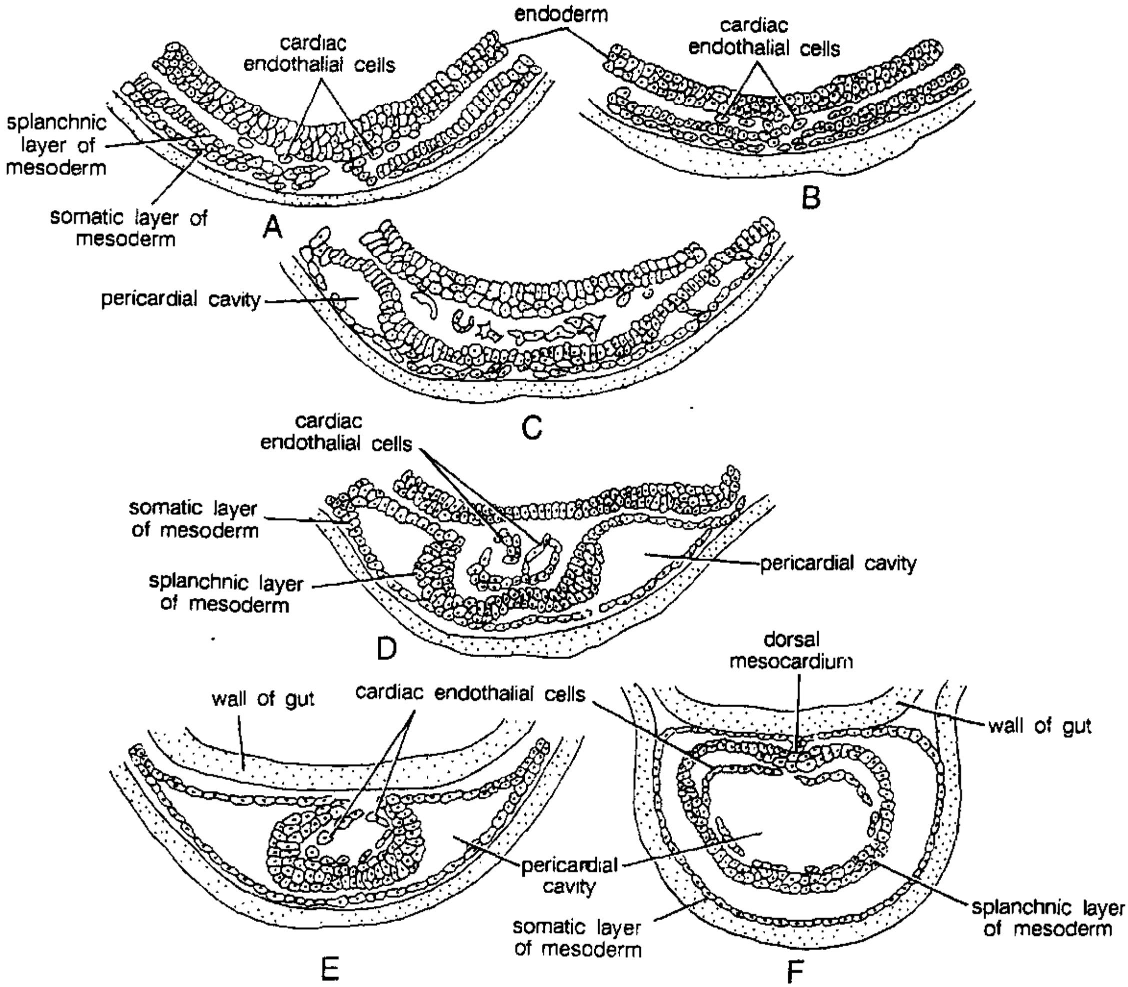

Fig. 12. Formation of heart in frog. A–B—Mesoderm reaching midline. C—Enlargement of pericardial cavity. D—Endothalial cells being arranged in the form of a tube. E—Heart tube established. F—Dorsal mesocardium still present.

free edges of the mesodermal mantle gradually converge towards the mesodermal free area in the pharyngeal region. They get thickened in the region of the heart and thus form the heart rudiment. A number of loose cells are derived from the ventral edge of the mesodermal mantle. They form the *endocardium*. These cells accumulate in the middle line and get arranged to form the endocardial tube. This tube bifurcates at the two ends. At the anterior end it extends as aortae and at the posterior end it receives two vitalline veins. Soon the lateral plate of mesoderm come closer and fuse with each other. The visceral layer of mesoderm envelops the endocardial tube on the dorsal side as well. By fusion of the mesodermal layers of the right and left sides, epithelial partitions are formed above and below the endocardial tube and thus pericardial coelom is formed around the endocardial tube. The visceral layer of mesoderm gives rise to the myocardium.

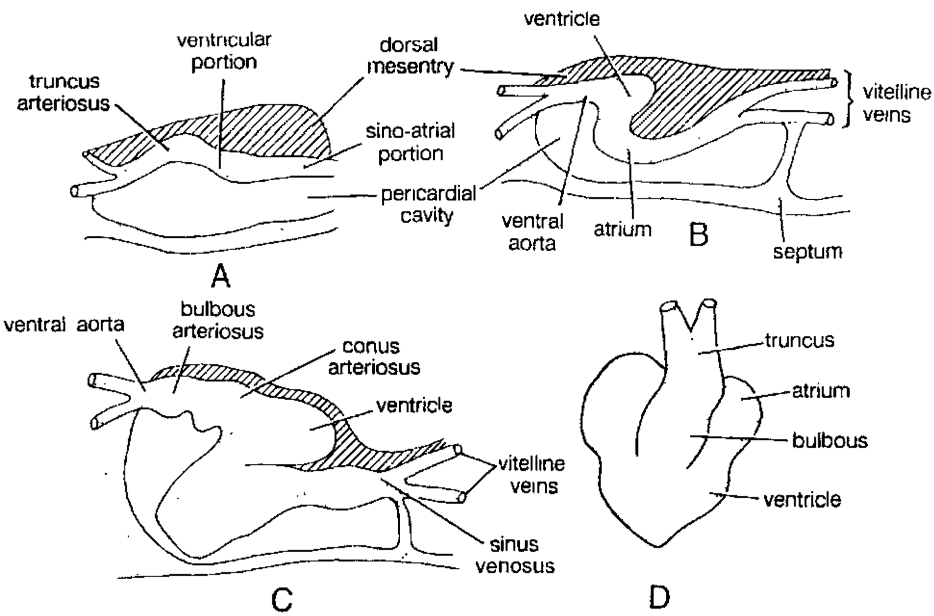

Fig. 13. Stages of development of heart in frog.

The parietal layer of mesoderm forms the pericardium. The cells of the endocardial tube continue to multiply mitotically and as a result of this the tube undergoes a folding and attains an S-shaped structure. It becomes constricted in some places and dilated at others. In the posterior part where the vitalline views are present, the sinus venosus is formed. Anterior to sinus venosus the atrium is developed ventral to the atrium the thick walled ventricle is formed. Most anteriorly the ventricle forms two dilations called the conus anteriors and bulbus anteriosus. Later the single atrun gets divided into right and left atria. The two ventral aortae of arising from the ventricle give rise to the truncus anteriosus (Figs. 12 & 13).

Post-neural or pre-hatching embryo

Even during formation of neurula, the embryo begins to elongate and acquires a flat surface eminence, called *gill plate,* on either side near the anterior end. Soon after completion of neurula, a postero-dorsal projection above the proctodaeal pit forms the *tail bud.* It grows out posteriorly into a *post-anal tail.* The proctodaeal pit breaks through into mesenteron to become the *cloacal opening.* Three ridges on either side on each gill plate mark the position of first three *branchial arches.* Behind them light dorso-lateral elevations indicate the positions of first 2 to 3 pairs of mesodermal *somites.* On the ventral side of head is a shallow *oral* or *ventral sucker* containing *mucous* or *cement glands.* Anterior or above the sucker an oral depression, the *stomodaeal pit,* marks the beginning of mouth. While still within its egg membranes, the embryo moves about by means of cilia on its epidermis, with an occasional twitching caused by contraction of muscles developed from somites (Fig. 14).

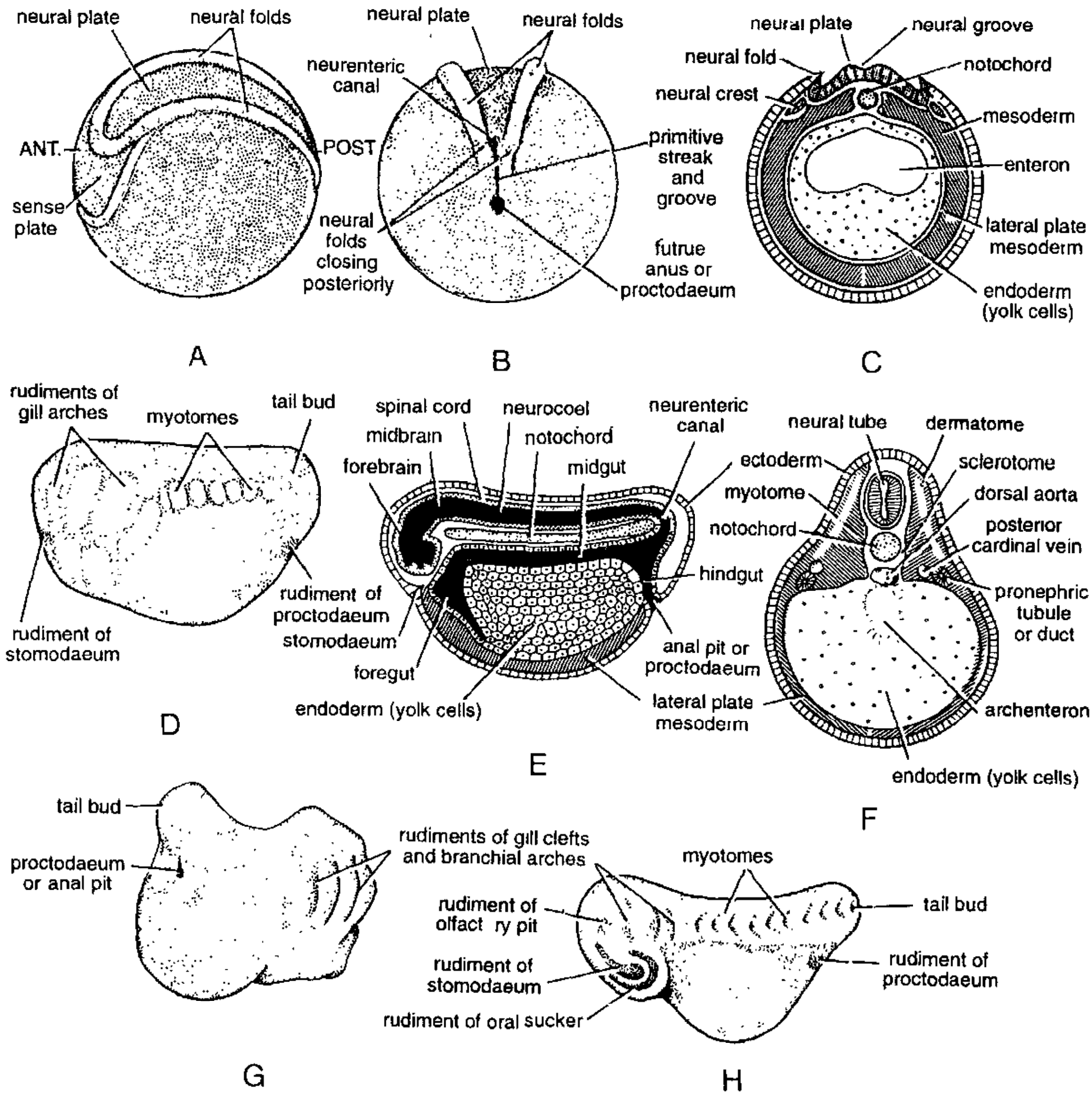

Fig. 14. Frog. Neurula stage. A—Early neurula in side view. B—Early neurula in posterior view. C—T.S. early neurula. D—Late neurula in side view. E—M.L.S. late neurula. F—T.S. late neurula. G—Postneural or tail bud stage. H—Prehatching stage.

Larval Development

Newly hatched tadpole

Hatching occurs about 2 weeks after fertilization. After hatching, the free larval stages of frog are known as *tadpoles*. The newly hatched tadpole is a small blackish, fish-like creature about 6 mm long. Body shows distinct head, trunk and tail regions. Its respiratory organs are two pairs of small branched *external gills* growing out from the first and second branchial arches. *Stomodaeal pit* has still not perforated into pharynx. *Cement glands* form a single U-shaped *ventral sucker*. Rudiments of *eyes* are indicated externally by a thickening of ectoderm on either side of head. *Gill slits* have not yet opened. Above the gills appear invaginations forming *auditory pits* or *vesicles* of internal ears. At the front of head are present a

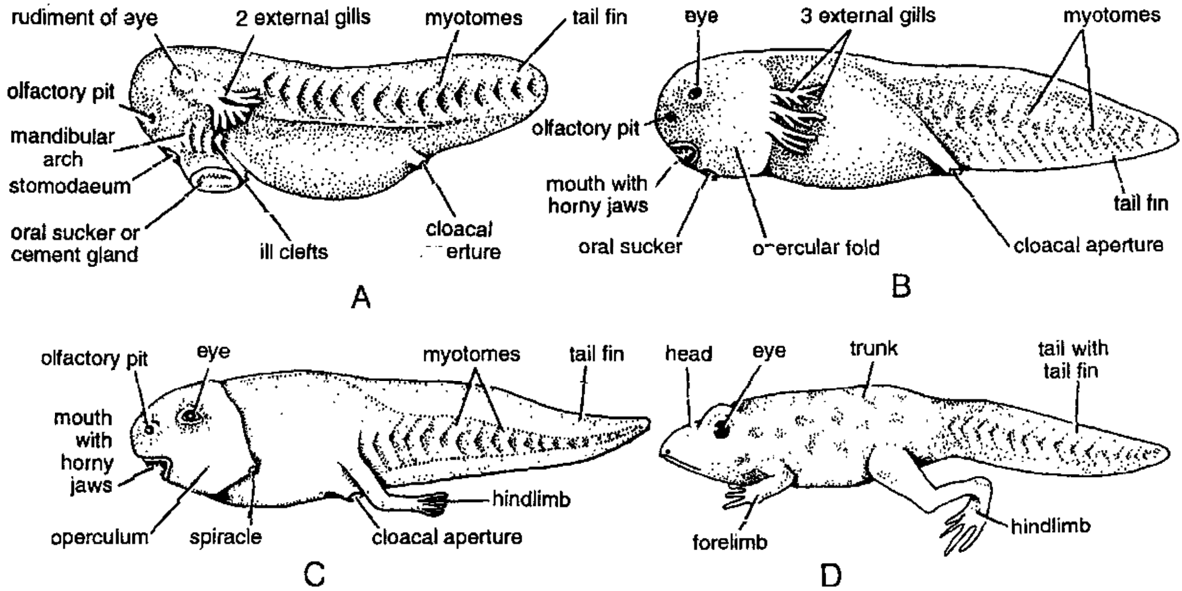

Fig. 15. Frog. Tadpoles. A—Newly hatched. B—External gills stage. C—Internal gills stage. D—Fully formed.

couple of depression, the *olfactory pits*. Mesodermal *somites* or myotomes are numerous and extend into the tail. Ventral portion of trunk bulges out due to yolk massed on the floor of mesenteron. Gut is a straight tube leading to outside through *cloacal aperture* ventrally at the base of tail which lacks a tail fin. Functional kidneys are a pair of *pronephros*. Epidermis is ciliated. *Heart* is a simple S-shaped tube without chambers. Since there is no mouth, the tadpoles spend a few days attached to objects in water by their ventral sucker and nourish themselves from the yolk still present in the cells of archenteron.

External gills stage

A few days after hatching yolk is all used up and stomodaeum breaks through into pharynx forming *mouth*. The mouth acquires a pair of *horny jaws* and *frilly lips* bearing *horny papillae* or *teeth*. Three pairs of branching filamentous *external gills* grow longer and blood is circulating in them. Five pairs of pharyngeal or *visceral pouches* push from pharynx towards ectoderm. Of these the first pair *(hyomandibular)* does not open to exterior and gives rise to middle ears and eustachian tubes. Remaining four pairs become perforated to the exterior as four pairs of *gill slits* or *branchial clefts*. Tail becomes longer and develops delicate thin dorsal and ventral *caudal fins* continuous around the tip and without fin rays. By undulating movements of its tail, the tadpole swims like a fish feeding on algae and other vegetable matter scrapped off with horny teeth.

Internal gills stage

Soon after the formation of branchial clefts, a fold of skin, called *operculum*, grows backwards from hyoid arch on either side covering the external gills and the branchial clefts. The two opercular folds or gill covers fuse with one another ventrally and behind with the bodywall. Thus they enclose an *opercular chamber* or *branchial pouch* into which open the branchial clefts. In turn, the branchial pouch open to the exterior on the left side only by a circular opening, called *spiracle*, on a spout-like funnel. Meanwhile the 3 pairs of external gills gradually shorten and disappear and replaced by 4 pairs of *internal gills* arising ventrally on the interbranchial septa.

Fully formed tadpole

A fully formed tadpole of frog hatches about 14 days after fertilization in normal condition and is essentially a fish-like creature in form and

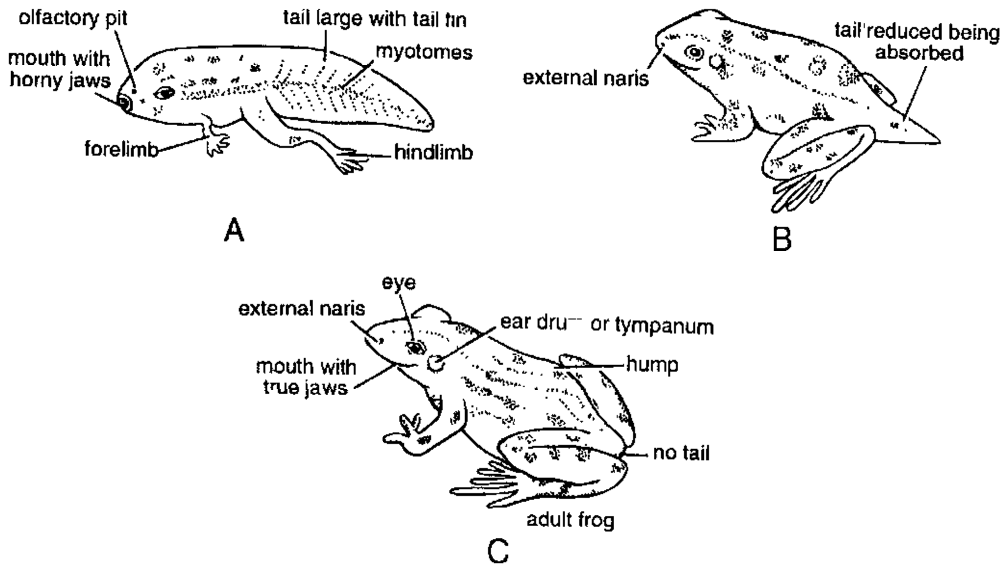

Fig. 16. Frog. Stages in metamorphosis.

functions. It has a well-developed locomotory tail with caudal fin and muscles for swimming. It has eyes, external nostrils, mouth, long spirally coiled intestine, cloacal opening and spiracle which are readily visible. Cement glands (ventral sucker) have disappeared. In respiration water passes through mouth, pharynx, branchial clefts, over internal gills into the opercular chamber and out again through the spiracle. In later stage lungs develop from pharynx so that tadpole uses both gills and *lungs*. Soon the branchial clefts close, internal gills absorbed and opercular cavity disappeared. The tadpole now frequently comes to the surface to take in air into buccal cavity and lungs for respiration. A well developed *lateral line system* is also present. *Mesonephric kidneys* are developed. Of the two pairs of limbs, the *hind limbs* appear first as tiny hemispherical elevations or *buds* at the base of tail. Buds of *forelimbs* are not visible at first being covered by the operculum. Later, the left forelimb emerges through the spiracle, while the right forelimb breaks through the wall of opercular pouch.

Metamorphosis

Two or three weaks, after breathing with lungs, the tadpole undergoes drastic changes called *metamorphosis*, and converted into a tiny young frog differing from the adult only in size (Fig. 16). Some of the important changes are as follows :

(1) Tadpole stops feeding but frequently visits water surface to engulf air into lungs via mouth and then sinks down to water bottom again.

(2) Anterior limbs break through operculum.

(3) Tail gradually shortens providing nourishment.

(4) Head and body become increasingly frog-like. Eyes become prominent and legs become longer.

(5) Ciliated larval skin, frilly lips and horny jaws are cast off.

(6) Mouth grows wider, true jaws develop, tongue enlarges, stomach and liver also enlarge, but long and coiled intestine of predominantly herbivorous tadpole greatly shortens into small gut of carnivorous frog.

(7) Bone formation begins in hitherto wholly cartilaginous endoskeleton and musculature develops rapidly.

(8) Vascular system is modified for air breathing with lungs assuming more importance as respiratory organs.

(9) Skin becomes vascular, respiratory, pigmented and slimy.

(10) Pronephros is replaced by mesonephric kidneys.

(11) Lateral line sense organs disappear.

(12) Young frog has a stumpy tail. It leaves water to live in damp places on land. It feeds on insects and grows into the adult.

Significance. Study of the embryology of frog is practically useful to us in variety of ways :

(1) It helps in interpretation of avian and mammalian development.

(2) It explains the evolutionary transition of lower chordates into higher chordates.

(3) It explains the evolution of lung breathing animals from gill breathing animals.

(4) It also explains the evolution of various physiological requirements present in air breathing and land living animals.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the life history of Indian bull-frog, *Rana tigrina*.
2. Describe the development of frog upto the end of gastrulation.
3. Describe the development of frog upto formation of three germinal layers and mention their fate.
4. What do you mean by metamorphosis ? Explain with reference to the life history of frog.
5. Describe the structure of tadpole of frog. Discuss the metamorphic changes it undergoes to become the adult.

» *Short Answer Type Questions*

1. Write short notes on— (i) Neurogenesis, (ii) Notogenesis, (iii) Presumptive areas, (iv) Fate maps in frog, (v) Formation of heart in frog, (vi) Formation of eyes in frog, (vii) Formation of coelom and mesoderm.

» *Multiple Choice Questions*

1. On forelimbs of male frog, well developed pads are found for clasping the female at the time of copulation is called :
(a) Nuptial pads (b) Tuberocities
(c) Suchial buds (d) None of these

2. In case of frog, fertilization is :
(a) Internal (b) External
(c) Both these (d) None of these

3. Development of frog is :
(a) Direct (b) Indirect
(c) Both of these (d) None of these

4. Diploid number of chromosomes in the zygote of frog is :
(a) 22 (b) 26 (c) 24 (d) 25

5. Fertilization membrane is formed in case of frog :
(a) Before fertilization (b) After fertilization
(c) After oviposition (d) Before oviposition

6. First cleavage in frog is :
(a) Holoblastic equal (b) Holoblastic unequal
(c) Meroblastic (d) Horizontal

7 Eggs of frog are .
(a) Microlecithal (b) Megalecithal
(c) Alecithal (d) Telolecithal

8. Blastula of frog is called .
(a) Coeloblastula (b) Discoblastula
(c) Holoblastula (d) Amphiblastula

9. On the basis of pigmentation surface of the blastula of frog can be divided into :
(a) Three regions (b) Two regions
(c) Four regions (d) Five regions

10 Coelom of frog is ·
(a) Acoelous (b) Pseudocoelous
(c) Enterocoelous (d) Schizocoelous

11 Coelom of frog is derived from :
(a) Splitting of mesoderm (b) From archenteron
(c) Both of these (d) None of these

12. Innermost compartment of *myocoel* called *Sclerotome* contribute to the formation of :
(a) Dermis (b) Muscles
(c) Vertebral skeleton (d) All these

ANSWERS

1 (a) 2. (b) 3. (b) 4. (b) 5. (b) 6. (b) 7. (d) 8. (a) 9. (a) 10. (d) 11. (a) 12. (c).

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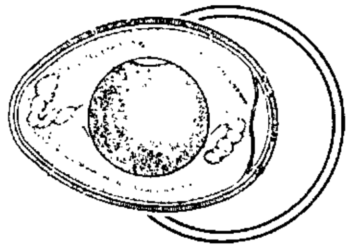

Development of Chick (Fowl)

It is preferable to study the embryology of chick or the common fowl (*Gallus gallus*) to that of pigeon (*Columba livia*) because of several advantages. Eggs of fowl are large in size, easily available throughout the year and can be incubated artificially. Moreover, the process of development has been most thoroughly worked out in fowl. A comparative study of embryology of different birds shows that it is essentially similar in all the birds with only minor unimportant differences. Embryology of birds is much like that of reptiles in general. Development is *direct*, without a larval stage.

Fertilization

Ova leave the ovary (*ovulation*) as *primary oocytes*. They are released in coelom and caught by the expanded funnel-like opening of oviduct. They are fertilized in the upper part of oviduct which also receives sperms from the male bird during copulation. The sperm of cock have long lives about three weeks or so. Several (5 or 6) sperms enter the oocyte (polyspermy) which immediately undergoes two maturation divisions. The resulting two *polar bodies* degenerate and disappear. The nucleus of only one sperm then fuses with the nucleus of *ovum proper* resulting in fertilization. The remaining sperms migrate to the periphery of the ovum and ultimately die. Thus fertilization is *internal* in birds. Fertilized ovum or zygote normally takes 24 hours to pass down the oviduct, before being laid. While descending, it is surrounded in succession by various envelopes of albumen, shell membranes and porous calcareous shell, all secreted by the wall of oviduct.

Structure of Egg of Hen or Fowl

Shape and size. Generally the eggs are laid at the rate of one egg per day. A fully formed and newly laid egg is large and elliptical with one end broader than the other. It is about 3 cm broad and 5 cm long. By the time it is laid, the embryo is in the blastula stage or undergoing gastrulation. As the eggs are deposited outside water, on land, they have *protective envelopes* as a safeguard against drying and mechanical injuries.

Egg shell. The egg is externally protected by a firm white or brown *shell*, at least 94% of

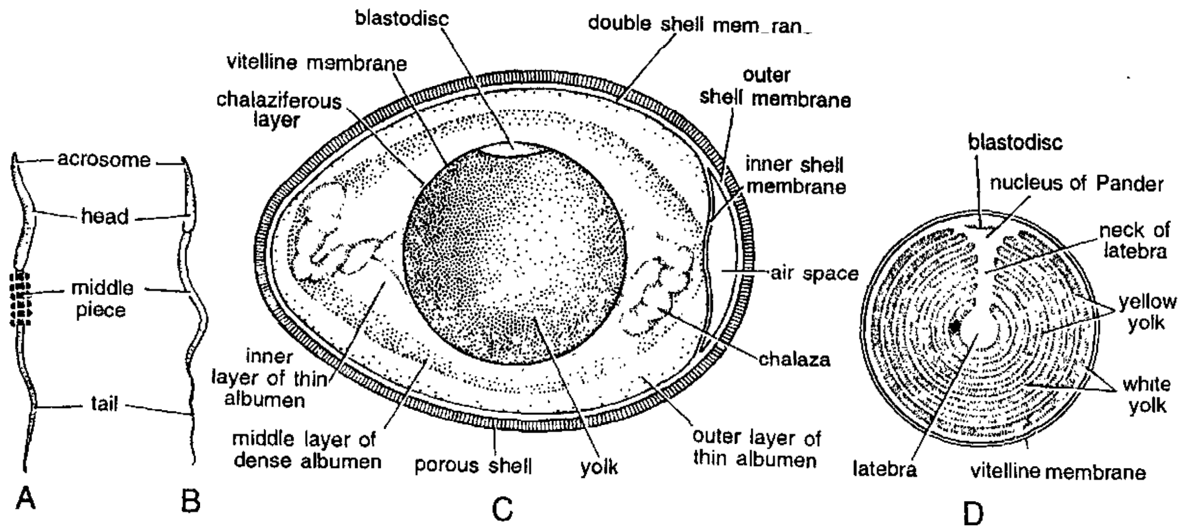

Fig. 1. Fowl. A—Fowl's sperm. B—Pigeon's sperm. C—Hen's egg partially in section. D—V. S. ovum.

which is calcium carbonate. The shell is porous and allows diffusion of O_2 and CO_2 through it. The shell is soft and flexible in a freshly-laid egg but soon becomes hard and brittle. The shelled-egg, shut off from its surrounding, is termed *cleidoic* (Fig. 1).

Shell membrane. Immediately underneath the shell is a thin but tough, white *shell membrane* consisting mostly of keratin. It is made of two layers which are mostly in close contact with each other but are separated at the broad end of the egg to enclose an *air space*. As development proceeds, the air space grows larger, and a little before hatching the young chicken pierces the air space with its beak and takes its breath of air, inflating its lungs.

Albumen. Beneath the shell membrane lies the *albumen* or *white* of egg, surrounding a central mass of *yolk*. The albumen consists chiefly of water (85%) and protein albumen. Other proteins are also present. The albumen is deposited in several layers. The outermost albumen is more water-like and known as the *fluid, liquid, watery*, or *thin albumen*. The middle layer of albumen is thick and viscous and known as the *dense albumen*. The innermost layer is made of very viscous albumen called the *chalaziferous layer*, which surrounds the yolk. It forms a pair of spirally twisted ropes or cords, the *chalazae*, one towards each end of the egg. The way in which they are formed is uncertain, but probably they are produced by the rotation of the egg in the oviduct. They are formed by the fibres of a glycoprotein, called *ovomucoid*.

Ovum. The true *ovum* or *egg cell* proper of fowl is very large, with its enormous mass of yolk. It is invested in a thin transparent *vitelline* or *fertilization membrane*, which separates the yolky ovum from the surrounding albumen. The membrane is formed by the union of a primary membrane with a secondary membrane deposited by the follicle cells of the ovary. The granules of yolk, being slightly denser than cytoplasm, sink to the bottom of the ovum, towards its *vegetal pole*. Due to the large yolk contents, the egg of fowl is an extreme example of *polylecithal, macrolecithal* and *telolecithal egg*. The yolk is not homogeneous in composition but consists of alternate layers of *yellow* and *white yolk* arranged concentrically around a central flask-shaped mass of white yolk. The layers of yellow yolk are thicker than those of the white yolk. Yolk consists largely of phospholipid lecithin and fat. Analysis of solid yolk shows 60% fat and 30% protein. The white yolk contains less fat and also less of the fat-soluable pigment carotene to which the yellow

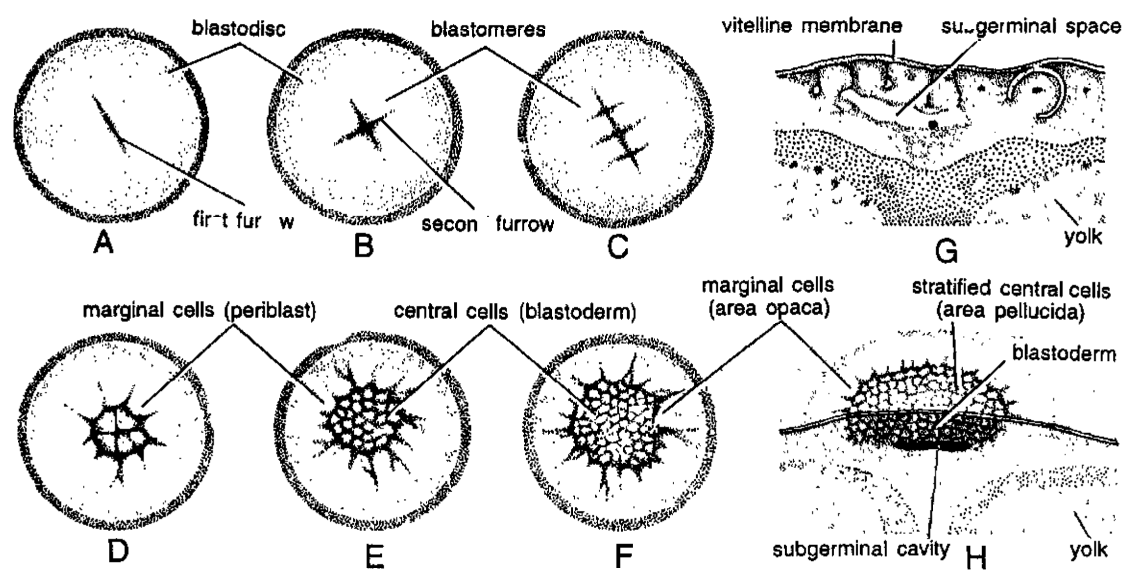

Fig. 2. Fowl. Early stages in cleavage of the germinal disc. A—2-cell stage. B—4 cells. C—8 cells. D—16 cells. E—32 cells. F—154 cells. G—V.S. of 32-cell stage. H—Hemisection of 154-cell stage.

colour is due. The yolk contains about 50% water. The central flask-shaped mass of white yolk is termed *latebra*, which its outer neck-like part is known as the *neck of latebra*, which expands under the blastodisc into a broad disc, the *nucleus of Pander*. The ovum contains a *nucleus* surrounded by a negligible amount of yolk free cytoplasm forming the *germinal disc* or *blastodisc*. It always floats on the upper surface of yolk and represent the *animal pole* of the ovum.

Yolk and albumen provide food (protein) to the developing embryo. Towards the end of incubation, a part of shell dissolves and the $CaCO_3$ released is utilized to build the developing bones. The shell also provides a little protein. The egg-white or albumen supplies water and minerals, while vitamins come from both yolk and albumen.

Cleavage or Segmentation

Cleavage begins about 3 hours after fertilization As already stated, cleavage and early gastrulation are completed by the time the egg is laid. Cleavage furrows do not extend into the yolk but are confined to the tiny germinal disc (blastodisc) of cytoplasm occupying a small circular area on the top of yolk. *First cleavage* is a vertical furrow between two daughter nuclei. It does not extend right across the disc, nor through its whole thickness. As a result the disc is divided only incompletely into two cells or blastomeres. *Second cleavage* furrow is also incomplete and at right angles to the first, resulting in four blastomeres. It is followed by more incomplete and irregular furrows in rapid succession. The entire blastodisc is thus cut up into a sheet of cells called the *blastoderm*. Since many of the cleavages are horizontal, the blastoderm is several cells thick. The partial and superficial cleavage in chick resulting in the formation of a blastoderm, is called *discoidal* and *meroblastic* in which yolk, forming the greater part of ovum, remains permanently undivided. It is different from the *holoblastic* cleavage of *Branchiostoma* and frog in which the entire ovum is involved in the division. A marginal zone of unsegmented cytoplasm, called *periblast*, unites blastodisc with the yolk mass, thus forming a *zone of junction* (Fig. 2).

Blastulation

The free margin of blastoderm grows rapidly over the surface of yolk. Soon its central region is separated from the underlying yolk by a

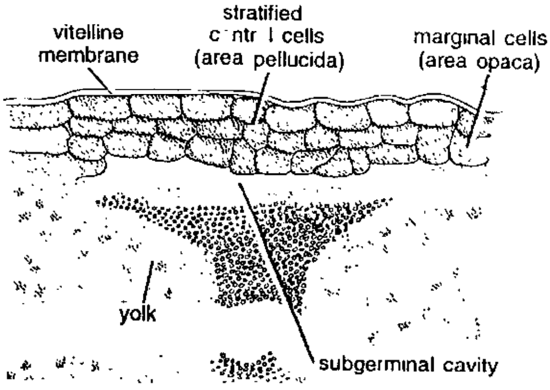

Fig. 3. Fowl. V. S. through blastoderm of an early blastula stage.

fluid-filled space, *the subgerminal* cavity. This causes the central zone above to look distinct and transparent, the *area pellucida*. In contrast, the surrounding ring-like marginal or peripheral zone of blastoderm, lying directly on the surface of yolk, looks opaque and which is known as the *area opaca.* Area pellucida later forms the body of the embryo proper, while the area opaca forms the accessory extra-embryonic structures, such as the yolk sac. Some large yolky cells of uncertain origin develop on the floor of subgerminal cavity but soon disappear (Fig. 3).

According to some workers, this stage corresponds to the *blastula* stage of amphioxus and frog. Subgerminal cavity is regarded equivalent to *blastocoel,* yolky cells equivalent to megameres and central cells to micromeres. However, the subgerminal cavity is not a true blastocoel so that this stage in chick is called a *pseudoblastula.*

Presumptive Areas

Before gastrulation, the multi-layered blastoderm of area pellucida becomes rearranged to form a single layer of cubical epithelial cells, called *epiblast* or *ectomesoderm.* Various authors (Jacobson, Pasteel, Spratt,) have mapped on this layer the *prospective* or *presumptive areas* which will later form the main embryonic structures. However, their exact locations and limits are not so well-defined as in

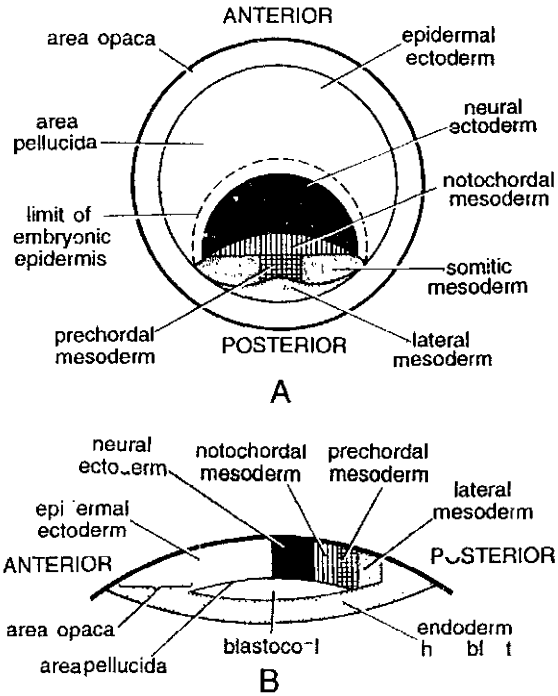

Fig. 4. Fowl. Presumptive areas in chick blastoderm before gastrulation. A—Surface view. B—In M.L.S.

the early gastrula of Amphibia (Fig. 4). Starting at the future posterior end of embryo, the presumptive areas are as follows :

(1) A small disc of *endoderm.* It is not shown in some fate maps because in early stages of gastrulation, the prospective endoderm cells migrate rapidly downwards into subgerminal cavity.
(2) A broad rear band of *lateral mesoderm.*
(3) A small area of *prechordal mesoderm* flanked on either side by *somitic mesoderm.*
(4) A narrow band of *notochordal mesoderm.*
(5) A large crescentic area of *neural plate* or *neural ectoderm.*
(6) A still larger area of *embryonic* or *epidermal ectoderm.*

All these presumptive areas lie within area pellucida. *Embryonic ectoderm* is continuous with *extra-embryonic ectoderm* on area opaca, which covers *extra-embryonic endoderm.*

Gastrulation

Endoderm formation. Gastrulation begins even before laying of eggs. It involves the formation of endoderm so that the *monoblastic* embryo or *blastula* is converted into *diploblastic* or two-layered *gastrula*. There is disagreement in different workers about the actual mode of gastrulation, that is, formation of endoderm in chick embryo. There is no *invagination* of prospective endoderm through a blastopore as found in amphioxus and frog. From near the posterior end of embryo, prospective endodermal cells migrate down (*involution*) into the subgerminal cavity, forming a coherent sheet throughout the area pellucida. There is also, to some extent, a sinking down or *ingression* of individual yolk laden ectoderm cells thus adding to the thickness of blastoderm. The latter now splits (*delamination*) anteriorly into outer *epiblast* or *ectoderm* and inner *hypoblast* or *endoderm*. The epiblast contains the prospective neural plate, notochord, mesoderm and ectoderm (Fig. 5).

Like ectoderm, the endoderm also has two distinct origins. The *embryonic endoderm*, formed by migration of cells from area pellucida into subgerminal cavity, lines the gut of embryo. Whereas *yolky* or *extra-embryonic endoderm*, formed by area opaca, lines the yolk sac. Later on, both become continuous with each other.

Gastrulation is completed within 2 or 3 hours after laying. With its completion, the embryo becomes diploblastic consisting of an outer epiblast (ectoderm) and an inner hypoblast (endoderm). The original subgerminal cavity is divided by hypoblast into a narrow outer space or *secondary blastocoel* and inner *archenteron* or primitive gut of embryo.

Incubation

Development of freshly-laid egg is arrested due to drop in temperature. It can not be resumed unless temperature is kept at about 37°C to 40°C. This is done by the body heat of parent birds, one (*Gallus*) or both (*Columba*) of which sit upon the eggs. The process is known as *incubation*. Egg is

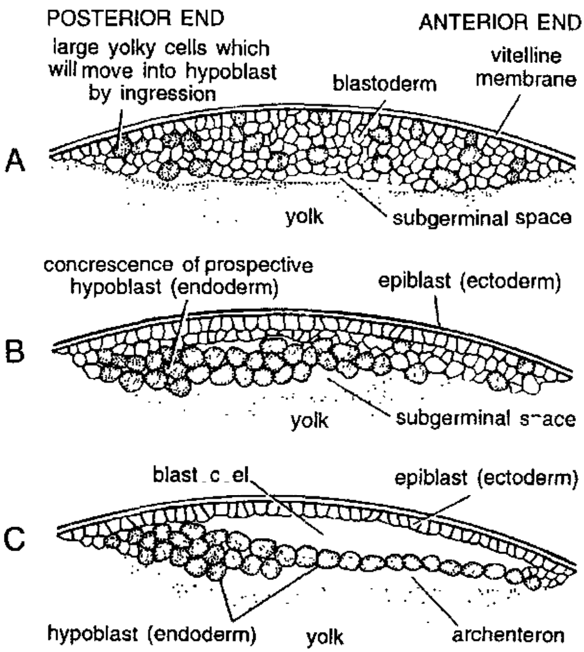

Fig. 5. Fowl. Blastoderm in L.S. showing gastrulation or successive stages of endoderm formation. A—Large yolk cells intermixed with smaller cells. B—Concrescence and delamination of endoderm cells. C—Organization of larger yolk cells to form endoderm.

warmed during incubation by the bird's breast. In artificial incubation, the required temperature is maintained in an incubator by poultry farmers. *Incubation* is carried until hatching of young takes place. *Incubation period* lasts about 14 days in pigeon and 21 days in chick (Figs. 6–9).

Mesoderm Formation : Primitive Streak Stage

With the resumption of development under heat of incubation, after 3-4 hours there is a distinct movement of cells (*concrescence*) from all directions towards the mid-line of area pellucida. Accumulation of presumptive lateral plate mesoderm cells creates a broad thickened area, the beginning of *primitive streak*, at the mid-posterior end of area pellucida, representing the caudal end of embryo. Continued convergence of more and more mesoderm cells causes anterior elongation of primitive streak forming a distinct, dark, opaque and longitudinal band or streak.

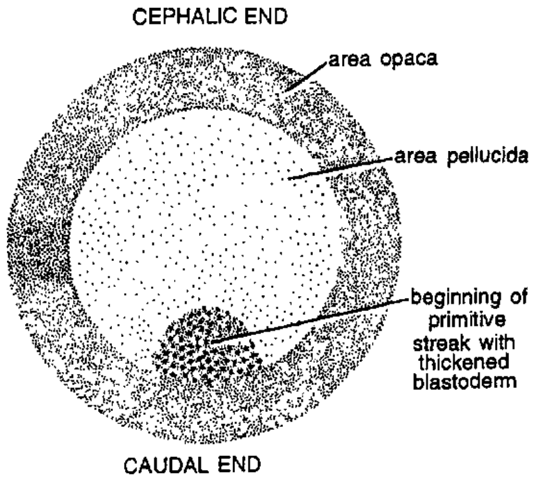

Fig. 6. Fowl. Chick embryo of 3 to 4 hours of incubation showing beginning of primitive streak.

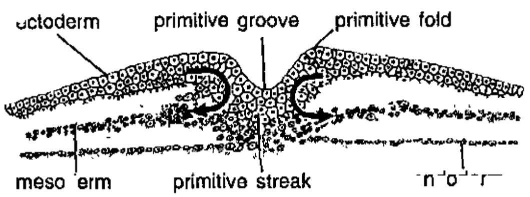

Fig. 7. Fowl. T. S. primitive streak showing mesoder for ation.

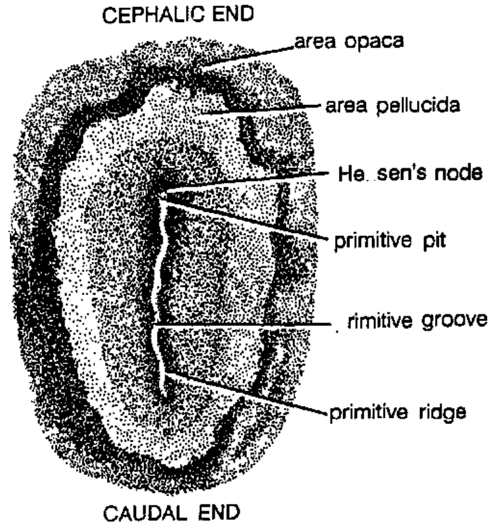

Fig. 8. Fowl. Chick embryo in primitive streak stage at about 16 hours of incubation.

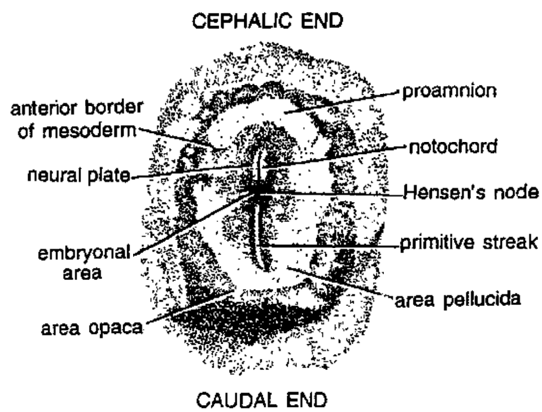

Fig. 9. Fowl. Chick embryo of 18 hours of incubation showing formation of notochordal process and mesoderm.

Mesoderm cells accumulating on the primitive streak turn downwards (*involution*) and spread out i___ _l_s__c__l ___ .i.h.r si b.tw n the inner ..,pobl_st (_n_o__rm) and th_ surface layer (ectoderm), forming *mesoderm*. The embryo now is *triploblastic* as all the three germinal layers have become established, namely the outer *ectoderm*, middle *mesoderm* and inner *endoderm*. Mesoderm extends as two wing-like sheets throughout the area pellucida except, for a time, into its anterior region called *proamnion*.

After incubation for about 18 hours, area pellucida loses its circular shape and becomes elongated, oval and pear-shaped with a broader anterior end. By this time primitive streak becomes so prominent, that embryo is said to be in *primitive streak stage*. Along the length of streak runs a shallow groove, the *primitive groove*, which terminates anteriorly into a rounded *primitive pit*. Immediately in front of the pit is a distinct swelling or dense spot, the *Hensen's node* or *primitive knot*. It is formed by cells of presumptive notochord and floor of neural tube. Thickened margins of groove form the *primitive ridges* or *folds*.

Primitive streak and groove are considered to be equivalent of coalescent lips of blastopore of frog and reptiles, while primitive knot represents the dorsal lip of blastopore, although no aperture is present. Fully developed primitive streak extends from posterior edge of area pellucida to about two-third of distance anteriorly, but it gradually disappears by the end of second day of incubation.

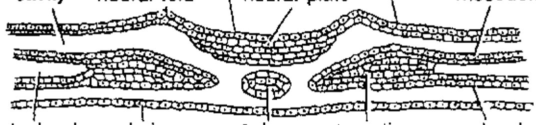

Fig. 10 Fowl. T. S. chick embryo after formation of notochord

Formation of Notochord (Notogenesis)

A narrow strip of blastoderm just in front of primitive knot consists of presumptive notochordal cells. These cells roll over the edge of primitive knot and migrate forward into subgerminal cavity to occupy a central position beneath neural plate and between strips of somitic mesoderm. Their modifications results in the formation of a rod, the *notochord* (Fig. 10).

Formation of Neural Tube (Neurogenesis)

Immediately in front of primitive streak lie the *neural plate cells*. As these cells start to sink, a *medullary* or *neural groove* appears bounded by lateral *medullary* or *neural folds*. The folds roll up and unite mid-dorsally, thus enclosing a *neural tube* which opens to the exterior at the anterior end by a *neuropore*. In some birds, an invagination at the anterior end of the primitive groove becomes the neurenteric canal through which the neural tube communicates with the archenteron. The neuropore closes during the second day of incubation. The anterior end of neural tube enlarges to form the *primary cerebral vesicle*. From this by constrictions develop the fore, mid and hind-brain vesicles. The forebrain bends downwards by the development of a cranial flexure in the region of the mid-brain. Behind the brain, the neural tube forms the spinal cord.

Formation of Mesoblastic Somites

On either side of notochord lies thick, solid, dorsal *somitic* or *paraxial mesoderm* flanked ventro-laterally by thinner *lateral plate mesoderm*.

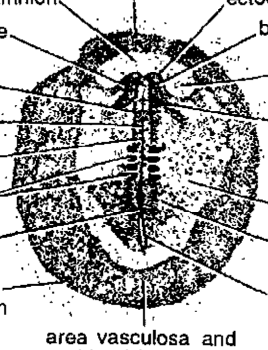

Fig. 11. Fowl. Chick embryo with 4 pairs of somites (about 24 hours of incubation).

The somitic mesoderm becomes transversely segmented into a series of cubical blocks on either side of notochord, termed *mesoblastic somites*. Their appearance is the first sign of *metameric segmentation* of embryo. As in frog, they are formed only from somitic (paraxial) mesoderm, while lateral plate mesoderm remains unsegmented, a point of difference from amphioxus. First pair of somites is formed at about 20 hours of incubation a little in front of primitive knot, that is, in neck region. Subsequent pairs appear behind the first, by further transverse splits from somitic mesoderm, usually at the rate of one pair per hour. Thus, the number or somites present gives an idea of the age of embryo. However, actual time required varies with the temperature at which incubation is taking place, as well as the time taken by egg to descend the oviduct. Hence it is more appropriate to call any particular stage of embryo by the number of somites actually present instead of the time interval after the start of incubation. 3 or 4 pairs of somites have been formed by the end of first day (24 hours). About 52 pairs are ultimately formed of which the last 10 pairs later degenerate. As more and more somites are added, the primitive streak and groove gradually retreat backwards (Fig. 11).

Formation of sclerotomes, dermatomes, myotomes (muscle plates) and nephrotomes occurs as already described in frog tadpole.

Origin of Coelom

The ventral or lateral plate mesoderm does not undergo segmentation to form somites. Instead it splits into two layers. The outer *somatic* or *parietal layer* lies next to ectoderm with which it forms the *somatopleure*. The inner *splanchnic* or *visceral layer* in contact with endoderm forms the *splanchnopleure*. The space or cavity formed between these two mesodermal layers is coelom or *s~l~nchnocoel*. Thus, ori~in of coelom is *schizocoelic*.

Like blastoderm, coelom also extends beyond the limits of embryo proper so as to enclose yolk and form the *extraembryonic coelom* or *exocoel*.

"Folding Off" of Embryo

As already stated, the whole blastoderm does not form embryo. The actual embryo is formed only by the central area pellucida, while the peripheral area opaca gives rise to extra-embryonic structures, such as yolk sac and foetal membranes, which do not enter into the formation of embryo. Their demarcation begins towards the end of first day of incubation (24 hours), and the embryo proper gradually becomes folded off from the yolk sac. Anterior region of area pellucida, just in front of neural plate, is raised up forming the *head process* or *head fold*. This region is without mesoderm and called *proamnion*. As the head fold grows downwards and backwards beneath the neural plate, it encloses the anterior portion of archenteron (mesenteron) forming the so-called *foregut* lined by endoderm. Next appear the lateral folds, followed by a *tail fold* including the *hindgut*. The embryo is now perched above the extraembryonic region (yolk sac) with which it remains attached by a narrow hollow stalk, the *umbilical cord*, opening into its mesenteron (Fig.12).

Organogeny

Organogeny of chick is similar to that of frog. A description of organogeny in the development of chick is beyond the scope of this text. By the end of 3rd day of incubation, most of the organ systems have made their appearance. Gill pouches

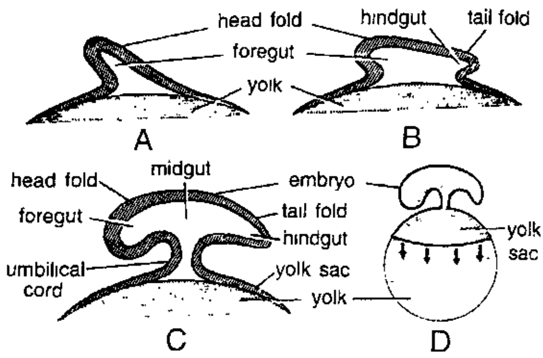

Fig. 12 Fowl Folding off of embryo from yolk sac

and gill slits appear in the first few days but soon close. *Blood capillaries* develop in splanchnic mesoderm in mottled region of blastoderm, called *area vasculosa*. Capillaries unite to form two large *vitelline veins*, which extend through umbilical cord to enter the embryo ventrally and join the developing *heart* posteriorly. From dorsal aorta, two large *vitelline arteries* branch off to connect with the capillary network. *Blood islands* of mottled area vasculosa give rise to red blood corpuscles. During 2nd or 3rd day rudiments of *optic vesicles, lens*, as well as *inner ear* develop.

Extra-embryonic or Foetal Membranes

Embryos, like adults, required protection, food and oxygen. The lower vertebrates lay their eggs in water which provides a friendly environment by supplying the requisite food, inorganic salts and oxygen etc., to the embryos. The higher land vertebrates, such as the reptiles and birds, on the other hand, lay their eggs on land. The dangers of mechanical injuries and desiccation are met by the calcareous shell, while specially developed *foetal membranes* serve for nutrition, respiration, excretion and protection of the embryos and fit them for a thoroughgoing life on land. The foetal membranes are developed from the extra-embryonic blastoderm and do not participate in the formation of the embryo proper, hence they are also termed *extra-embryonic membranes*. After serving their purpose, they are lost. The extra-embryonic membranes are three viz., *amnion,*

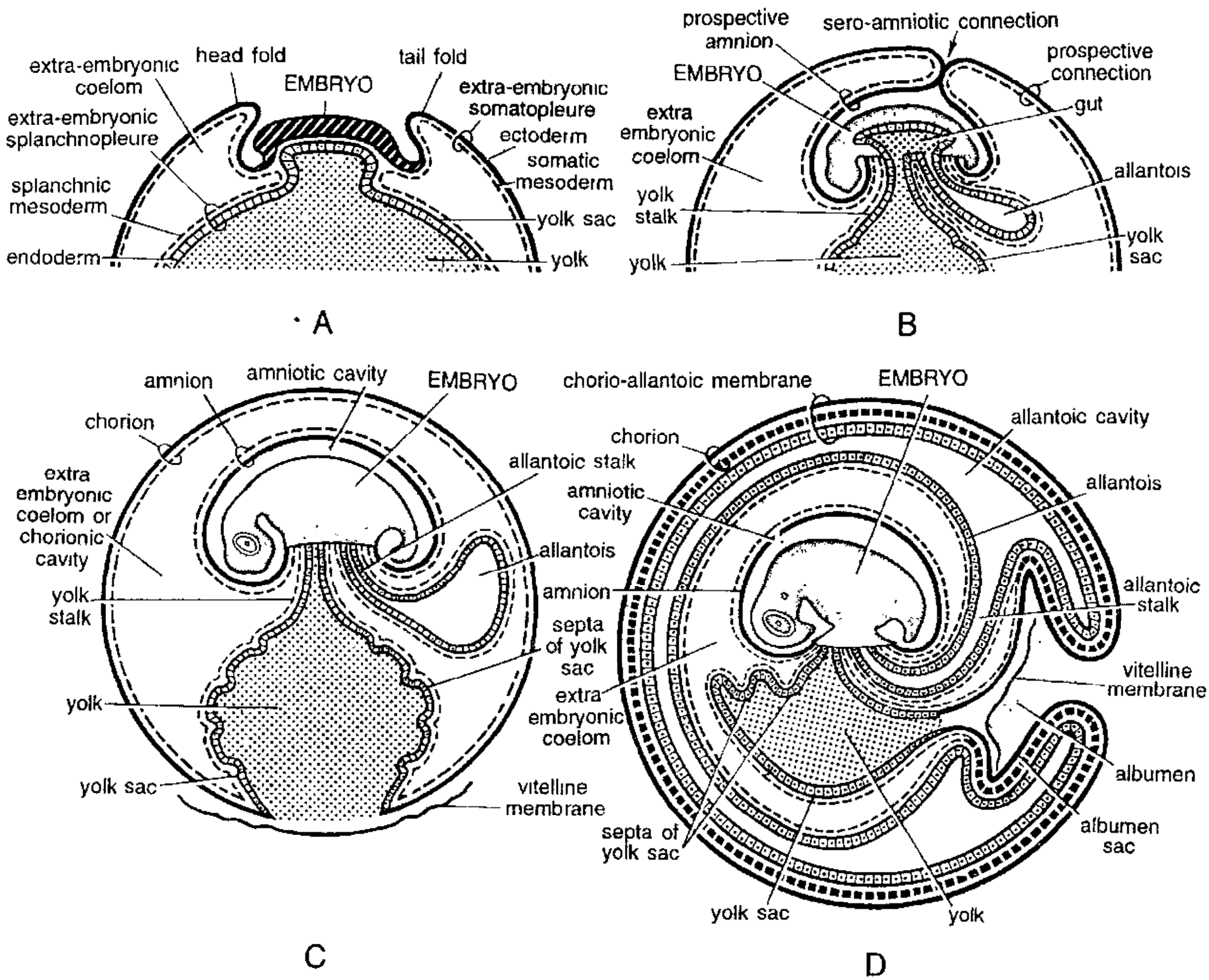

Fig 13. Fowl. Stages in the formation of foetal membranes. A—Formation of head and tail folds delimiting embryo from extra- embryonic areas. B—Early stage showing allantois. C—Formation of amnion and chorion. D—Fully formed extra-embryonic membranes.

chorion and *allantois*. These are characteristic of the three higher classes of vertebrates Reptilia, Aves and Mammalia—which are grouped together under Amniota (Fig. 13).

1. Yolk sac. The chief source of embryonic food is the yolk. It is enclosed in a sac-like investing membrane, the *yolk sac*. The yolk sac does not envelop the yolk completely, leaving a small passage ventrally through which the remains of albumen are absorbed. The yolk sac is formed by a layer of extra-embryonic splanchnopleure i.e., splanchnic layer of mesoderm lined by the extra-embryonic endoderm. This endodermal lining digests and absorbs the yolk and becomes deeply folded into the yolk forming the so-called *yolk-sac septa*. As yolk cannot be taken directly, the endoderm of the yolk sac secretes digestive enzymes, which change the yolk into a soluble form. The products of digestion reach the embryo at first by diffusion and later through the capillary network in the splanchnic mesoderm. Thus, to transport the absorbed food yolk to embryo, the blood vascular system makes an early appearance both in embryo and the extra-embryonic region, and joining through the umbilical cord. As the yolk is gradually digested to provide nourishment to the embryo, the yolk sac becomes gradually smaller and finally absorbed into the midgut.

The yolk sac protects the yolk, keeps it in position, and digests and absorbs it. Thus, it is the primary organ of nutrition of embryo.

2. Amnion and chorion. From about the first day of incubation the embryo seems to sink farther into the yolk and becomes more and more delimited from the extra-embryonic structures. The extra-embryonic somatopleure (i.e., ectoderm and somatic mesoderm) rises up both infront and behind the embryo in the form of the *head* and *tail folds* of the *amnion.* Both the folds are hollow outgrowths, containing a space, the *extra-embryonic coelom,* formed by the splitting of the mesoderm. The growing folds meet above the embryo in an arch or dome and later coalesce and the place to their junction is termed the *sero-amniotic connection.* The inner layer forms the *true amnion*, having the ectoderm towards the embryo and the somatic mesoderm towards outside. The outer layer is called the *false amnion* or *serous membrane* or *chorion*, in which the ectoderm is on the outside and the somatic mesoderm on the inside. Both the layers are continuous with the corresponding layers of the embryo. The space between the amnion and the chorion is continuous with the extra-embryonic coelom (chorionic cavity), and is termed the *sero-amniotic cavity.* The space left between the embryo and the amnion is called the *amniotic cavity*, which is lined by ectoderm and filled with *amniotic fluid.*

The amniotic fluid serves as a protective cushion, breaking the mechanical shocks and lessening the effect of changes of temperature. The development of amnion in all terrestrial vertebrates (Aves, Reptilia and Mammalia) is of great functional significance. It provides a watery pool around the embryo, thus preventing any danger of desiccation. This watery cushion also protects the embryo from damage as the incubating hen frequently changes or disturbs the position of eggs while sitting on them. The chorion serves for respiration in association with the allantois, while both amnion and chorion probably keep the embryo from adhesion with the shell and shell membranes by keeping it in slight motion.

Development of amnion and chorion begins on the second day and is completed on the third day of incubation.

3. Allantois. To meet with the growing need of respiration of the embryo a blind diverticulum grows out ventrally from the hind gut of the embryo into the extra-embryonic coelom. This bladder-like outgrowth is the *allantois*, which appears on about the fourth day of incubation (28-somite stage). Because of its origin it is internally lined by endoderm and externally covered by *splanchnic mesoderm* and its cavity is in continuation with the enteron. At first, it has the form of a small ovoid sac with proximal narrow part of *allantoic stalk* and a distal broader part of *allantoic vesicle.* The allantois grows rapidly and within ten days completely surrounds the embryo and yolk sac and fills the entire extra-embryonic coelom or sero-amniotic cavity between the amnion and the chorion. Its mesodermal layer, fuses with that of the chorion, forming a compound membrane the *chorio-allantois* or *allanto-chorion.*

The functions of allantois are many. The chorio-allantois is richly vascularised by the capillaries of allantoic veins and arteries. The primary function of allantois is to serve as the *embryonic respiratory organ.* The oxygen diffusing inwards through the porous shell and shell membrane is received by blood in the capillaries of the allanto-chorion and transported to the embryo in the allantoic veins. The allantois also serves as an *embryonic urinary bladder.* The embryonic urine (solid crystals of uric acid) is stored in the allantois and left behind in the egg when the young bird hatches. The allantoic stalk and the yolk-sac stalk, surrounded by a common somatopleure of the ventral body-wall, together form the *umbilical cord.* It breaks at the time of hatching and the allantoic vesicle containing the excreta remains as a wrinkled membrane adjacent to the broken shell. The urine is thus prevented from escaping to other parts of the embryo where it may cause harm. Later, the place of attachment to umbilical cord to the body heals up, leaving a permanent scar, the *umbilicus*, on the body.

Thirdly, the allantois collaborates with the amnion. Fourthly, allantois forms the *albumen sac.* The egg white or albumen loses water rapidly and sinks towards the lower pole of the yolk. As the chorio-allantois grows, it folds around the remaining egg-white enclosing it in an albumen sac which is a nutritive organ. It not only digests and absorbs the albumen but the allantoic blood vessels take water from it and send to the embryo.

Hatching

Hatching occurs after about 21 days of incubation. The chick develops a little calcareous elevation, the *egg-tooth* or *caruncle*, at the tip of the upper beak. A day earlier or on the day of hatching, the chick ruptures the shell membrane by means of its beak and breathes air of the air space through its nostrils into the lungs. Since the inside surface of the shell is concave, it is easier for the chick to break open the shell and shell membrane as all the force is concentrated one point. The outer surface of the shell is convex, hence, the force exerted on the outside of the shell is distributed on all sides and the shell does not break easily. The chick breaks open the shell by repeated blows of the egg-tooth and hatches out leaving behind the allanto-chorion and amnion in the shell. The newly hatched chick is *precocious* or *nidifugous*, i.e., it is fully clad with wet feathers which soon dry up on exposure to air, and is able to walk and feed.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the structure of a freshly laid hen's egg.
2. Give an account of development of chick till the formation of germinal layers.
3. Describe chick development upto the development of primitive streak.
4. What do you understand by foetal membranes ? Describe their formation and functions in chick.

» *Short Answer Type Questions*

1. Differentiate between — (i) Blastulation and gastrulation, (ii) Area opaca and area pellucida, (iii) Development and growth, (iv) Embryo and larva.
2. Draw fully labelled diagrams of— (i) An avian egg in section, (ii) Entire embryos of chick about 33, 36, 48 and 72 hours old, (iii) Stages of development of chick from fertilized egg, upto the formation of amnion and chorion.
3. Write short notes on— (i) Allantois, (ii) Egg of fowl, (iii) Extra-embryonic membrane, (iv) Primitive streak, (v) Hensen's node.

» *Multiple Choice Questions*

1. Viability period of a Cock's sperm is :
   (a) About 3 hours (b) About 3 days
   (c) About 3 weeks (d) About 3 months
2. At the time of laying the Chick embryo is in :
   (a) 2 cell stage (b) Early blastula stage
   (c) Morula stage (d) Early gastrula stage
3. At the broad end of egg the shell membranes enclose :
   (a) Excretory space (b) Circulatory space
   (c) Air space (d) Nutritive space
4. Chalaziferous layer of albumin is made up of :
   (a) Ovomucoid (b) Lipoprotein
   (c) Hyaluronidase (d) Cholesterol
5. Ovum is separated from albumin by
   (a) Shell membrane (b) Dense albumin
   (c) Plasma membrane (d) Fertilization membrane
6. White yolk beneath the blastodisc :
   (a) Latebra (b) Nucleus of Pander
   (c) Neck of Latebra (d) Germinal disc
7. Blastodisc is united with the yolk mass by :
   (a) Epiblast (b) Endoblast
   (c) Periblast (d) Mesoblast
8. Body of embryo proper is formed by :
   (a) Area opaca (b) Nucleus of Pander
   (c) Latebra (d) Area pellucida
9. Extra embryonic structures are formed by :
   (a) Area opaca (b) Nucleus of Pander
   (c) Latebra (d) Area pellucida
10. In Chick the incubation period is :
    (a) 14 days (b) 21 days (c) 28 days (d) 35 days
11. Hensen's node is formed by the cells of presumptive .
    (a) heart (b) gut (c) kidney (d) notochord
12. Primitive streak stage begins after :
    (a) 12 hours (b) 15 hours (c) 18 hours (d) 24 hours
13. The first sign of metameric segmentation in the chick embryo is the appearance of :
    (a) Mesoblastic somites (b) Ectoblastic somites
    (c) Endoblastic somites (d) Meroblastic somites

14. 4 pairs of somites are formed after :
    (a) 12 hours of incubation (b) 15 hours of incubation
    (c) 18 hours of incubation (d) 24 hours of incubation
15. Region of area pellucida without mesoderm :
    (a) Preamnion (b) Postamnion
    (c) Proamnion (d) Mesoamnion
16. The embryonic respiratory organ :
    (a) Amnion (b) Chorion
    (c) Allantois (d) Yolk sac
17. The embryonic urinary bladder :
    (a) Amnion (b) Chorion
    (c) Allantois (d) Yolk sac

ANSWERS

1. (c) 2. (d) 3. (c) 4. (a) 5. (d) 6. (b) 7. (c) 8. (d) 9. (a) 10. (b) 11. (d) 12. (c) 13. (a) 14. (d) 15. (c) 16. (c) 17. (c)

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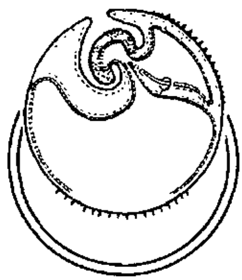

Development of Rabbit

Monotremes (platypus and spiny anteater) are primitive egg-laying or oviparous mammals. Their eggs are 4 to 6 mm in diameter and resemble those of reptiles and birds in structure. They are enclosed in a layer of albumen and a tough protective calcified shell. They are extremely telolecithal as the albumen encloses a large yolky mass. Cytoplasm forms a small germinal vesicle or blastodisc at the animal pole on the yolky mass. After fertilization, cleavage of egg is meroblastic and discoidal and development is essentially like that of reptiles and birds.

All the remaining mammals are viviparous. *Marsupials* (kangaroo, opossum, etc.) show some variation in the structure and development of their eggs which measure 0.15 to 0.25 mm in diameter. They have a distinct albumen layer, enclosed by shell membrane and a horny shell. In some cases (*Dasyurus*) eggs are telolecithal, but in others (*Didelphis*), they are isolecithal. Cleavage is holoblastic.

Eutheria or *placental mammals* (rabbit, etc.) have minute eggs, with only a limited amount of yolk. Since the mother supplies food to the developing embryo through placenta, their ova contain very little yolk and are therefore, small and microlecithal like that of amphioxus. There is no protective egg-shell and practically no albumen. Cleavage is apparently total or holoblastic and approximately equal.

Structure of Egg of Rabbit

Egg or ovum liberated (*ovulation*) by the bursting of Graafian follicle of ovary into oviduct is a *secondary oocyte*, as in *Branchiostoma*. In frog and fowl, the primary oocyte is set free. Egg of rabbit is a small and spherical cell 0.11 to 0.12 mm in diameter. It is *microlecithal*, that is, it contains a small amount of yolk somewhat evenly distributed in its cytoplasm. *Nucleus* is placed excentrically nearer the animal pole having *polar bodies* attached. A true *vitelline* or *primary egg membrane* is lacking. Instead egg is surrounded by a thin striated secondary egg membrane, the *zona pellucida*, which is apparently secreted by the follicle cells of the ovary. The term *corona radiata* is applied to certain large follicle cells which often remain for a short time attached to zona pellucida, but soon disappear. In some mammals including rabbit, the oviduct secretes on to the outer surface of ovum a coat of dense *albumen* forming a tertiary egg membrane. No other tertiary membranes (shell and shell membranes) are formed.

Fertilization

During fertilization, the genetic material from a sperm cell is merged with that of a secondary oocyte into a single nucleus. Of the large number sperm that enter the vagina less than 1% reach the secondary oocyte. Fertilization is internal, takes place in the fallopian tube about 12-24 hour after ovulation. Peristaltic contractions and the actions of cilia transport the oocyte through the uterine tube. Sperm swim up the female tract by whip like movements of their tail. The acrosome of sperm produces an enzyme called *acrozin* that stimulates sperm motility and migration within female reproductive tract. Also muscular contraction of the uterus stimulated by prostaglandins in semen aid sperm movement towards the uterine tube. The oocyte is thought to secrete a chemical substance that attracts sperm. Although sperm undergo maturation in the epididymis, they are still not able to fertilize an oocyte until they have been in the female tract for several hours. This functional change that the sperm undergo in the female reproductive tract is known as *capacitation*. It involves the process in which the membrane around the acrosome becomes fragile so that several destructive enzymes viz., hyaluronidase, and acroin are released from the acrosome. It requires the collective action of many sperm for one sperm to enter the secondary oocyte. The enzymes help in penetration of carona radiata, the ring of cells that surrounds the oocyte and a clear glycoprotein layer internal to corona radiata called zona pellucida. Normally only one sperm cell enters a secondary oocyte. This event is called *syngamy*. Syngamy causes depolarization which triggers the release of calcium ions inside the cell. Calcium ions stimulate the release of granules by the oocyte that in turn promote changes in the zona pellucida to block the entry of other sperm. This prevents polyspermy i.e., fertilization by more than one sperm cell. Once a sperm cell has entered a secondary oocyte, the oocyte completes the meiosis II. It divides into a larger ovum (Mature egg) and a smaller second polar body that fragments and disintegrates.

After entry of the sperm into the secondary oocyte the tail of the sperm is shed and the nucleus in the head develops into a structure known as male pronucleus. The nucleus of the fertilized ovum develops into a female pronucleus. These pronuclei fuse to form a segmentation nucleus which is diploid. The fertilized ovum consisting of a segmentation nucleus, cytoplasm and zona pellucida is called the zygote.

Early Embryonic Development

Cleavage. Cleavage is *holoblastic* and begins as the zygote passes down the oviduct. First two cleavages are vertical and at right angles to each other, so that zygote divides first into 2 and then into 4 cells or *blastomeres*. After first cleavage division the resultant blastomeres are unequal. One blastomere remains slightly larger than the other. During second cleavage, larger cell divides first, forming three blastomeres. Later smaller blastomere divides. Third cleavage is horizontal and slightly above the equator, resulting into 8 cells. Further cleavages become irregular.

Morula. Cleavage results in the formation of a more or less spherical solid mass or ball of cells called *morula*. A fully formed morula shows an outer or superficial layer of cells, the *trophoderm* or *trophoblast*, surrounding an *inner cell mass* of larger polyhedral cells. The morula stage passes down the oviduct to enter the uterus (Fig. 1).

Blastocyst. Morula absorbs fluid secreted by the uterine mucous membrane and swells rapidly. A fluid-filled cavity now appears between trophoblast and inner cell mass, the latter attached to trophoblast only at the animal pole, like a knob.

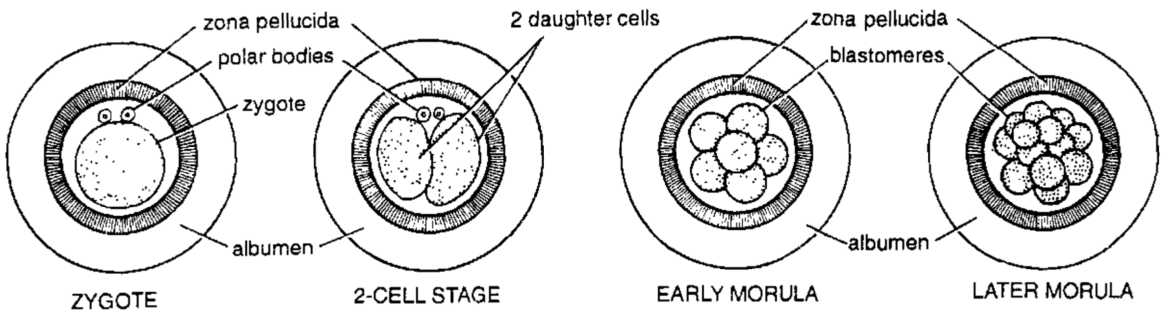

Fig. 1. Rabbit. Early cleavage stages.

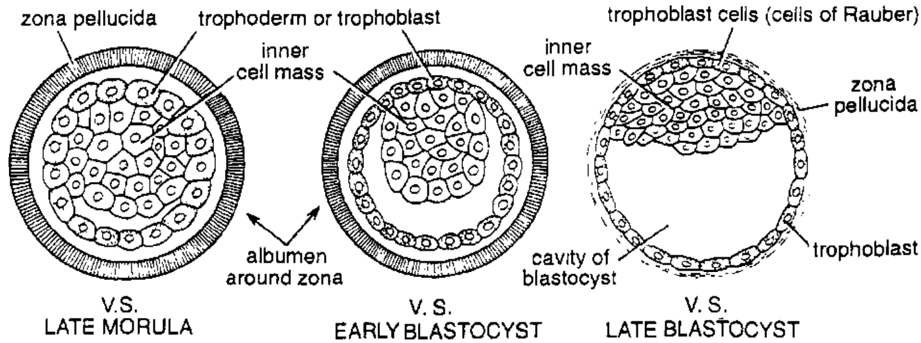

Fig. 2. Rabbit. Stages of blastocyst formation.

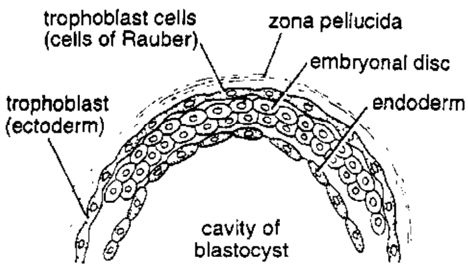

Fig. 3. Rabbit. V. S. of blastocyst showing gastrulation or formation of endoderm.

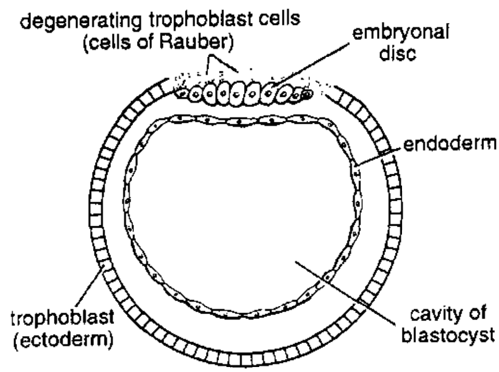

Fig. 4. Rabbit. Fully formed blastodisc or embryonal disc in V. S.

The embryo now forms a vesicular structure called *blastocyst* or *blastosphere*. It is not equivalent to a blastula, nor its cavity is a blastocoel. As the cavity enlarges, the knob-like inner cell mass becomes flattened and known as *germinal* or *embryonal disc* which gives rise to embryo proper.

In some mammals, including rabbit, the trophoblastic cells (*cells of Rauber*) overlying embryonal disc disintegrate. As a result the embryonal disc comes to lie at the surface of the blastodermic vesicle or blastocyst and its edge becomes continuous with the trophoblast around it.

Blastocyst stage is peculiar of mammalian development. It may be considered equivalent to chick blastoderm. Similarly, its embryonal disc is comparable to area pellucida, trophoblast to extra-embryonic ectoderm, and its cavity to subgerminal cavity of chick (Figs. 2–3).

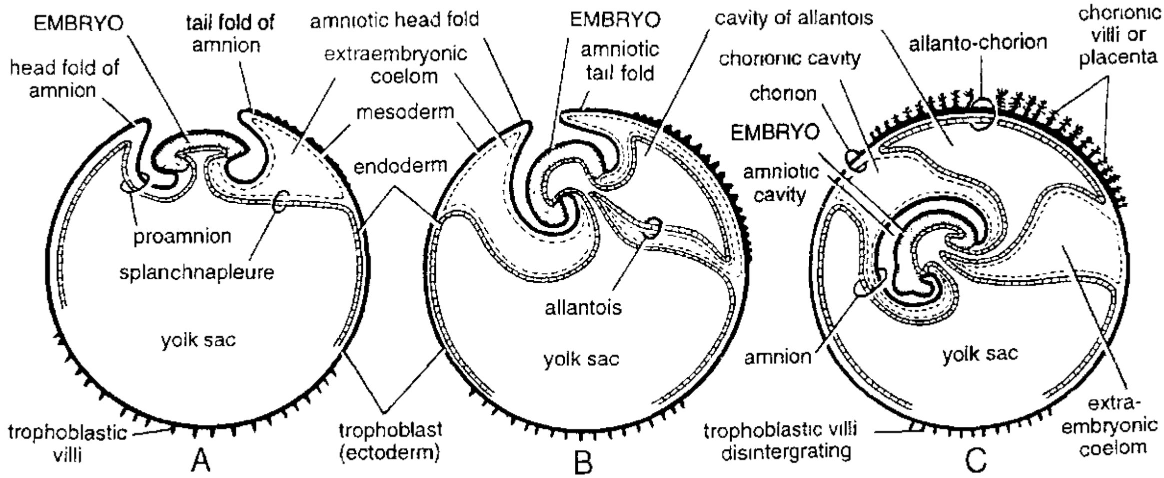

Fig 5. Rabbit Formation of foetal or extra-embryonic membranes. A—Formation of head and tail folds of amnion. B—Allantois formed. C—Completed foetal membranes and placenta.

Gastrulation. Gastrulation is not properly understood in mammals. Shortly after formation of embryonal disc, its lower cells spread downwards forming a distinct layer of flattened epithelial cells beneath the trophoblast. The blastocyst is now converted into a two-layered *gastrula.* Its fluid-filled cavity is a functionless *yolk sac* which, however, contains no yolk. Trophoblast now becomes *ectoderm* of yolk sac, while the inner epithelial layer forms its *endoderm.*

Implantation. The zygote undergoes rapid cleavage, while it is still covered by zona pellucida. The smaller cells so produced (blastomeres) form the solid sphere the morula. The morula moves towards the uterus in the fallopian tube which later changes into blastula with the development of a blastocyst. The blastocyst remains free for some time (about two days) in the uterine cavity and derives nourishment from the uterine fluid which is rich in glycogen, therefore the uterine fluid is also known uterine milk. Later the blastocyst is attached to the wall of the uterus. This is known as implantation. The trophoblast opposite embryonal disc forms small finger-like projections or papillae, called *trophoblastic villi.* These penetrate into corresponding depressions, or *crypts,* into the uterine wall which becomes more vascular, glandular and thicker. By means of villi the embryo is not only firmly anchored or implanted but also absorbs nutrients form the maternal uterine wall for its further development.

Further development. Further development very much resembles that of reptiles and birds. Presumptive areas of mammalian embryo are similar to those of chick blastoderm. However, in mammals, the endoderm arises independently by delamination from underside of embryonal disc, as already described above. Formation of mesoderm involves the development of a primitive streak, groove and knot at the future posterior end, as in chick embryo. Sections show mesodermal cells extending laterally from primitive streak between ectoderm and endoderm. A notochordal process extends in front of primitive knot much as in chick. Formation of neurula and organogeny are also fundamentally similar. Formation of mesodermal somites and splitting of lateral plate mesoderm with the appearance of splanchnocoel proceed in the same manner as in chick. However, in rabbit, the lateral plate mesoderm extends as far as the equator, so that the lower wall of yolk sac consists only of ectoderm (trophoblast) and endoderm. Further differentiation and 'folding off' of embryo from lower yolk sac are the same as in chick. The mammalian embryo in its later stages is called a *foetus.*

Extra-embryonic Membranes of Rabbit

As already described in case of chick, during development of all higher vertebrates are produced certain membranous structures which do not enter into the formation of the embryo itself. These are known as *extra-embryonic membranes.* They include amnion, chorion, allantois and yolk sac. They serve for nutrition, respiration, excretion and protection of the developing embryo and foetus. Their origin and development is similar to that in chick except that the allantois in most mammals gives rise to a *placenta* (Fig. 5).

1. Yolk sac. In mammals, as the lower part of blastocyst becomes progressively lined by endoderm, it becomes the *yolk sac* or *umbilical vesicle.* It does not contain yolk, still its development and structure in mammals is regarded as an inheritance from reptilian ancestors with large-yolked eggs and meroblastic cleavage. In rabbit, the upper part of yolk sac is lined by endoderm and covered externally with splanchnic mesoderm. However, its lower half is made by endoderm and ectoderm (trophoblast) because mesoderm does not extend upto that region. Yolk sac is connected to the enteron of embryo by a slender *yolk stalk.* Upper wall of *yolk sac,* or splanchnopleure, develops area vasculosa containing vitelline arteries and veins. In rabbit, yolk sac is quite large. The trophoblast on its lower side (opposite embryo) develops small villi which penetrate into corresponding crypts of maternal uterine wall for attachment and for absorbing secretions of uterine glands. After a time, lower wall of yolk sac ruptures so that now it receives uterine secretions directly which are passed on through vitelline circulation to enteron for nourishment. Thus, yolk sac serves for the nutrition of embryo. In marsupials (e.g. opossum), yolk sac wall is intimately connected with uterine wall to form a *yolk sac placenta.*

2. Amnion and Chorion. After the formation of primitive streak, the somatopleure (trophoblast plus somatic mesoderm) is raised into *amniotic folds* around the embryo, as in chick. However, the *tail fold* grows more rapidly than the *head* and *lateral folds.* Finally, when these folds converge and meet over the embryo, their point of fusion or *sero-amniotic connection* lies above the anterior region of embryo. Fusion of amniotic or somatopleural folds results in two membranes over the embryo : inner *amnion* and outer *chorion.* Amnion is made of outer somatic mesoderm and inner ectoderm. The fluid-filled *amniotic cavity* bounded by ectoderm between amnion and embryo serves to protect the embryo from mechanical shocks and prevents its desiccation. Chorion is made of outer ectoderm and inner somatic mesoderm. The space between chorion and amnion, bounded by mesoderm, is the *chorionic cavity* or extra-embryonic coelom. Chorion develops larger *chorionic villi* which later disappear except in the region of allantoic placenta. In most mammals, including man, the amnion develops in a different way.

3. Allantois. In rabbit, the allantois grows out as a vesicle from hindgut of embryo into the extra-embryonic coelom just as in chick. It consists of splanchnopleure, that is, endoderm inside and splanchnic mesoderm outside. Behind the embryo over a small disc-shaped area, the allantois comes into contact with chorion and their mesodermal layers fuse together and become highly vascular. Thus a compound layer is formed called *allanto-chorion* or *chorio-allantois.* It consists of outer ectoderm, middle thickened mesoderm and inner endoderm. Its *chorionic villi* invade the maternal uterine wall forming an *allantoic placenta* for absorbing nutrients. Thus, alanto-chorion of mammals is not only an efficient organ of respiration and excretion, as in birds, but also of nourishment by forming a placenta with allantoic circulation. In some mammals (man and apes), allantois remains rudimentary. It does not reach the chorion but remains buried as a small tube inside the body stalk (umbilical cord). Their chorion still forms a placenta known as *chorionic placenta.*

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Describe the development of foetal membranes in a mammal (rabbit).
2. Draw neatly labelled diagrams to illustrate the development of foetal membranes of Rabbit and state their functions in detail.

» *Short Answer Type Questions*

1. Write short notes on — (i) Structure of rabbit egg (ii) Early embryonic development of rabbit, (iii) Yolk sac, (iv) Amnion and chorion in rabbit, (v) Allantois in rabbit.

» *Multiple Choice Questions*

1. The egg of mammals are :
   (a) Alecithal (b) Mesolecithal
   (c) Telolecithal (d) Isolecithal
2. The cleavage in mammals is :
   (a) Holoblastic equal (b) Holoblastic unequal
   (c) Meroblastic (d) Apiblastic
3. The chorion is composed of :
   (a) Cytotrophoderm (b) Syncytial trophoblast
   (c) Ectoderm and mesoderm (d) All these
4. The cells destined to become the embryo proper in mammal constitute the :
   (a) Trophoblast (b) Cells of Rauber
   (c) Inner cell mass (d) Cellular capsule
5. The acrosome of the sperm produces an enzyme :
   (a) Androgammone (b) Gynogammone
   (c) Hyaluronidase (d) Acrozin
6. In rabbit morula develops into fluid filled ball called :
   (a) Coeloblastula (b) Trophoblastula
   (c) Blastocyst (d) Gastrula
7. Cells of Rauber are found in :
   (a) Amphioxus (b) Frog
   (c) Chick (d) Rabbit
8. Yolk sac placenta where yolk sac wall is intimately connected to uterine wall is found in :
   (a) Rabbit (b) Opossum
   (c) Man (d) Rat
9. Chorio-allantois in case of mammals performs following functions :
   (a) Respiration (b) Excretion
   (c) Nutrition (d) All these

ANSWERS

1 (a) 2. (c) 3. (c) 4. (a) 5. (d) 6. (c) 7. (d) 8. (b) 9. (d)

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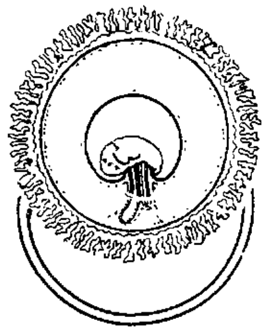

Placentation in Mammals

What is Placenta

Modes of embryonic nutrition differ in different mammals. Prototheria or monotremes (*Tachyglossus, Ornithorhynchus*) are *oviparous* like most reptiles and birds. They produce large, heavily yolked and shelled eggs. The vitelline vessels developed in the wall of yolk sac carry yolky nutrients to the developing embryo. *There is no uterine gestation and no formation of placenta.* Newly hatched young are exceedingly immature and complete their growth in a temporarily developed abdominal pouch of mother during which they are fed upon milk.

All other mammals (Metatheria and Eutheria) are *viviparous*. The development of their young is intra-uterine, that is, inside the uterus of mother. But their minute eggs contain so little yolk that they could never develop beyond the very early stages unless additional nourishment is somehow provided by the mother. This is done by the formation of a characteristic organ called *placenta* by which the embryos establish close contact with the utrine wall of mother. The term *placenta* may be defined as the structure by which the developing embryo or foetus of viviparous mammals obtains its nourishment from the maternal uterine blood. It is formed by the interlocking of both foetal as well as maternal tissues. The part derived from foetus is called *foetal placenta*, while that derived from uterine wall is called *maternal placenta*. The term placentation may be defined as an intimate relation between a portion of maternal uterine wall and a part or whole of the chorionic membrane or trophoblast of embryo for the purpose of nutrition, respiration and excretion. Placentation involves a series of events following implantation of embryo and leading to development of placenta. Placenta is not exclusively found in mammals but also present in other animal groups like— Onychophora (*Peripatus*), Ascidians (*Salpa*), Elasmobranchs (*Mustelus*) and some lizards also. But the tissues which help in formation of placenta are different from those of mammals.

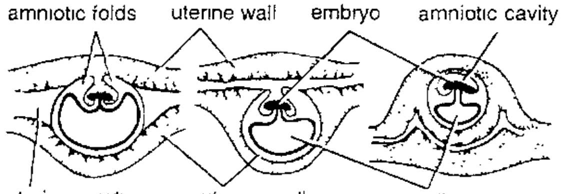

Fig. 1 Modes of uterine implantation of embryo in mammals.

Implantation of Embryo

First step towards formation of placenta is the attachment of developing embryo to the wall of uterus, called *implantation*. This is effected by small finger-like processes, the *villi*, which grow out from a particular area or areas of trophoblast of embryo and penetrate into corresponding *crypts* in the maternal uterine wall. Blood vessels, lymphatic vessels and glands of uterine wall enlarge and their secretions in the lumen of uterus provide nourishment to the embryo. Implantation generally occurs in one of the following three manners (Fig. 1) :

1. Central implantation. In rabbit, ungulates, carnivores and lower primates, embryo is attached to the surface of uterine lining and projects freely into uterine cavity. This is also known as *superficial implantation*.

2. Concentric implantation. In mouse, rat, squirrel, beaver, etc. the mucous lining of uterus gives out folds to cover the embryo which is embedded in a groove or pocket of main uterine cavity.

3. Interstitial implantation. In man, apes, pig and certain rodents such as guinea pig and hedgehog, the blastocyst or embryo actually burrows into uterine tissue to become completely surrounded by it.

As far as mechanism of implantation is concerned, when the blastocyst comes in the direct contact of the uterine epithelium, in the area of attachment, begins to break down by the action of some digestive enzymes secreted by trophoblast. The erosion of uterine epithelium creates gap through which invading trophoblast advances and comes into contact with the connective tissue layer of uterus. The secretion of *progesterone* by the *corpus luteum* makes the *endometrium* more receptive for implantation.

Classification of Placent

Mammals show many variations in the mode of origin and details of shape and structure of placenta, which are classified accordingly. The three main factors involved are : (i) Nature of extra-embryonic membranes involved, (ii) distribution of villi and shape of placenta, and (iii) degree of intimacy between foetal and maternal tissues or histology.

[I] Types according to extra-embryonic membranes involved or mode of origin

Depending on the foetal membranes forming placenta, three kinds are recognized : yolk sac, allantoic and chorionic.

1. Yolk sac placenta. In Metatheria or marsupials, such as kangaroo (*Macropus*) and opossum (*Didelphys*), placenta is derived from yolk sac and chorion. Yolk sac developed from the lower part of blastocyst is very large and nearly encloses the entire embryo and its amnion (Fig. 2). Wall of yolk sac lies in direct contact with chorion (trophoblast) which sends out finger-like villi into uterine wall. Yolk sac wall also develops vitelline blood vessels for transporting secretions. Uterine milk absorbed from uterus to the developing embryo. Allantois remains poorly developed and never comes in contact with chorion.

In Metatheria, yolk sac placenta is only weakly developed so that embryonic nutrition and growth remain limited and the young is born very small and immature. To compensate the deficiency of intra-uterine development, it is transferred to the abdominal pouch or marsupium and fed on milk until fully formed.

In higher mammals (Eutheria), a yolk sac placenta is usually not found. But, it may be large and temporarily develop in early stages in some mammals such as hedgehogs and rabbits. Or, it

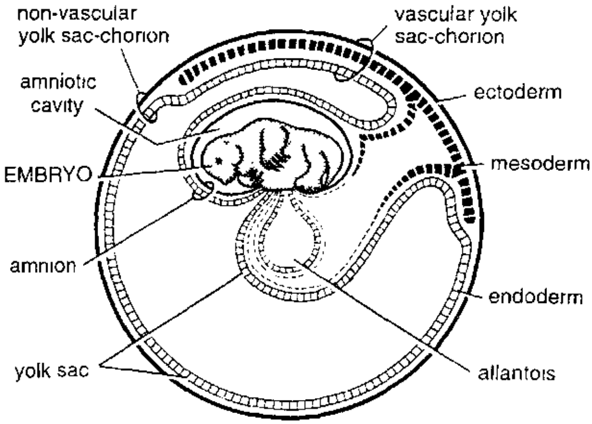

Fig. 2. Yolk sac placenta of opossum

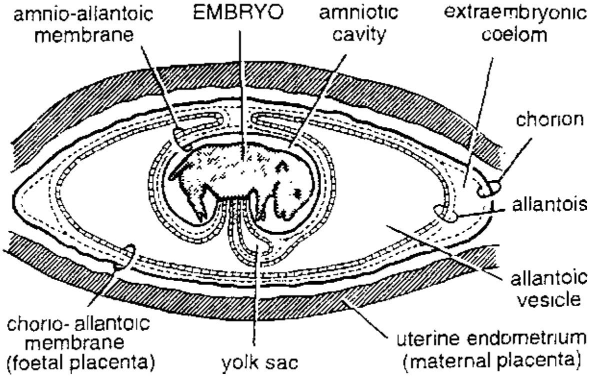

Fig. 3. Allantoic placenta of pig

may be small ending in a small tube in the umbilical cord, as in man.

2. Allantoic placenta. In the majority of Eutheria, the chief organ of embryonic nutrition is the *allantoic placenta* consisting of allantois and chorion (Fig. 3). Allantois is a sac-like outgrowth from the hindgut of embryo. It is lined internally by endoderm and externally by mesoderm. As allantois grows and spreads in the extra-embryonic cavity, its mesoderm fuses with that of chorion over a somewhat restricted region. The layer formed by fusion of allantois and chorion is termed *allanto-chorion*. It becomes richly vascular and thrown into small, finger-like processes, the *villi*. The uterine wall forms corresponding depressions, called *crypts*, which are penetrated by foetal villi forming allantoic placenta. Materials absorbed from maternal blood through allantoic placenta are carried to the foetus by allantoic blood vessels.

Outside Eutheria, a primitive allantoic placenta occurs only in *Perameles* (bandicoot) which is a metatherian. But it also has an efficient yolk sac placenta. In this case yolk sac and allantois are large, well developed but it is allantois that supplies blood vessels to chorion. The trophoblast of the chorion, at places of contact with uterine wall disappears. The uterine wall is syncytial and highly vascularised. Physiological exchange takes place between the foetal blood and maternal blood.

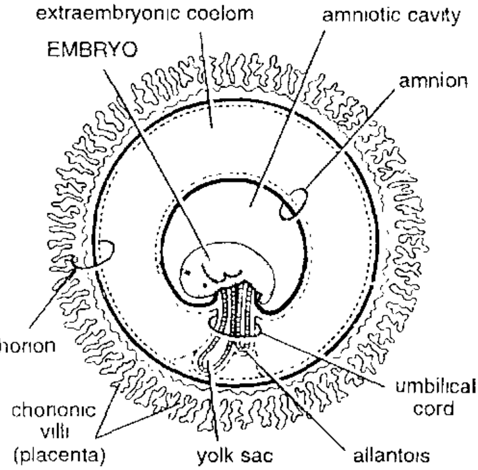

Fig. 4. Chorionic placenta of man

3. Chorionic placenta. It occurs in man and apes and is formed only by chorion. Allantois remains small, burrows into body stalk (umbilical cord) and does not reach chorion. However, its mesoderm and blood vessels grow up to chorion whose villi enter the uterine crypts forming *chorionic placenta* (Fig. 4).

[II] Types according to shape and distribution of villi

Depending on the shape of placenta, manner or distribution of villi, degree of connection between foetal and maternal tissues and behaviour of placenta at the time of birth, the following types and subtypes of allantoic placenta can be recognized (Fig. 5) :

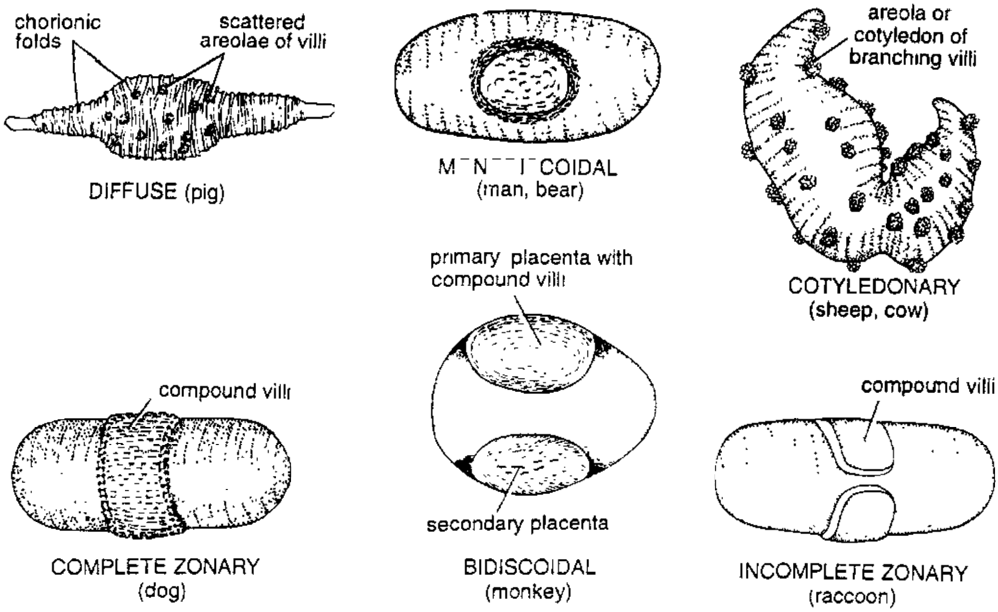

Fig. 5 Types of placenta according to villi. Diffuse (pig). Cotyledonary (sheep). Zonary (dog). Discoidal (bear). bidiscoidal (monkey).

1. Non-deciduous placenta. In most mammals villi are simple, unbranched and merely apposed without intimate contact between foetus and uterine wall. At the time of birth or *parturition*, villi are easily withdrawn from maternal crypts without causing any tissue damage. Thus no part of uterine tissue comes out and no bleeding occurs. Non-deciduous or non-deciduate placenta has following subtypes according to the manner of distribution of villi.

*(a) **Diffuse.*** Villi remain scattered all over the surface of allantochorion. Ex. Pig, horse, lemur.

*(b) **Cotyledonary.*** Villi are arranged in separate tufts or patches called cotyledons. Ex. Goat, sheep, cow, deer.

*(c) **Intermediate.*** Villi are arranged in cotyledons as well as scattered. Ex. Camel, giraffe.

2. Deciduous placenta. Villi are complicated, branched and intimately connected. At birth, a variable amount of maternal tissue is pulled out with the shedding of blood. Deciduous or deciduate placenta is also differentiated in the following subtypes :

*(a) **Zonary.*** Villi form an incomplete (e.g. racoon) or complete girdle encircling the blastocyst. Ex. cat, dog, seal, elephant.

*(b) **Discoidal.*** Villi are restricted to a circular disc or plate on the dorsal surface of blastocyst. Ex. insectivores, bats, rodents (rat, mouse), rabbit, bear.

*(c) **Metadiscoidal.*** Villi are at first scattered but later become restricted to one or two discs. It is *monodiscoidal* in man and *bidiscoidal* in monkeys and apes.

3. Contra-deciduous. Foetal villi and uterine crypts are so intimately connected that even most of foetal placenta is left behind at birth to be broken and absorbed by maternal leucocytes. Ex. Bandicoot (*Perameles*), mole (*Talpa*).

[III] Histological types

Foetal and maternal bloods in placenta do not mix up with each other. To start with, the two blood streams are separated from each other by atleast the following 6 tissue barriers or membranes :

(1) Endothelium of maternal blood vessels
(2) Uterine connective tissue
(3) Uterine epithelium
(4) Chorionic epithelium or trophoblastic ectoderm
(5) Chorionic + allantoic mesoderm
(6) Endothelium of foetal blood vessels

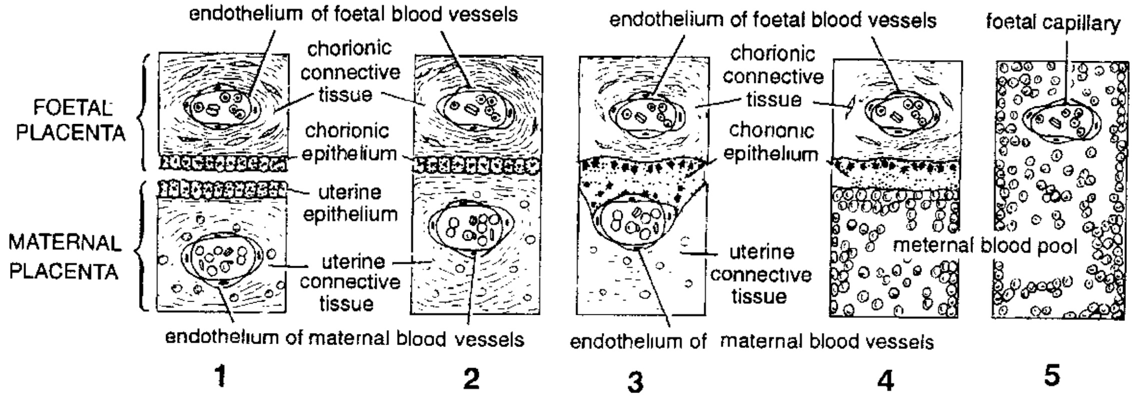

Fig. 6. Histological types of mammalian placentae.

Exchange of substances in solution between two blood streams occurs by diffusion through these tissues. To increase effectiveness or efficiency of placenta, it is necessary to reduce the number of tissues between foetal and maternal blood streams. Nature of reduction or erosion of tissues varies greatly in different mammals. Grossor recognizes the following 5 histological types or grades of reduction (Fig. 6) :

1. **Epithelio-chorial.** It is the simplest type with all the six tissue barriers present. It is supposed to be most primitive from which other types have been derived. Ex. Pigs, lemurs.

2. **Syndesmo-chorial.** Only uterine epithelium is eroded so that chorionic epithelium (or trophoblastic ectoderm) comes in contact with uterine connective tissue. Ex. Cattle, sheep.

3. **Endothelio-chorial.** Uterine epithelium as well as uterine connective tissue breakdown so that chorionic epithelium comes in contact with the endothelium of maternal blood vessels. Ex. Carnivore (cat, dog), tree shrew, mole.

4. **Haemo-chorial.** Endothelium of maternal blood vessels also disappears. Thus chorionic epithelium and blood vessels of foetal villi are directly bathed in maternal blood flowing in sinuses. Ex. Man, apes, monkeys, some insectivores and some rodents.

5. **Haemo-endothelial.** Finally, the chorionic epithelium and mesoderm also disappear allowing the foetal capillaries to come in direct contact with maternal blood. Ex. Rat, guinea pig, rabbit.

On the basis of electron microscopic studies of the histology of placenta, placenta can be classified into three categories only viz., *Epithelio-chorial placenta, Endotheliochorial placenta* and *Haemochorial placenta.* Goel (1984) further classified haemochorial type of placenta into three subtypes — haemomonochorial type, haemodichorial type and haemotrichorial type, based on the number of layers of trophoblast involved in covering the foetal endothelium.

Physiology and Functions of Placenta

Placentation is the mechanism by which the foetal and maternal blood circulations are brought very close together to provide for the respiration, excretion and nutrition of the foetus. However, there is no mixture or fusion of these two blood streams. Foetal blood does not circulate in mother and vice versa. *Exchange of substances* occurs from one circulation to the other by diffusion in which the intervening tissue barriers serve as an *ultrafilter.* Only selected substances can pass through placenta. All food materials and oxygen of maternal blood diffuse into foetal capillaries, while excretory wastes and carbon dioxide produced by foetus diffuse in the opposite direction. In addition, placenta *stores materials* such as fat, glycogen and iron for the use of embryo while it still has no liver. Placenta also participates in the *metabolism of proteins* and serves as an *endocrine gland.* In rabbit, placenta secretes a protein hormone, *relaxin,* which causes relaxation of pelvic ligaments and pubic symphysis to facilitate birth of the young. In human and other placental mammals it secretes placental lactogen, chorionic gonadotropin, estradiol, progesterone, etc. Besides these, significant immunological function has also been reported by the trophoblast (Dutta, 1987).

Placenta and Diseases

Viral or bacterial infection of placenta is known as *placentitis*. If the mother suffers from certain diseases like *syphilis, small pox, chicken pox, measles*, etc., their viruses or pathogenic organisms may pass through placenta to infect the foetus with these diseases. Drugs such as *thalidomide* taken as a sedative by mother during early pregnancy, may effect serious deficiency in limbs, heart or digestive tract of foetus. Normally maternal blood does not come in direct contact with foetal blood. However, accidental breaking of placental capillaries may result in some red blood cells of foetus entering maternal circulation. If per chance mother is Rh negative and foetus is Rh positive, the positive red cells of foetus will induce production of Rh antibody in maternal blood plasma, which can easily diffuse through into foetal circulation damaging its red cells, and resulting in jaundice or even death of foetus.

On the other hand, if mother has acquired immunity against certain diseases like *diphtheria, small pox, measles*, etc., the antibodies developed in maternal blood are passed to foetus which also acquires immunity against such diseases.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. What is placentation? Describe various types of placenta found in mammals.
2. Describe structure, formation and function of placenta in mammals.
3. Write an essay on placentation in mammals.

» *Short Answer Type Questions*

1. Write short notes on— (i) Implantation of mammalian embryo, (ii) Parturition, (iii) Placenta, (iv) Physiological role of placenta.
2. Draw labelled diagrams of — (i) Epitheliochorial type of placenta, (ii) Syndesmochorial type of placenta, (iii) Endotheliochorial type of placenta, (iv) Haemochorial type of placenta.

» *Multiple Choice Questions*

1. The egg laying mammals are :
   (a) Prototherians (b) Metatherians
   (c) Eutherians
   (d) Both prototherians and metatherians
2. Yolk sac placenta is found in :
   (a) *Macropus* and *Didelphis* (b) *Rattus rattus*
   (c) *Perameles* (d) *Talpa*
3. Yolk sac placenta is derived from :
   (a) Yolk sac and allantois (b) Yolk sac and chorion
   (c) Yolk sac and amnion (d) Yolk sac only
4. The type of placenta found in primates
   (a) Yolk sac placenta (b) Allantoic placenta
   (c) Allantochorionic placenta (d) Chorionic placenta
5. Following is the complete set of placenta of non-deciduous type :
   (a) Diffuse, cotyledonary, zonary
   (b) Diffuse, discoidal, intermediate
   (c) Diffuse, cotyledonary, intermediate
   (d) Diffuse, zonary, discoidal
6. Cotyledonary placenta is found in :
   (a) Cow and camel (b) Cow and deer
   (c) Camel and giraffe (d) Pig and horse
7. Contra-deciduous placenta is characteristic of :
   (a) Elephant (b) Tiger
   (c) Bandicoot (d) Cow
8. Match the following :
   (a) Diffuse (i) Monkey
   (b) Zonary (ii) Pig
   (c) Metadiscoidal (iii) Camel
   (d) Intermediate (iv) Cat

	A	B	C	D
(a)	(ii)	(iv)	(iii)	(i)
(b)	(iv)	(ii)	(iii)	(i)
(c)	(ii)	(iv)	(i)	(iii)
(d)	(i)	(ii)	(iii)	(iv)

9. All six barrier tissues are present in :
   (a) Endothelio-chorial placenta
   (b) Haemochorial placenta
   (c) Epithelio-chorial
   (d) Haemoendothelial
10. Find the correct match from the following :
   (a) Corpus luteum — Testosterone
   (b) Endometrium — Corpus luteum
   (c) Trophoblast — Testosterone
   (d) Corpus luteum — Progesterone
11. Hormone secreted from the placenta at the time of parturition :
   (a) Progesterone (b) Relaxin
   (c) Estradiol (d) Lactogen
12. Functions of placenta include :
   (a) Exchange of substances between mother and foetus
   (b) Ultrafilter
   (c) Endocrine gland
   (d) All of the above
13. Viral or bacterial infection of placenta is known as :
   (a) Syphilis (b) Placentitis
   (c) Dermatitis (d) Appendicitis
14. Haemochorial placenta is found in :
   (a) Man and monkeys (b) Cat and camel
   (c) Lion and tiger (d) Giraffe and horse
15. Eutherian mammals are :
   (a) Oviparous (b) Viviparous
   (c) Ovoviviparous (d) None of the above
16. Attachment of developing embryo to the wall of uterus :
   (a) Implantation (b) Ovulation
   (c) Placentation (d) Orientation
17. Yolk sac placenta is derived from :
   (a) Allantois (b) Yolk sac and chorion
   (c) Chorion (d) Yolk sac and allantois
18. In chorionic placenta allantois is limited to :
   (a) Chorionic villi (b) Uterine wall
   (c) Umblical cord (d) Yolk sac
19. In pig the placenta is :
   (a) Cotyledonary non deciduous
   (b) Diffuse non deciduous
   (c) Intermediate non deciduous
   (d) Deciduous
20. Syndesmo-chorial placenta lacks :
   (a) Chorionic epithelium (b) Uterine connective tissue
   (c) Uterine epithelium
   (d) Chorionic + Allantoic mesoderm

ANSWERS

1. (a) 2. (a) 3. (b) 4. (d) 5. (c) 6. (b) 7. (c) 8. (c) 9. (c) 10. (d) 11. (b) 12. (d) 13. (b) 14. (a) 15. (b) 16. (a) 17. (b) 18. (c) 19. (b) 20. (c).

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Organ Histology of Frog and Rabbit

Body of multicellular animals and plants is built up of *cells*. These are arranged in *tissues* or groups of cells having similar structure and function. When several tissues are combined and coordinated, they form an *organ*. Various organs are put together and arranged to form different *systems* of the body, each performing a particular function.

Microscopic study of tissues and organs is termed *histology* (Gr. *histos*, tissue + *logos*, discourse). This chapter deals with the histology of some familiar organs of frog and rabbit as revealed mostly by ordinary microscopy.

Types of tissues. Four different types of tissues are seen in animals *viz., epithelial, connective, muscular* and *nervous* each of this group includes several types as shown in flow chart.

Animal Tissue

- **Epithelial**
  - **A. according to function**
    - (i) simple
    - (ii) striated
    - (iii) pseudostratified
    - (iv) transitional
  - **B. according to shape**
    - (i) squamous
    - (ii) cuboidal
    - (iii) collumner
    - (iv) ciliated
      - ciliated
      - flagellated
      - stercocilated
      - brush border
  - **C. According to function**
    - (i) covering epithelium
    - (ii) glandular epithelium
- **Connective**
  - **A. connective tissue proper**
    - (i) mucous tissue
    - (ii) reticular tissue
    - (iii) areolar tissue
    - (iv) fibrous tissue
    - (v) adipose tissue
  - **B. skeletal connective tissue**
    - (i) bone
    - (ii) cartilage
  - **C. vascular connective tissue**
    - (i) blood
    - (ii) lymph
    - (iii) bone marrow
    - (iv) lymphatic tissue
- **Muscular**
  - **striated**
  - **smooth**
  - **cardiac**
- **Nervous**

Epithelium

The word epithelium means covering and epithelia are the tissues bounding the surface of the body as a whole, the surface of the various organs forming the lining of the gut and glands. Those epithelia which line the internal spaces such as body cavity or the blood vessels are referred to as endothelia. Various types of epithelia can be classified on the basis of the (i) structure and arrangement of the cells and (ii) function of the tissue.

Epithelia consists of the cells arranged in sheets, the cells being formed together by a small amount of intercellular cement and invariably the cells rest on a delicate structureless or fibriller *basement membrane*. In sections of epithelia examined under electron microscope the plasma membranes of the component cells are seen as derase parallel lines separated by an intercellular gap of about 200°A which probably represents intercellular cement.

Many epithelia contain bundles of fine filaments which contribute towards mechanical strength of the tissue and are particularly dense in the cells of the external layers of the vertebrates where they may be keratinised to form a protective covering. The cell surfaces are often studded with dense deposits from which tufts of intracellular fibrils may extend. The adhesion between the cells at such points is particularly strong and greatly reinforces the strength of the whole cellular formation. Such deposits are referred to as *desmosomes* but are also called as terminal bars where they run completely around the edges of cells, facing an open cavity or intercalated discs in striated muscles. Under the electron microscope, basement membranes are seen to consist of an amorphous layer about 400-600°. A thick, running parallel to the plasma membranes of the cells. Beyond this layer may be deposits of collagen fibrils, laid down by the fibrocytes of the underlying connective tissue. Epithelia may be

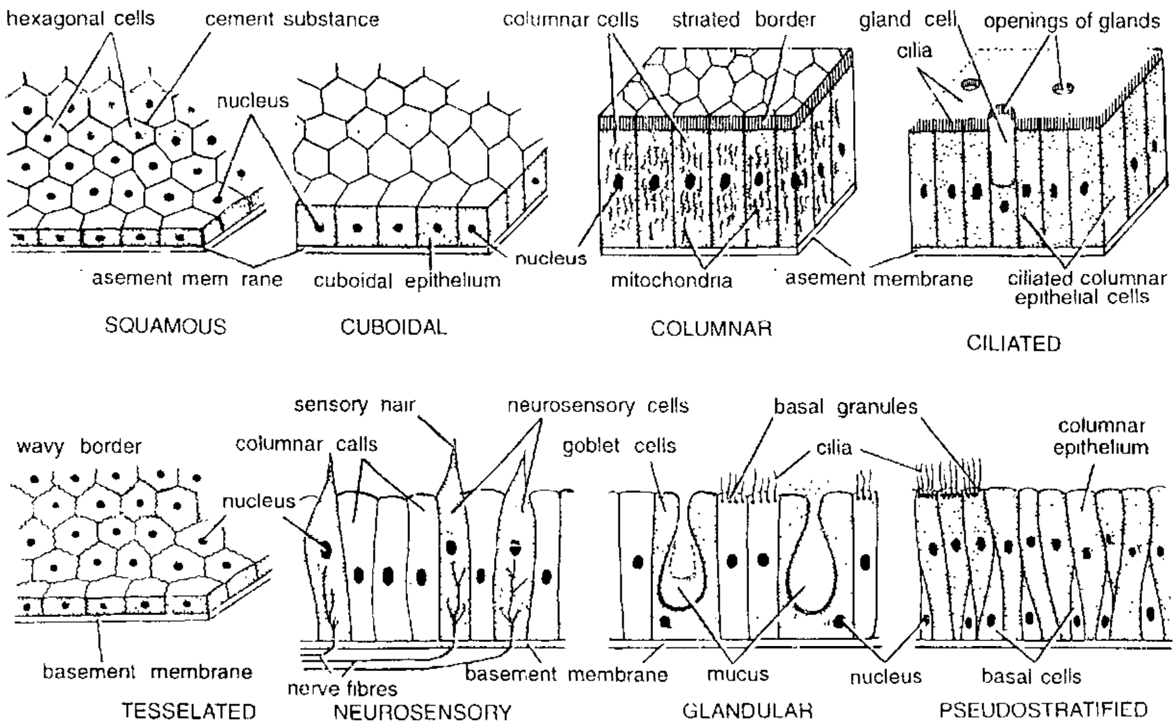


Fig. 1. Different types of epithelial tissues

composed of a single layer or of many layers of cells and, therefore, epithelia may be classified as (i) Simple epithelia and (ii) Compound epithelia.

Types of epithelia

Squamous epithelium. This type consists of single layer of flattened plate like cells whose edges fit closely together to form a mosaic and therefore, it is also known as '*pavement epithelium.*' The cells generally have a roughly hexagonal outline but in some types the outline of cells is vary and the epithelium is said to be tessellated.

Cuboidal epithelium. This type resembles the squamous type but the cells are cubical in shape. The nucleus is spherical and lies centrally in cells. In surface view, the cell outlines are polygonal. Cuboidal epithelium is found lining many glands like thyroid, sweat glands etc.

Columnar epithelium. There is no sharp distinction between columnar and cubical epithelium except that is columnar epithelial cells are taller and resemble pillars or columns. The nucleus is elongated. This type of epithelium is found in the wall of the alimentary canal, gastric glands and intestinal glands.

Ciliated epithelium. This type of epithelium is formed usually by columnar cells, while have on their free surface numerous cilia. The base of each cilium has one or more darkly stained granules. In small animals which have ciliated outside surface move with the help of the cilia.

When the cilia are present in the epithelium lining the cavities in larger animals, they are to produce a current for the flow of the fluid present in the cavity nasal cavity, trachea and bronchi.

Compound epithelia

The epithelia described above have little wear and tear. Arrangement of cells in a single layer does not offer early replacement of cells at the positions where there is considerable friction such as the outside surface of land living animals. To meet three conditions compound epithelia have developed.

1. Stratified epithelium. (F.G.H.) This type of epithelium is made of many layers of cells. The lower most layer i.e. the layer next to the basement consists of roughly spherical cells, whose nuclei stain darkly with haematoxylene. This type of epithelium is also known as germinative layer. This layer is always in active cell division so that cells are to always being produced to remain the overlying layer.

The outermost layer consists of dead flattened. Friction at the surface causes sloughing of these dead cells. The underlying layer of epithelial cells occupy a superficial position (skin, buccal and oesophageal epithelium).

2. Pseudostratefied epithelium. In this type the cells are not uniform in size and their nuclei appear at different levels. Many cells do not reach the free surface. It is more commonly found in invertebrates.

3. Transitional epithelium. In this type appearance is variable. Shape of the superficial cells ranges from squamous to cuboidal depending on the degree of distention (streching). This type of epithelium is found lining the lumen of urinary bladder.

Cell Junctions

First of the epithelial cells, some muscle cells and some nerve cells are tightly joined to form a functional unit. The points of contact between cells are known as cell junctions. Three major types of cell junctions are described here which serve different functions.

1. Tight junctions. They form fluid tight seals between cells like the ziplock used in garments.

2. Anchoring junctions. They fasten cells to one another or to the extracellulary material and.

3. Gap junctions. They permit electrical or chemical signals to pass from one cell to the other cell.

Connective Tissue

Connective tissues are characterized by group of cells which remain embedded in extracellular material called matrix. They have their own blood supply and ability to convert themselves into other type. On the basis of nature of matrix, connective tissue can be grouped into three broad categories :

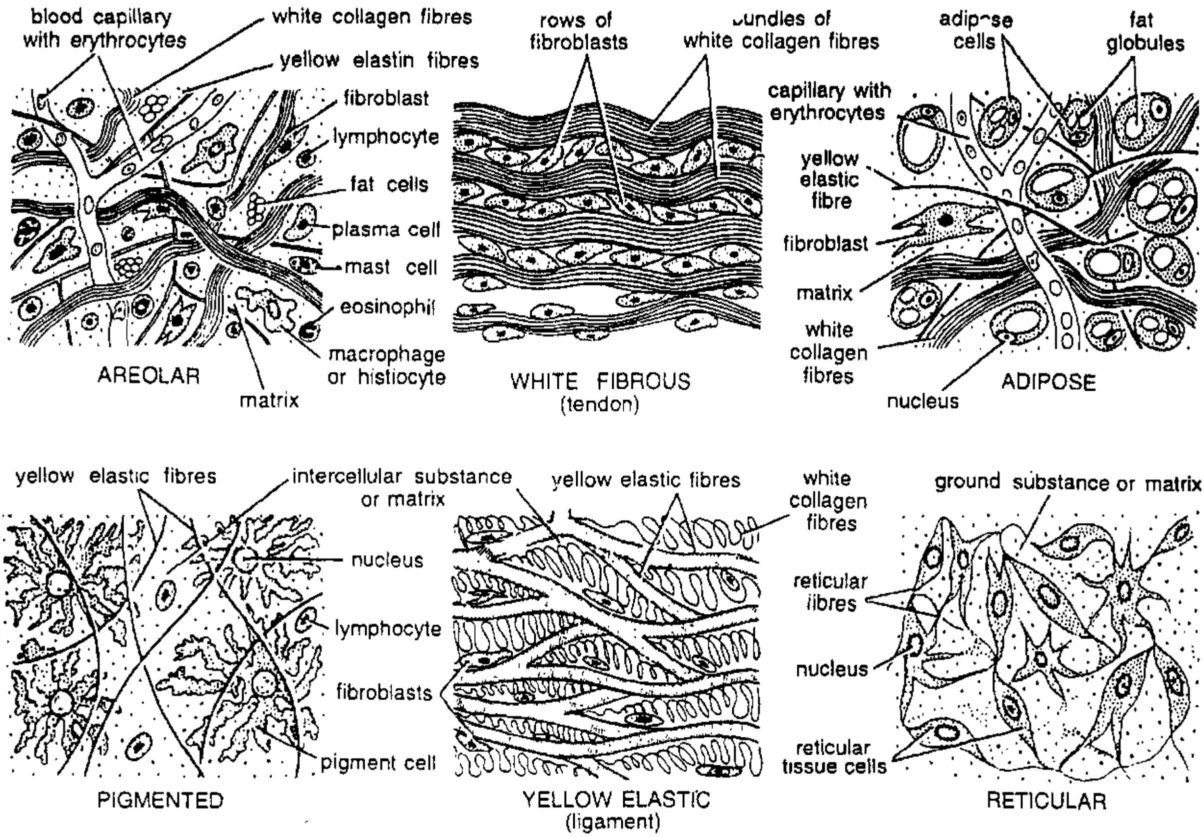


Fig. 2. Different types of connective tissues

[I] Connective tissue proper

This type of connective tissue are concerned with binding and packing of different parts of the body, they are of the following types :

1. Mucous tissue. These connective tissues are best seen in jelly fishes, in eyes of vertebrates, umbilical cord of embryo and comb of cock. The matrix is jelly like, slippery mucopolysaccharide called, *Wharton's jelly.* It also contains *fibrocytes.*

2. Reticular tissue. The matrix of this type of connective tissue is lymph in which network of *reticular fibers* and *reticuloendothelial* cells are found suspended. The fibers are made of special kind of protein called *reticuline,* which is not digested by enzyme pepsin. The reticulo-endothelial cells on the other hand are phagocytic in nature and can transform themselves into other types of cells like-macrophages, lymphocytes, adipose cells etc. Predominantly this connective tissue is found in lymphoid organs of vertebrates.

3. Areolar connective tissue. In this type of connective tissue matrix is very large, containing various types of cells. The fibers are very loosely arranged, having good quantity of space called *areolar.* The two types of cells present in the matrix are *fibroblasts* secreting fibers and matrix cells secreting matrix. The fibers are of two types-*yellow elastic fibers* which are branched and made up of *elastin* and white fibers containing collagen fibres.

4. Fibrous tissue. Fibrous connective tissues are entirely made of fibers with very little matrix and they form a sheath over the *muscles, tendons* and *ligaments*. The fibers are of two types, white fibers made of collagen and yellow fibers made of elastin. Tendons connect muscles to bones and ligaments connect bone to bone.

5. Adipose tissue. This type of tissue contains *adipose cells*, specialized for storing fat. The cells are of two types-*monolocular adipose cell* and *multilocular adipose cell.* Storage of white fat takes place in the former and brown fat is stored in the latter. Brown colour of the fat is due to the presence of a pigment *cytochrome*.

[II] Skeletal connective tissue

Skeletal connective tissue is of two types :

1. Cartilage. This type of connective tissue is rigid and elastic, capable of enduring mechanical stresses. The matrix of this connective tissue, *chondrin* forms the ground substance, containing a protein and a polysaccharide. Cartilage cells the *chondrioblasts* are found in this matrix. The cells are enclosed in a specified space in the matrix, called *lacunae*. These cells multiply in the lacunae and remain in groups of 2-4 cells. A special type of areolar connective tissue, the *perichondrium* is found around the cartilage. Based on the nature of matrix, cartilage is classified into three types : *Hyaline cartilage* having membranous and transparent matrix, usually seen in lárynx, trachea and suprascapula. *Fibrous cartilage* having matrix made of fibers and not provided with perichondrium. It is found in discs, knee, and mandibular joints. *Elastic cartilage* having matrix filled with elastin fibers as in ear pinnae, epiglottis etc.

2. Bone. It is the hard connective tissue forming the skeletal framework of the body. Each bone has a central cavity called *bone marrow,* bounded by concentric layer of *bony lamellae.* Through these lamellae, numerous small channels pass from the bone marrow called *haversian canals.* These canals are also lined by concentric rings of lamellae called *lacunae.* These lacunae are connected with the help of *canaliculi.* The matrix of the bone is made of protein fibers and mineral deposits (calcium, phosphorus, magnesium and fluoride etc.) and cells called *osteoblasts* which are spider shaped. Externally bone is covered by a fibrous sheath called *periosteum.* Bones are of two types-*compact bones* and *spongy bones.* Haversian canals are prominently developed in compact bones and absent in spongy bones.

[III] Vascular tissue

It includes blood, lymph, bone marrow and lymphatic tissue.

1. Blood. This vascular tissue connects different parts of body and performs several important functions. This tissue has been dealt separately later in this chapter.

2. Lymph. It is modified tissue fluid. It is pale yellow in colour, but after meals it turns milky due to presence of emulsified fat droplets in it. It contains 94% water and 6% solid particles including protein, fats, carbohydrates and other substances. Besides these it carries some wandering lymphocytes in it. It performs following important functions —(i) It acts as medium between blood and cells. (ii) It transports fat droplets. (iii) It protects cells and tissues of the body from foreign invasion with the help of leucocytes.

3. Bone marrow. Spaces inside the bones are filled up with a special type of vascular tissue called bone marrow. It is of two kinds-*yellow bone marrow* contains fatty tissue and no production of blood corpuscles takes place here, and *red bone marrow* is red in colour, produces blood corpuscles. In young stages all marrow present in bones is red bone marrow. But with the advancement of age, in most of the bones except upper end of femur and humerus yellow marrow replaces the red bone marrow. Bone marrow serves following important functions-produces RBC, WBC and thrombocytes and with the help of specialized cells called, *reticulo endothelial cells,* it destroys old erythrocytes.

4. Lymphatic tissue. This tissue is responsible for production of lymphocytes and found in

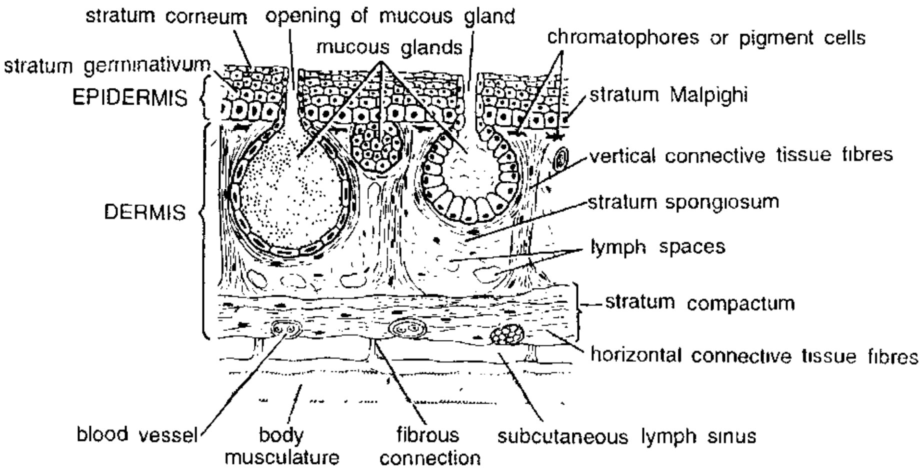


Fig. 3. V. S. skin of frog

lymphoid organs like *spleen, thymus* and *lymph nodes* etc.

Muscular tissue and nervous tissue are the two other types of tissue. But to describe them here is beyond the scope of this book.

Skin of Frog

Skin of frog is smooth, moist, slimy, fitting loosely on body and characterized by the presence of large flask-shaped mucous glands. Large subcutaneous space called *lymph space* separates the skin from body wall. The skin of dorsal surface is thicker than the ventral. Its vertical section reveals two distinct regions, an outer *epidermis* and inner *dermis* (Fig. 3).

1. Epidermis. It is the thin outer ectodermal layer of stratified squamous epithelium, 6 to 12 cells deep. One or two outermost layers of cells form *stratum corneum*. Its cells are much flattened, dead, without nuclei and their cytoplasm replaced by a horny protein, *keratin*. These cells secrete a kind of hormone which inhibits cell division in stratum germinativum. This horny or keratinized layer is periodically moulted or shed in large patches. With this periodic moulting, inhibiting hormones also goes off with the casted skin, and the cells of stratum germinativum again start multiplication. This periodic shedding of epidermis is under the control of pituitary and thyroid gland and does not take place if either of these is removed. Deeper layers of cells are irregularly polyhedral, forming *stratum germinativum*. Its basal or innermost cells are cuboidal or columnar, with large nuclei, called *stratum Malpighi*. It rests on a *basement membrane*. Cells of Malpighian layer undergo mitosis to produce new cells of epidermis.

2. Dermis. The underlying connective tissue layer, called *corium* or *dermis*, constitutes the major part of skin. It contains *blood capillaries, nerve* and *muscle fibres*, vertical connective tissue fibres, pigment cells called *melanophores* or *chromatophores* and large flask-shaped *epidermal glands* embedded in it. Each pigment cell is irregular in outline with branched processes. Chromatophores have black *melanin* and yellow *Xanthine* pigments in it. They are responsible for the change of colours of skin. Colour change is produced by spreading or condensation of these pigments in these cells. This spreading and condensation of pigments is under the control of *melanophore stimulating hormone from posterior pituitary* and *sympathetic nervous system.* The chromatophores although present in the dermis, are in fact ectodermal derivatives. Each *gland* opens by a small narrow duct on the skin surface. Most

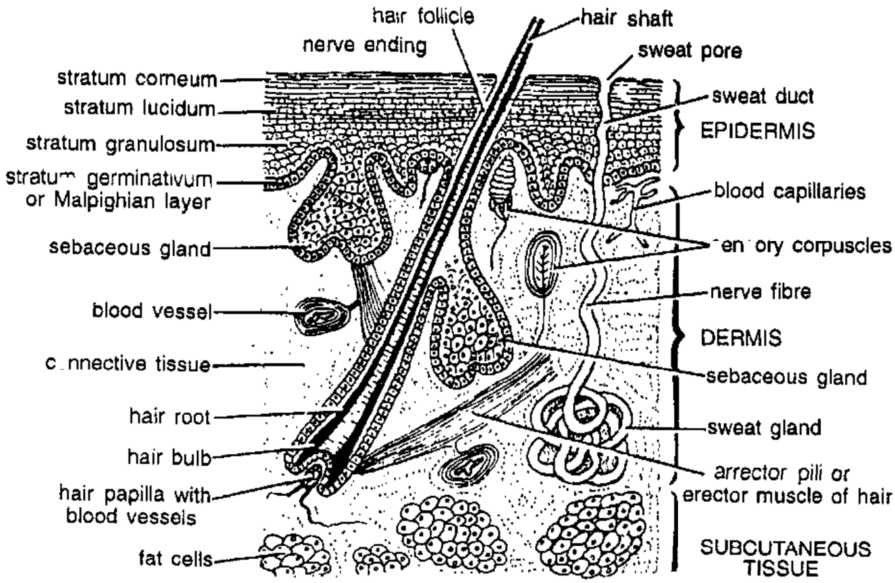


Fig. 4. V. S. skin of rabbit.

glands secrete mucus which keeps the skin surface moist and slippery. Some glands secrete unpleasant tasting poisonous substance to discourage attacks by enemies. Just beneath epidermis, dermis is made of loose connective tissue called *stratum spongiosum*. Deeper part is made of dense connective tissue with collagen fibres arranged in thick bundles, hence named *stratum compactum*.

Skin of Rabbit

Mammalian skin is characterized by the presence of hairs, sebaceous glands and sweat glands, but any or all of them may be absent. V.S. of skin of rabbit shows two definite regions : outer *epidermis* and inner *dermis* (Fig. 4).

1. Epidermis. It is the outer ectodermal layer of stratified squamous epithelium. It differs from that of frog in being much thicker and made of two distinct zones.

(a) Stratum germinativum. It is the deeper zone consisting of living polyhedral cells, joined to one another by cytoplasmic bridges. Its basal layer made of columnar cells forms the *stratum Malpighi* which lies on a *basement membrane*. New cells are budded off from Malpighian layer mitotically and move upwards. Pigment cells, *melanophores* are found in this layer.

(b) Stratum corneum. It forms the thick outer zone or *horny layer* made of flattened, keratinized and dead cells. Next to stratum germinativum lies the transitional layer called *stratum granulosum*. Its cells are flattened and angular, nuclei indistinct and cytoplasm contains refractile *keratohyalin granules* (or *eleidin*). In palm and sole, outside granular layer is present a thin, clear, homogeneous layer, called *stratum lucidum*, of indistinct dead cells. The outermost or surface layer is made of flat dead shiny *scales* composed of a scleroprotein, the *keratin*. The scales become detached or worn away by friction.

2. Dermis. Dermis, is a layer of tough and fibrous areolar connective tissue connecting epidermis to underlying muscles. Embedded in dermis are found hair follicles, sweat and sebaceous glands, blood vessels, nerves, pigment cells, pacinian corpuscles and fat deposits.

(a) Hairs. Hairs are characteristic of mammalian skin only, projecting freely on the body surface. These are formed in epidermal pits, called *hair follicles*, which are inturnings of epidermis into dermis. From each hair follicle runs obliquely a bundle of smooth muscle fibres and inserted below the Malpighian layer. This is called *errector pili*. Its contraction erects the hair.

(b) Sebaceous glands. Opening into each hair follicle is a branched, sacculate sebaceous gland. Its oily secretion, called *sebum*, lubricates the hair. Besides this, sebum contains good amount of *fatty acid* and *lactic acid*, which brings down the pH of skin and makes it acidic, making it unsuitable for the growth of microbes and other pathogens. Sebaceous glands are formed by invagination of epidermal Malpighian layer.

(c) Sweat glands. These are simple tubular glands also formed by downward growth of Malpighian layer. There inner ends remain coiled, while long narrow vertical ducts open on the surface of skin by sweat pores. Their secretion, called *sweat*, contains urea, inorganic salts and CO_2 dissolved in water, and serves in excretion and temperature regulation of body. Excessive output of urea in sweat is called *uridosis* and gets deposited on the skin and clothes in the form of white powder called *uraemic snow*.

General Structure of Alimentary Canal

Various regions of digestive tube or alimentary canal of vertebrates are composed of four fundamental and distinct concentric layers or coats. Beginning from inner side they are : *mucosa, submucosa, muscularis* and *serosa*. They become variously modified in different regions (Fig. 5).

1. Mucosa. It is the innermost coat or *mucous membrane*. It is variously folded forming innumerable pits and glands of different kinds. Mucosa is mainly concerned with secretion and absorption. It is further made of the following three layers :

(a) Epithelium. The innermost layer is usually simple columnar epithelium, often glandular and ciliated, and supported on a thin basement.

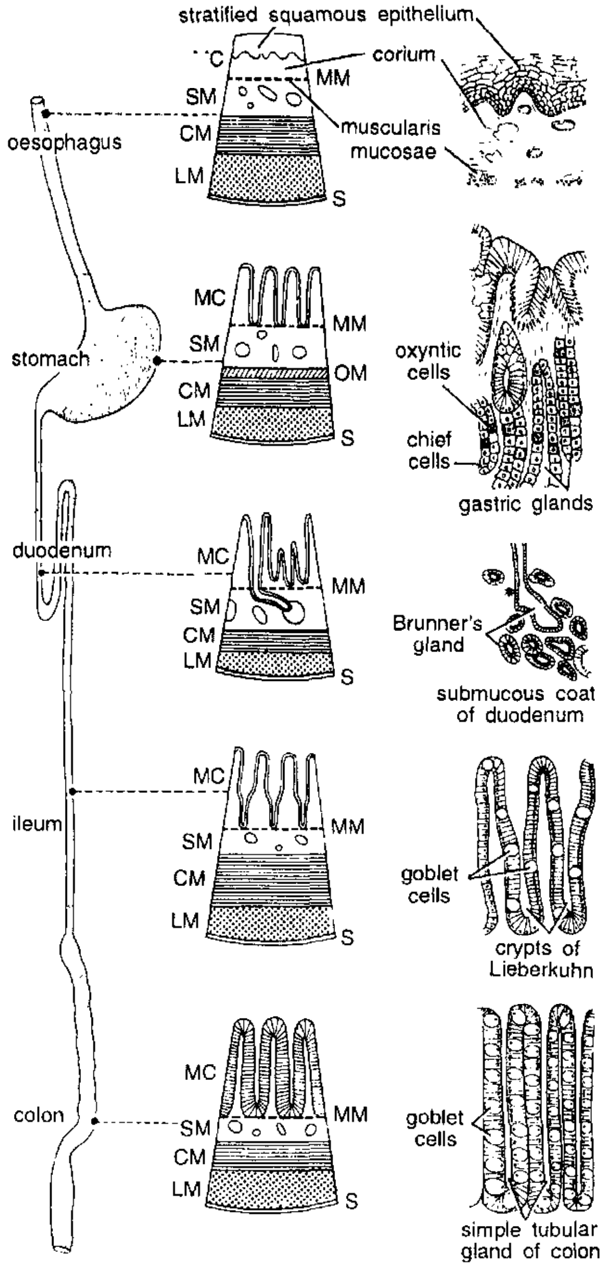


Fig. 5. General histological structure of different regions of vertebrate alimentary canal in transverse sections. CM = circular muscles. LM = longitudinal muscles. MC = mucous coat or mucosa. MM = muscularis mucosae. OM = oblique muscles S = serosa or peritoneum. SM = submucosa

(b) ***Lamina propria or corium.*** It is a thin ayer o oose connective tissue containing b ood capillaries, lacteal vessels and nerves.

(c) ***Muscularis mucosae.*** It is a narrow band of inner circular and outer longitudinal smooth muscle fibres. It separates mucosa from submucosa.

2. Submucosa. It is a connective tissue layer containing larger blood vessels, lymphatics and nerves. It may contain glands. It supports submucous plexus of Meissner composed of nerve cells and fibres.

3. Muscularis coat. The *muscular coat* is composed of smooth muscle fibres, arranged in two distinct layers : inner *circular* and outer *longitudinal*. In between the two is a thin layer of connective tissue containing autonomic ganglionated mycenteric plexus of Auerbach. Function of muscular coat is to mix food with digestive juices and to push the contents down by peristaltic waves of contraction.

4. Serosa. *Serous coat*, *serosa* or *visceral peritoneum* is the outermost protective covering of alimentary canal. It is continuous with the mesentery and the peritoneal lining of body cavity. Serosa consists of an inner very thin connective tissue layer and an outer layer of flattened mesothelial cells.

Oesophagus of Frog

Histologically, oesophagus of frog resembles the stomach or intestine (Fig. 6). But mucosa is made of a single layer of *ciliated columnar cells* supported by a basement membrane. It contains scattered large *goblet cells* which secrete mucus. Mucous epithelium is also invaginated into submucosa forming tubular branched glands which secrete the enzyme pepsin for digestion of proteins of food. Serosa is lacking as oesophagus lies outside coelom. But a fibrous layer, *tunica adventitia* covers oesophagus from outside.

Oesophagus of Rabbit

Histologically, the wall of oesophagus is composed of the same four fundamental layers occurring

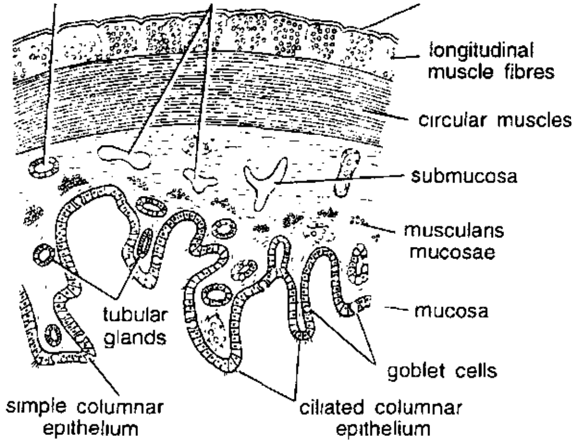


Fig. 6 T. S. Oesophagus of frog.

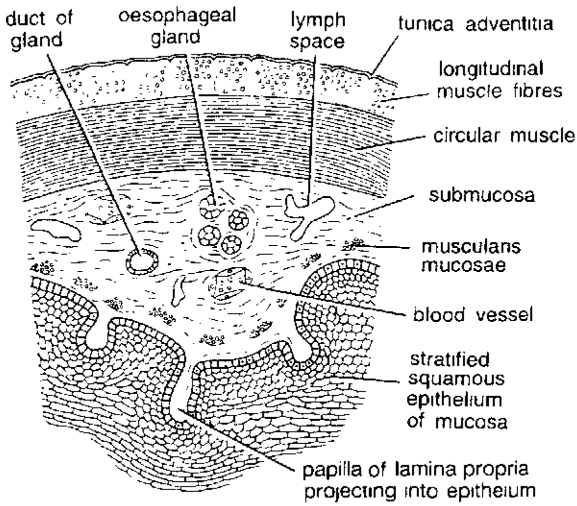


Fig. 7. T. S. Oesophagus of rabbit.

throughout the alimentary canal as described above. However, the following differences are seen in oesophageal region (Fig. 7) :

(1) Mucosa is folded and contains *stratified squamous epithelium* instead of columnar epithelial cells. Papillae of lamina propria project into epithelium.

(2) Muscularis mucosa is thick, mostly containing longitudinal fibres.

(3) Muscular coat is thick. It includes unstriped or smooth muscle fibres in the lower half

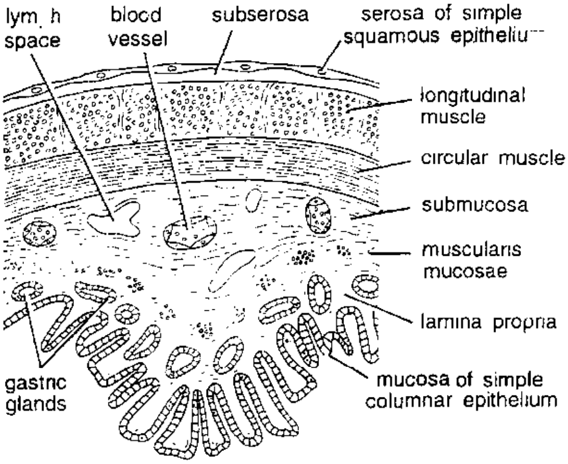


Fig. 8. T S. Stomach of frog.

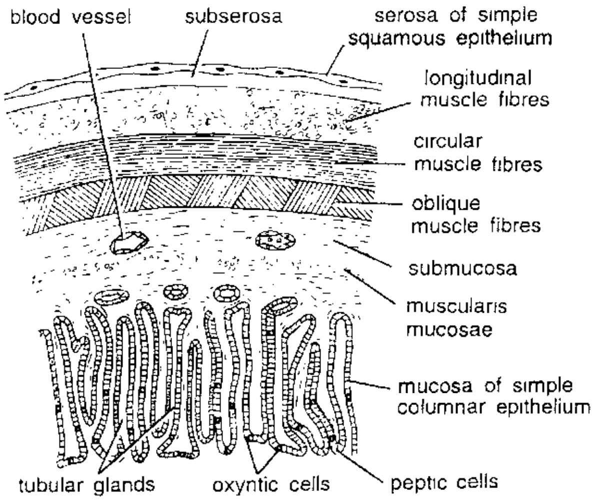


Fig. 9. T S. Stomach of rabbit

towards stomach. However, the upper half includes *striped muscle fibres* like those of pharynx.

(4) Upper end of oesophagus lacks serosa or visceral peritoneum as it does not lie in coelom. Instead, it is covered only by a thin layer of fibrous connective tissue called *tunica adventitia.*

Stomach

Wall of stomach is also constructed on the same fundamental plan and is made of the same typical four layers, i.e., mucosa, submucosa, muscularis and serosa. Main diagnostic features of stomach are (Figs 8–10) :

(1) Wall is thick and internally raised into prominent longitudinal folds (rugae). They disappear when stomach is distended with food.

(2) Mucous epithelium is uniform and made of simple columnar gland cells secreting mucus. It is invaginated at close intervals into connective tissue (lamina propria) forming *gastric pits* which lead into simple or branched tubular *gastric glands*. These are of three types-cardiac, fundic and pyloric, named according to the region of stomach in which they occur. A gastric gland has three types of cells : *mucous cells* secreting mucus, *chief* or

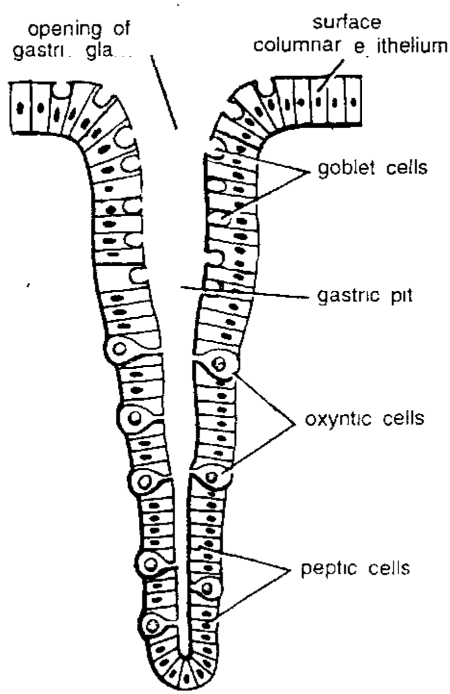


Fig. 10. V S Epithelium of a fundic gastric gland.

peptic or *zymogen cells* secreting pepsin, and *parietal* or *oxyntic cells* secreting hydrochloric acid.

(3) *Goblet cells* and *villi* are lacking.

(4) Muscular coat is well developed. It includes three layers : outer *longitudinal*, middle *circular* and inner *oblique*.

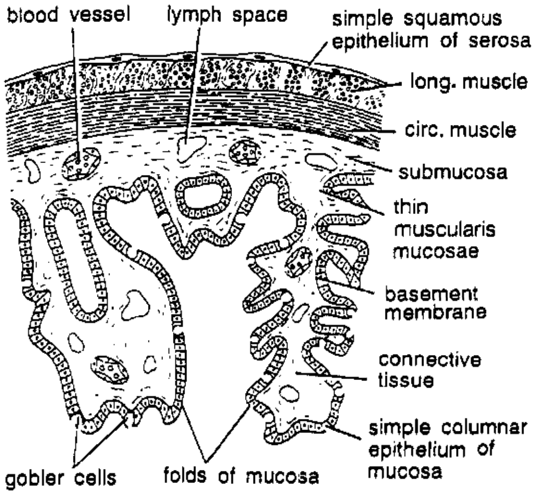


Fig. 11. T. S. Duodenum of frog.

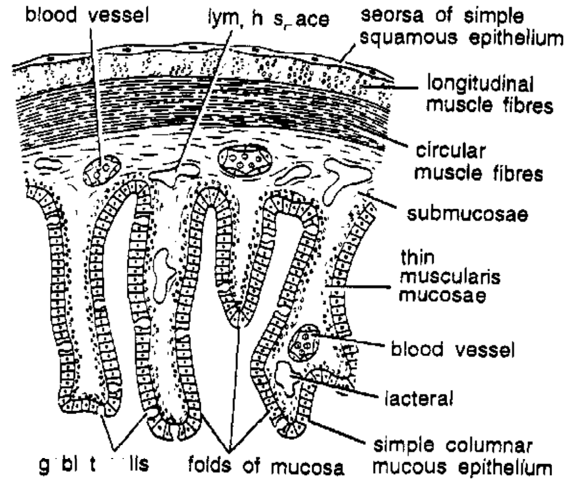


Fig. 12. T. S. Ileum of frog.

Duodenum of Frog

Histologically, duodenum of frog resembles the ileum (Fig. 11). There are no true villi, definite glands and crypts as present in higher vertebrates (rabbit). The mucosa is thrown into a network of irregular, branched transverse folds. It is made of simple columnar epithelial cells with mucous glands and is not invaginated into submucosa. Muscularis mucosae is thin. Rest of the layers are typical.

Ileum of Frog

Ileum of frog also consists of the usual four coats of the alimentary canal (Fig. 12). However, it shows greater simplicity than in mammals (rabbit). Mucosa or mucous membrane is thrown into several folds of different sizes, projecting freely into the intestinal lumen which is greatly reduced. These folds greatly increase the area of inner absorptive surface of intestine. True villi, crypts or definite glands are absent. Mucous epithelium consists of a single layer having two types of tall, cylindrical cells : narrow *absorptive cells* and broad *goblet cells* which produce a slippery mucus. As ileum is modified for absorption, its muscular coat is less developed and muscularis is very thin.

Duodenum of Rabbit

In rabbit, wall of duodenum is somewhat thicker than that of ileum (Fig. 14). Submucosa is raised up into low circular folds, called *plicae circulares,* which do not disappear on stretching. Mucous membrane is thrown into innumerable finger-like projections known as *villi* (singular, *villus).* These provide a velvety appearance and greatly increase the absorptive surface. Each villus contains connective tissue with lymphocytes, unstriated muscle fibres and a central lymph vessel or lacteal surrounded by a fine capillary network. Columnar epithelial cells of villi are of two types : absorptive and goblet. At the bases of villi are found simple tubular pits of intestinal glands known as *crypts of Lieberkuhn* (Fig. 13). They extend to muscularis mucosae but do not penetrate it. Intestinal glands are shorter than the gastric glands of stomach wall. Crypts have *Paneth cells* and *argentaffin cells* secreting digestive enzymes. Digestive juice of crypts or intestinal glands is called *succus entericus.* Located in submucosa are numerous racemose mucous glands, called *duodenal* or *Brunner's glands.* These are diagnostic for duodenum and occur nowhere else in small intestine. Mucus secreted by these glands is poured into crypts of Lieberkuhn. Muscularis

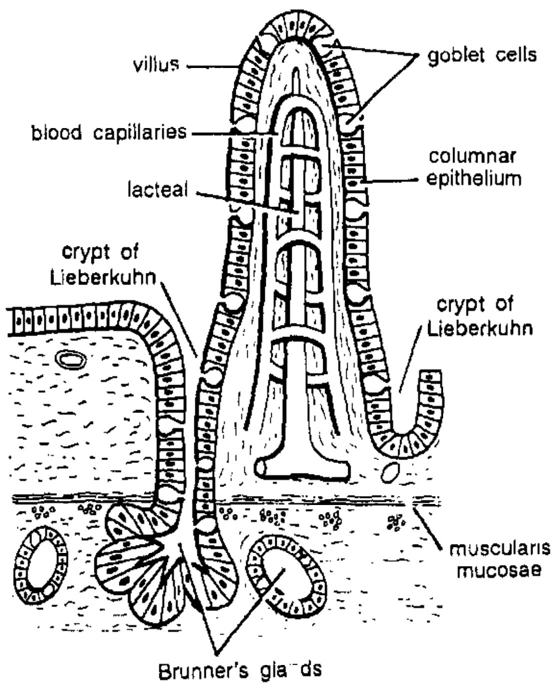


Fig. 13. V. S. Duodenal epithelium through a crypt of Lieberkuhn and a Brunner's gland.

mucosae is reduced. Muscular coat lacks oblique muscle fibres. Circular muscle layer is almost double in thickness than the longitudinal muscle layer.

Ileum of Rabbit

Histological structure of ileum is identical with that of duodenum except for minor differences (Fig. 15). (i) The circular folds or plicae are few in ileum, while they are taller and more numerous in jejunum. (ii) Villi are less abundant and finger-shaped in ileum, while they are tongue-shaped with swollen ends in jejunum. (iii) Only crypts of Lieberkuhn are present, whereas Brunner's glands are absent. (iv) Lamina propria shows yellow-coloured, oval, granular masses of lymph nodules, called *Peyer's patches*. These produce lymphocytes which destroy bacteria.

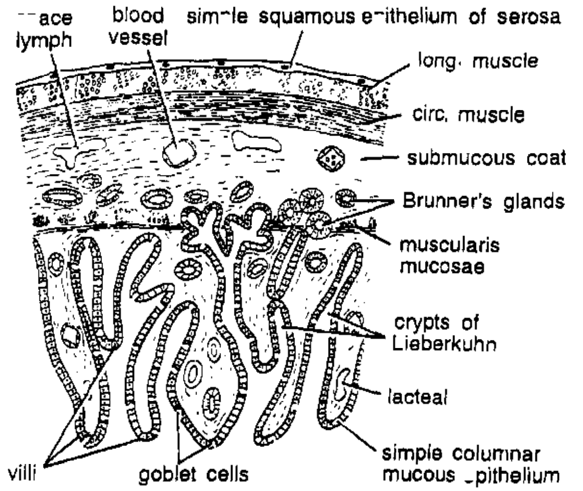


Fig. 14. T. S. Duodenum of rabbit.

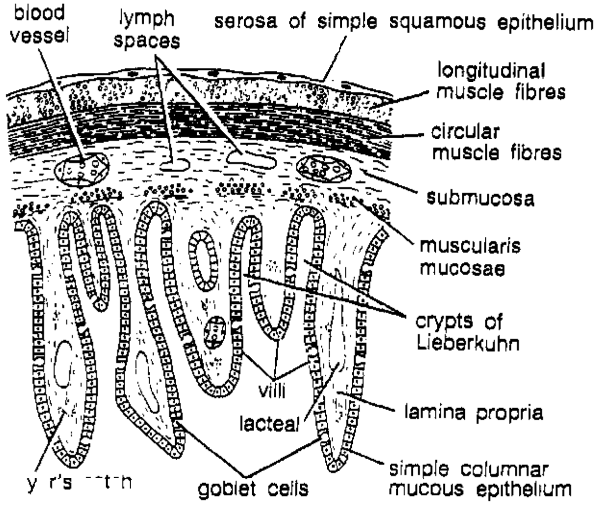


Fig. 15. T. S. Ileum of rabbit.

Colon of Rabbit

Lumen of colon is large and plicae, villi and Brunner's glands are absent (Fig. 16). Columnar mucous membrane is invaginated forming large simple tubular intestinal glands (crypts of Lieberkuhn). They possess goblet cells in abundance secreting mucous which lubricated the

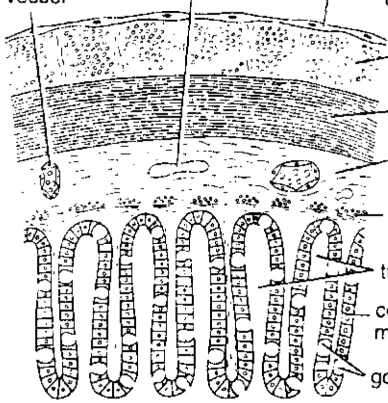


Fig. 16. T S Colon of rabbit.

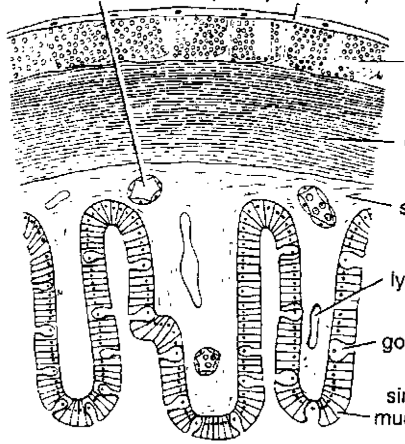


Fig. 17 T S. Rectum of frog.

semi-solid faeces for smooth passage. Lymph nodules or Peyer's patches are prominent and project into submucosa. Muscularis mucosae and ...uscular layers are thin.

Rectum

Histological structure of rectum in frog and rabbit resembles that of colon in rabbit with a few variations only (Figs 17–19). Mucosa is thicker and tubular intestinal glands longer than in colon. Villi are absent but goblet cells abundant. Epithelium becomes stratified near anus. Lymph nodules are few. Muscularis mucosae and muscular coat are thicker than in colon and contain striated or voluntary muscle fibres.

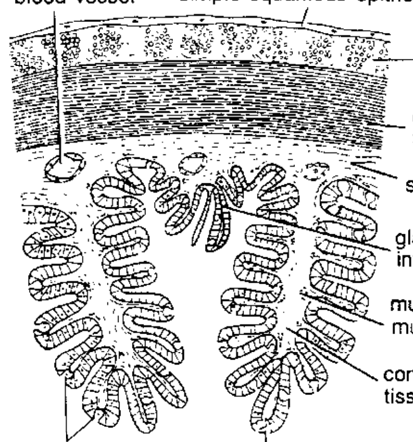


Fig. 18. T. S Rectum of rabbit.

Liver of Frog

Frog's liver is a dark chocolate coloured, spongy organ externally covered by a serous coat (Fig. 19). It is the largest gland in the body. Histologically, each liver lobe is made up of many s...all r_un_e_ *lobules* _r *acini*. Int_rspa_es __tw___ lobul_s _o_ain connective tissue, hepatic ducts, blood sinuses and blood vessels. Each lo' ule consists of large polygonal (or polyhedral) and cuboidal *hepatic cells* arranged in solid *cords* or *trabeculae.* Cells are especially large and clear in the liver tissue of amphibians. They possess

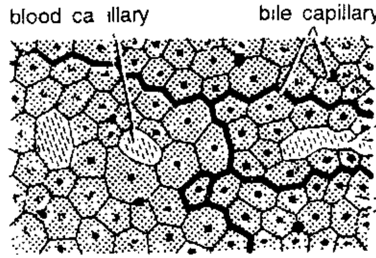


Fig. 19 A part of the section through liver of frog.

granular cytoplasm, large round central nuclei, fat droplets, glycogen and protein granules and often pigment granules. Adjacent liver cells enclose fine channels without wall, called *bile canaliculi* or *bile capillaries*. Liver cells secrete *bile* into bile canaliculi which join to form *bile ductules*. The latter unite to form bigger *hepatic ducts*, taking bile to the gall bladder for storage. Wall-less, irregular blood spaces between hepatic cords are called *lacunae* or *sinusoids*. These receive blood from finer branches of hepatic portal vein as well as hepatic artery. Sinusoids empty into the branches of hepatic vein. Some irregular cells lining the sinusoids are phagocytic in nature (*cells of Kupffer*).

Liver of Rabbit

Five-lobed liver of rabbit is a large spongy gland of racemose type, externally covered by a fibro-elastic serous coat or *liver capsule*. Each lobe is made of a number of smaller lobules separated from one another by a thin layer of connective

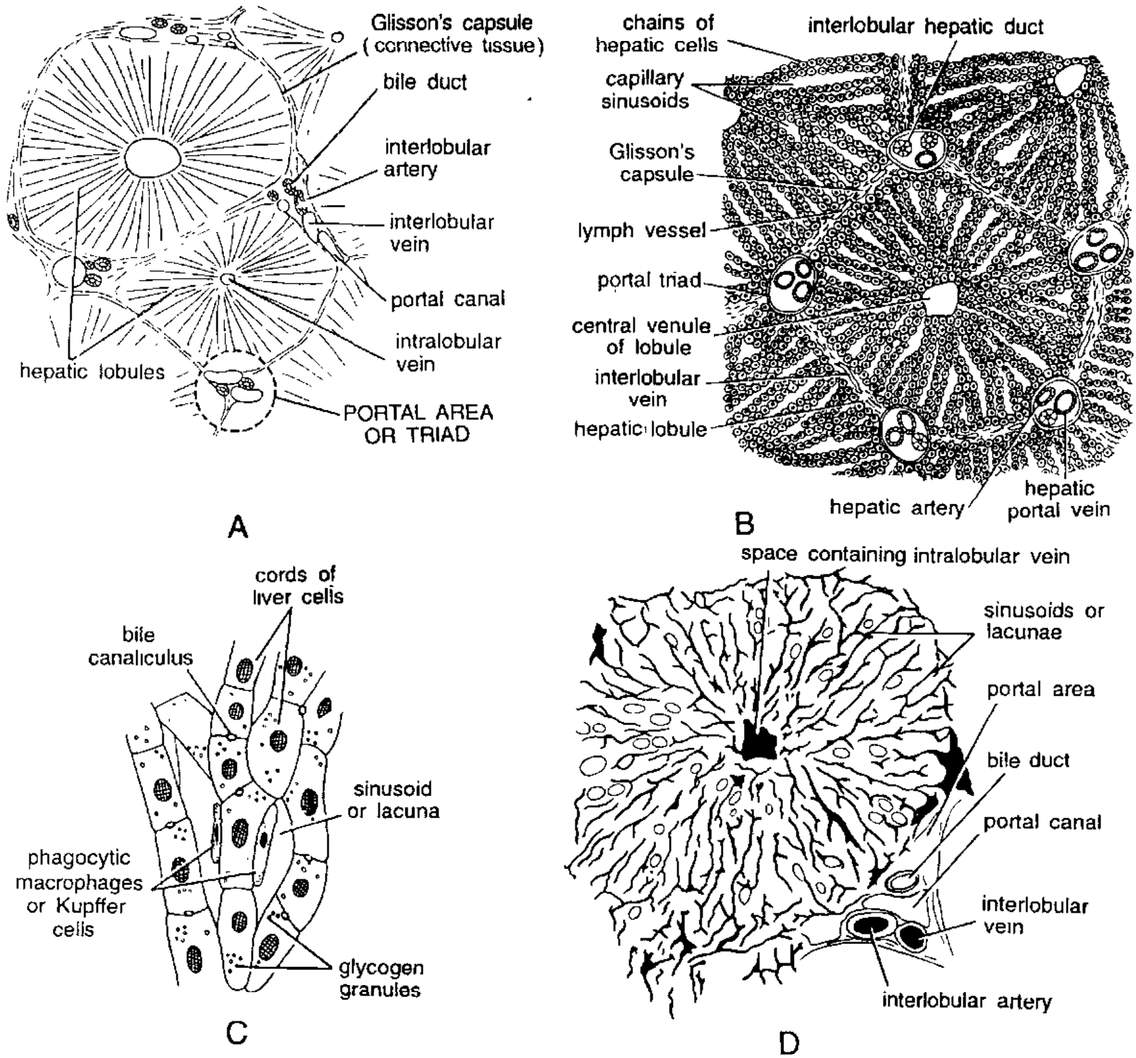


Fig. 20. Liver of rabbit A—T. S. to show a group of lobules. B—Histological structure of a lobule and a Glisson's capsule. C—Liver cords magnified. D—T. S of a lobule showing sinusoids with injected.

tissue called *septa* or *Glisson's capsules* (Fig. 20). In the liver of man and rabbit, Glisson's capsules demarcating lobules are incomplete and not clearly marked off. However, they are especially conspicuous in the liver of pig. In pig's liver, a lobule is polygonal, having 5 or 6 sides, and is about 1 mm wide and 2 mm long. In the centre of each lobule lies a branch of hepatic vein, the *intralobular vein* or *central vein*. Cuboidal or polyhedral *hepatic cells* are arranged in radial rows of 1 or 2 cell thick anastomosing solid *cords or trabeculae* which extend from the central or intralobular vein to the periphery of the lobule. Liver cells possess finely granular cytoplasm, large round central nuclei, and deposits of glycogen and lipids. Between hepatic cords is a labyrinth of narrow irregular spaces, or *lacunae*, through which run blood capillaries, called *hepatic sinusoids*, with discontinuous walls of endothelial cells. Some of these cells become highly phagocytic stellate *cells of Kupffer* which ingest dead erythrocytes and destroy harmful bacteria.

At the corners between adjacent lobules are strands of interlobular connective tissue called *portal areas* or *portal canals*. Each portal canal supports a branch of hepatic artery hepatic portal vein and bile duct which are often termed *interlobular*. In addition the portal canals contain lymphatic vessels and nerves. Sinusoids are derived from interlobular branches of hepatic portal vein and hepatic artery and empty into the intralobular central veins which unite to form the hepatic vein.

Surrounding liver cells is an intricate meshwork of fine intercellular channels or tubules, the *bile canaliculi* or *capillaries*. Liver cells secrete bile directly into bile canaliculi. They join to form *bile ductules* which in turn open into *hepatic ducts* which ultimately form the *common bile duct*.

Functions of liver. Liver is an important organ for metabolism in vertebrates. A summary of its important functions is as follows :

(1) Secretion of liver is *bile*. It is a dark green-coloured, alkaline fluid consisting of bile salts, bile pigments, cholesterol, lecithin, water, etc. Bile serves as follows :
   (i) Renders chyme *alkaline* for action of pancreatic juice.
   (ii) It brings about *emulsification* of fats.
   (iii) Helps in removal of *excretory products* such as bile pigments, inorganic salts, toxins etc.
   (iv) Bile salts help in absorption of fat soluble *vitamins* like 'K'.
   (v) Being *antiseptic* it keeps bacteria under control.
   (vi) It stimulates *peristalsis*.

(2) Liver *synthesizes* various enzymes, vitamins and lymph.

(3) It *stores* some vitamins, glucose, inorganic salts of iron and copper, and ribonucleoproteins.

(4) It *produces* red blood cells in embryos.

(5) It helps in *glycogenesis* and *glycogenolysis*.

(6) It brings about *deamination* of *proteins* and changes ammonia into urea by *ornithine cycle*.

(7) It *produces fibrinogen* and *prothrombin* for blood clotting, and heparian to prevent coagulation of blood in blood vessels.

(8) Its *Kupffer cells* kill harmful bacteria and worn out red blood cells by *phagocytosis*.

(9) It checks *anaemia* and regulates *body heat*.

(10) Harmful *prussic acid* formed as a bye-product in body is converted by liver into harmless *potassium sulphocyanide*.

Pancreas

Outer appearance of pancreas varies a good deal in different vertebrates. However, its essential histological structure remains the same (Fig. 21). It is a compound, recemose gland resembling with salivary gland in structure, but differs in the presence of *islets of Langerhans*. It is externally invested by a thin sheath of loose connective tissue. There is no true capsule. Pancreas is made of exocrine as well as endocrine parts. The *exocrine part* is divided into many lobes and lobules bound together by connective tissue

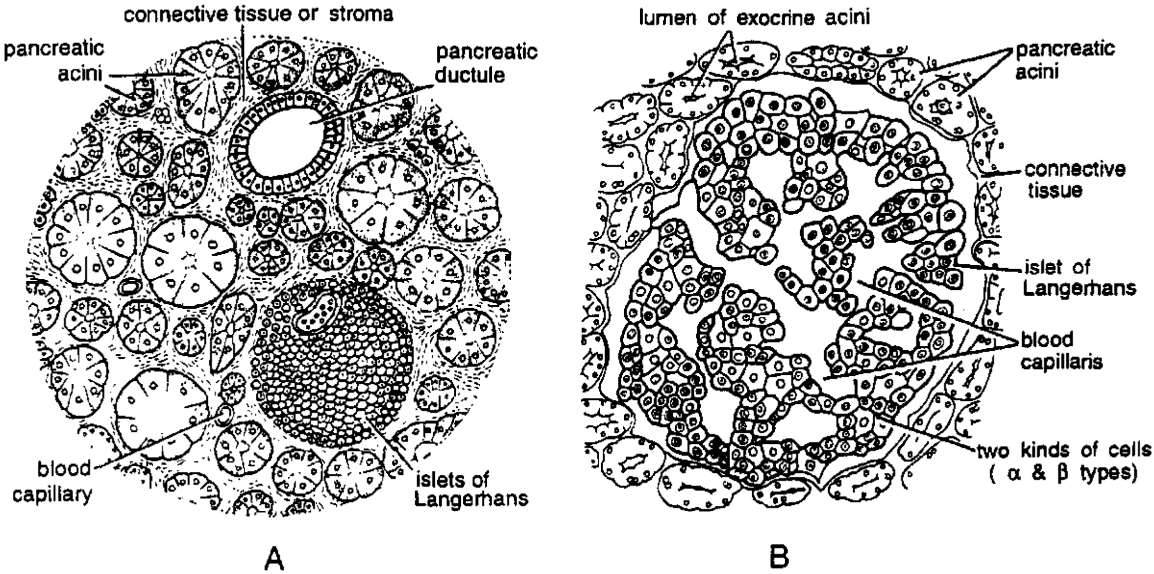


Fig. 21. Pancreas. A—T.S. of a portion. B—An islet of Langerhans magnified.

containing pancreatic ducts, blood vessels, lymphatics and nerves. Each lobule consists of several branching tubules, called *alveoli* or *acini*, embedded in connective tissue. Each *acinus* is made of pyramidal or wedge-shaped glandular *pancreatic cells* around a central *lumen*. Cells secrete the enzymatic pancreatic juice into ductules of acini which join larger ducts and ultimately the main *pancreatic duct* that carries the pancreatic juice to the duodenum for digestion of food.

The *endocrine part* of pancreas consists of *islets of Langerhans*. These are more lightly stained and somewhat spherical compact masses of cells present in the connective tissue binding the acini together.

A preparation stained with Mallory-azan or aldehyde fuchsin demonstrates the following three kinds of cells in an islet, separated by thin-walled capillaries :

1. Alpha cells (α-cells). They contain numerous large acidophilic granules and large achromatic oval nuclei. They secrete the hormone *glucagon* that increases concentration of sugar (glucose) in blood. Its deficiency causes *hypoglycemia*.

2. Beta cells (β-cells). They contain small orange-brown granules and small, spherical, deeply stained nuclei. They secrete the hormone *insulin* concerned with carbohydrate metabolism. It regulates the amount of sugar in blood. Its deficiency causes *hyperglycemia* or *diabetes*.

3. D cells. They contain basophilic granules and large vesicular nuclei.

Lung of Frog

Lung of frog is an ovoid, thin-walled, highly vascular and elastic sac covered externally by coelomic or *visceral peritoneum* (Fig. 22). Its thin wall is composed of outer peritoneum made up of squamous epithelial cells, middle connective tissue containing unstriated muscle fibres and blood capillaries, and inner epithelium. The lung wall forms a network of low internal transverse and longitudinal folds, called *septa* or *trabeculae*. These enclose many small shallow chambers, called *air sacs* or *alveoli*, leaving a clear large *central cavity*. The septa and alveoli greatly increase the inner respiratory surface of lung. They are richly vascular and lined with mucous epithelium secreting mucous which keeps the walls

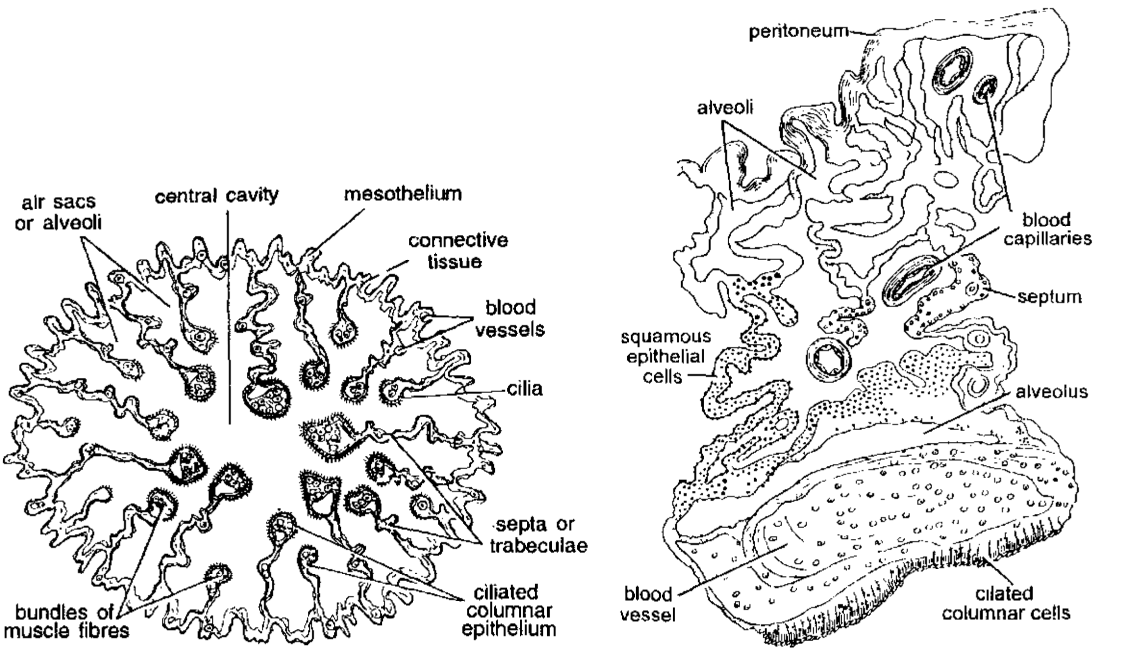


Fig. 22. A—T.S. lung of frog. B—A portion of T. S. magnified.

moist. The inner edges of septa bear tall ciliated columnar epithelial cells.

Lung of Rabbit

The mammalian lung is a pink-coloured, soft, spongy, highly elastic and highly vascular organ (Fig. 23). It lies enclosed within a special lateral air-tight compartment of thoracic cavity, the *pleural cavity*. The lung is invested by a fold of coelomic epithelium or *visceral peritoneum*. Histologically, a *bronchus* entering the lung repeatedly divides into finer branches, the *bronchioles*, each terminating into *air sacs* bearing numerous small hemispherical hollow projection or *alveoli* which present a honey-combed appearance or look like a bunch of miniature grapes. The alveoli represent the ultimate structural and physiological units of lung providing the great surface area for gaseous exchange. Extremely thin walls of air sacs and alveoli are made of a single layer of moist squamous epithelial cells and covered by a close network of capillaries, derived

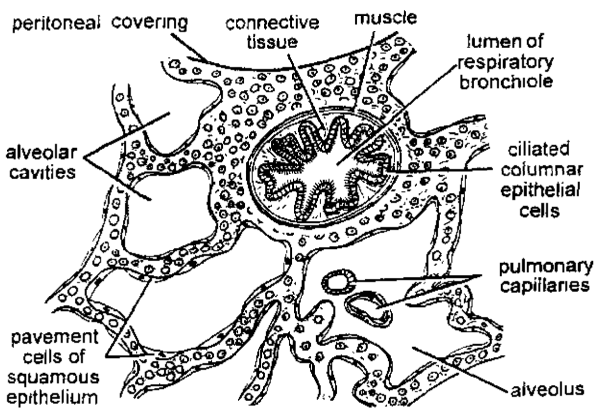


Fig. 23. T. S. portion of a mammalian lung through a bronchiole.

from branches of pulmonary artery and vein. A branchiole is lined with ciliated columnar epithelium, resting on a basement membrane, while its wall is made of elastic connective tissue and circular smooth muscle fibres. Branches of bronchus and alveoli are embedded in considerable connective tissue containing arteries, veins, lymphatics, nerves and smooth muscle fibres.

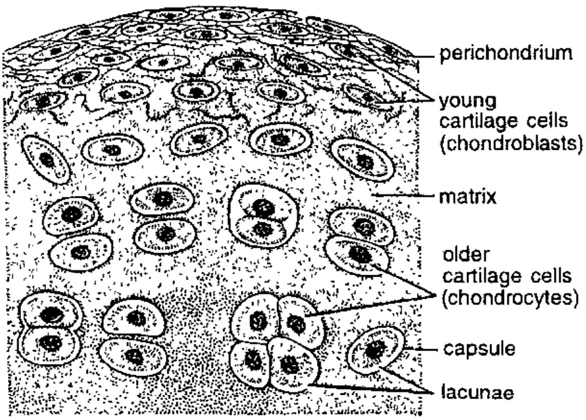


Fig. 24. T S. Hyaline cartilage.

Hyaline Cartilage

Cartilage is a type of skeletal connective tissue. Hyaline cartilage is the commonest type (Fig. 24). It forms the whole of the adult skeleton of cartilaginous fishes (e.g. dogfish). In frog it occurs at the ends of limb bones and sternum, in hyoid apparatus and supra-scapula, etc. In mammals (e.g. rabbit) it is found in nose, ears, larynx, trachea, bronchi, xiphisternum, sternal ribs and at the ends of long bones.

Peripherally, the cartilage is surrounded by a tough fibrous connective tissue sheath, called *perichondrium*, containing blood vessels. Often there is no sharp distinction between perichondrium and substance of cartilage. The ground substance or *matrix* chiefly consists of a tough, bluish-coloured, translucent glossy substance known as *chondrin*. Under microscope it appears h-------us unless specially treate˙ to s˙ow very fine collagen fabrils. The cells which produce ...a_ix a_e called *chondroblasts*, with deeply stained nuclei. They lie inside fluid-filled cavities in matrix, called *lacunae*. They are surrounded by more deeply stained matrix called *capsules*. Chondroblasts are capable of mitotic cell division and usually occur in small groups of twos and fours. The mature catilage cells are known as *chondrocytes*.

Bone of Frog

Unlike cartilage, the bone is a hard and rigid connective tissue of great strength. The intercellular substance or matrix of bone consists of an organic component, the *ostein* or *ossein*, and inorganic component including calcium and magnesium phosphates, calcium carbonate, and some sodium chloride. Ossein is in the form of collagen fibres which are somewhat difficult to detect. They yield gelatin on boiling. If a bone is burned, it becomes brittle as its organic matter is destroyed.

A thin section of a typical limb bone, such as the *femur* of frog, shows a large central *marrow cavity* (Fig. 25). It is filled with a soft adipose or fatty tissue and blood vessels and termed the *bone marrow*. The outer bone surface is covered by a two-layered sheath called *periosteum*. Its outer layer consists of dense connective tissue containing blood vessels, lymphatic vessels and nerves that enter the bone. The inner layer consists of bone-forming cubical cells, called outer

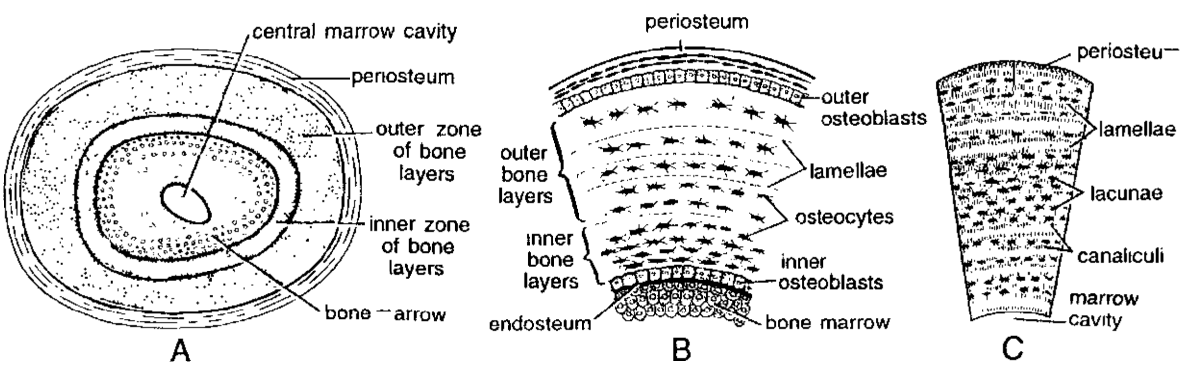


Fig. 25. Bone of frog. A—T. S. of decalcified femur. B—A part of decalcified bone magnified. C—A part of ground dried or calcined bone

osteoblasts, arranged like an epithelium. The central marrow cavity is similarly lined by a more delicate connective tissue sheath, called *endosteum*, containing the inner layer of bone-forming *osteoblasts*. Between periosteum and endosteum, the matrix occurs in thin concentric layers or *lamellae* around the central marrow cavity. Between adjacent lamellae are numerous small cavities called *lacunae*. A lacuna gives off numerous fine branching tubules, called *canaliculi*. These extend in all directions, those of neighbouring lacunae opening into one another. The lacunae are occupied by bone cells called *osteocytes*. They differ from cartilage cells in giving off fine branching protoplasmic processes which unite with those of neighbouring cells through canaliculi, forming a continuous protoplasmic network. Thus food and oxygen can reach from peripheral blood vessels in periosteum to cells spread throughout the matrix.

A ground section of *dried* or *calcined bone* seen under the microscope does not have osteocytes and their processes. Instead the lacunae and canaliculi appear black because of highly refractive air imprisoned by them. On the other hand, the section of a *decalcified bone* shows the osteocytes but their processes and canaliculi remain inconspicuous and often invisible.

Bone of Rabbit

The gross structure of a long bone of mammals is similar to that of frog. *Periosteum* is the thin, outer connective tissue sheath surrounding the bone (Fig. 26). The central *marrow cavity* contains *yellow marrow* in the shaft (diaphysis) and *red marrow* at the ends (epiphyses). Yellow marrow consists primarily of fat and produces white corpuscles. Red marrow consists primarily of cells called *myelocytes* and produces red corpuscles. However, the arrangement of *lamellae* varies from that of frog. Matrix between periosteum and endosteum is perforated by a series of fine channels called *Haversian canals* after the English anatomist, Clopton Havers. These run more or less parallel to the long axis of the bone. Each Haversian canal contains an artery, a vein, a lymphatic vessel, nerve fibres, occasional fat cells, flattened osteoblasts and a small amount of areolar connective tissue. Each canal is surrounded by concentric layers of bone or *lamellae*. Minute spaces or *lacunae* housing bone cells or *osteocytes* also form concentric rings alternating with the lamellae. Fine protoplasmic processes of osteocytes extend through *canaliculi* and freely anastomose linking cells to one another and to Haversian canal. Concentric lamellae enclosing an Haversian canal constitute a *Haversian system*, which

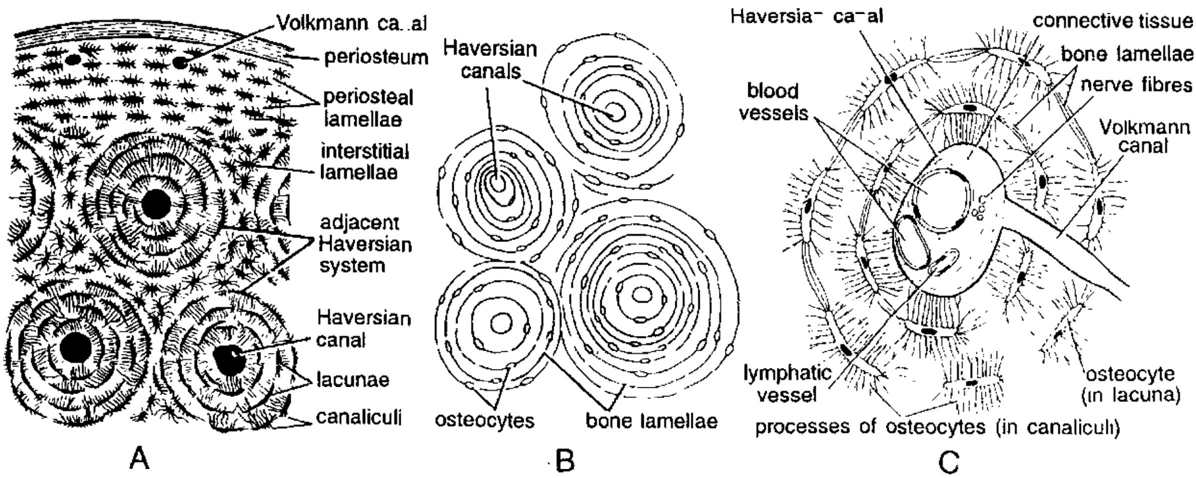


Fig. 26. Bone of rabbit. A—T S. of a part of dried or calcined bone B—Decalcified. C—A haversion system magnified

presents a very characteristic form in the section of a mammalia.. bone. Haversia.. ca..als are interconnected by transverse *Volkmann canals* which contain blood vessels but are not surrounded by concentric lamellae. The interstices or intervals between adjoining Haversian systems are occupied by irregular *interstitial lamellae* and cells.

Blood

Blood is a liquid tissue in which round cells *(corpuscles)*, entirely separate from one another, float in a pale straw-coloured intercellular fluid, the *plasma*. Blood cells or corpuscles are of two types : *red* and *white* (Fig. 27). Besides, there are cell fragments or blood plates or *platelets*.

1. Erythrocytes (red corpuscles). These are so called because they contain the red pigment *haemoglobin*. In lower vertebrates (e.g. frog), red corpuscles are oval, thin, biconvex discs, each having a large, oval, central nucleus. In mammals (e.g. rabbit), red corpuscles are circular, thin, biconcave discs without nuclei. Red corpuscles of rabbit are 8µ in diameter, while those of frog are much larger, about 25µ in length. They are formed in the red bone marrow and serve as oxygen carrier.

2. Leucocytes (white corpuscles). These are so called because they are colourless. They differ from erythrocytes in lacking permanent shape, in retaining nuclei, but having no haemoglobin. They are formed in bone marrow, spleen and lymphoid tissue and are *phagocytic* in nature. There are 5 or 6 different kinds of leucoc tes. The belon to two general types, *granulocytes* and *agranulocytes*.

(a) Granulocytes (polymorphonuclear leucocytes). The nucleus is strongly lobulated and variable in shape. The cytoplasm contains prominent granules with specific staining property. Accordingly, there are 3 types of granulocytes. Granules of *acidophils* or *eosinophils* stain pink with acid dyes, *basophils* stain blue with basic dyes, whereas *neutrophils* take up both the acid and basic dyes.

(b) Agranulocytes (mononuclear leucocytes). They lack the cytoplasmic granules. *Lymphocytes* have a large spherical nucleus which nearly fills the cell. *Monocytes* are relatively larger cells with an oval to kidney-shaped nucleus.

3. Platelets (thrombocytes). They are not considered proper cells but only cell fragments. They are very small bodies without nucleus in mammals. In other vertebrates (e.g. frog), they are spindle-like and nucleated. Blood platelets function in connection with clot-formation.

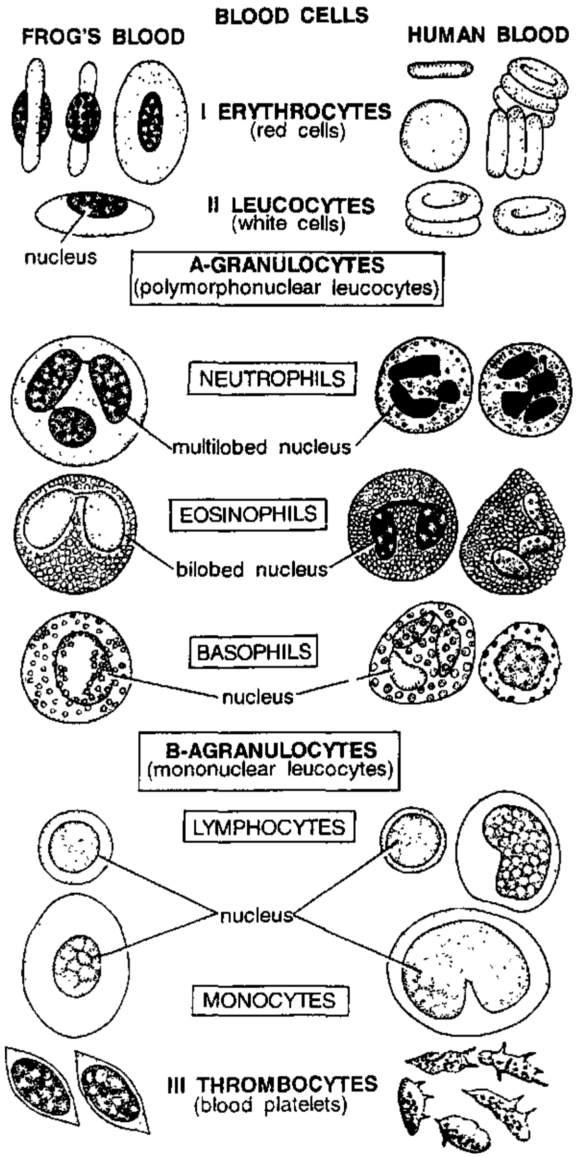


Fig. 27. Blood cells of frog and rabbit.

Spleen

Spleen is the largest lymphoid gland in the body of vertebrates (Fig. 28). It is surrounded by a definite fibromuscular *capsule* covered externally by a layer of flattened cells of *serosa* or *visceral peritoneum*. From the capsule extend, usually at right angles, numerous fibro-muscular strands or *trabeculae* into the soft spongy *parenchyma* or *splenic pulp* which is supported by *reticular tissue* and divided into *lobules*. The splenic pulp is composed of *red* and *white* pulps. The *red pulp*, forming the bulk, contains mostly free erythrocytes which give it red colour. Red pulp also comprises irregularly shaped *pulp cords* composed of erythrocytes, leucocytes, reticular cells, macrophages and splenocytes. Fairly large and irregular spaces also occur, called *venous sinuses* or *terminal veins*. The red pulp also contains scattered patches of *splenic nodules* forming *white pulp*. They look white in fresh tissue but darker white pulp in stained preparations. They are formed by accumulations of lymphocytes, large phagocytic macrophages or histiocytes and reticular cells, and usually posssess an eccentric artery or arteriole. Spleen also contains trabecular arteries, veins and nerves. Spleen serves as a reservoir of erythrocytes. Its macrophages destroy worn out old erythrocytes, while lymphocytes are concerned with the production of antibodies.

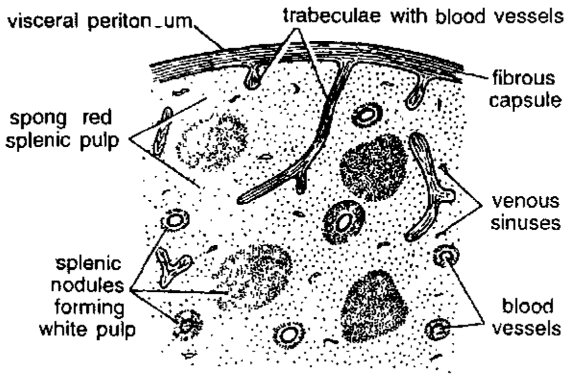


Fig. 28. T. S. of a small portion of spleen.

Spinal Cord

The histological structure of spinal cord, as seen in a transverse section, is the same in all the vertebrates (Figs. 29 & 30). Like brain, it is surrounded by two protective and fibrous membranes (*meninges*). The thick outer meninx is called *duramater*, while the thin, inner and vascular one, the *piamater*. Between the two lies the *subarachnoid fluid* which protects the spinal cord from external shocks. Two deep clefts or grooves, the *dorsal* and *ventral median fissures*, divide the spinal cord into right and left lateral halves. The lumen at the centre of the cord is called the *central canal*. It is lined with ciliated columnar epithelium (*ependyma*) and contains the

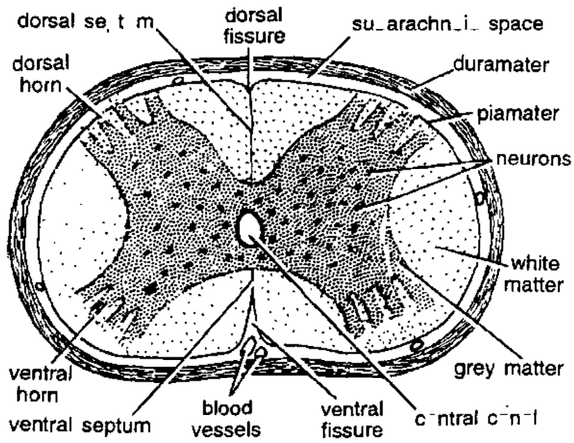


Fig. 29. T. S. Spinal cord of frog.

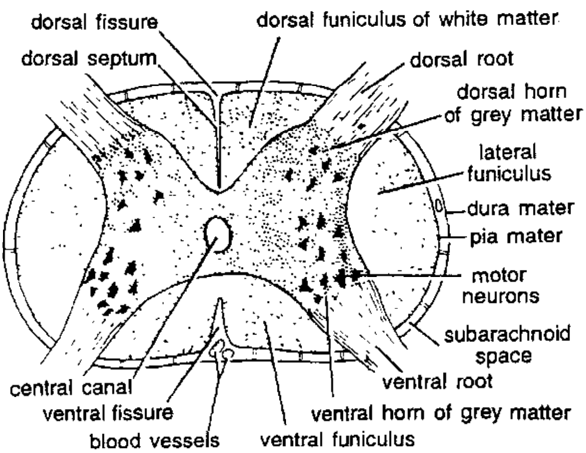


Fig. 30. T. S. Spinal cord of rabbit.

cerebrospinal fluid. Two types of nerve tissue make up the spinal cord, inner *gray matter* and outer *white matter,* so called because of their appearance in fresh condition. The central rectangular or H-shaped *gray matter* consists of nerve cells *(neurons),* non-medullated fibres, neuroglia and blood vessels. The central canal divides the gray commissure into dorsal and ventral portions. The gray matter is projected at the corners into *dorsal* and *ventral horns* to which roots of spinal nerves are attached. The outer or peripheral *white matter* mainly consists of medullated nerve fibres. Their bundles are arranged on either side into *dorsal, lateral* and *ventral funiculi.* The spinal cord conducts impulses to and from brain and also controls the reflex activity.

Kidney of Frog

Kidney of adult frog is an *opisthonephros* or *mesonephros* (Fig. 31). It is invested by a fibrous connective tissue *capsule*, which is covered only ventrally by *visceral peritoneum* of flat cells. In a T.S., kidney shows a large number of *uriniferous tubules* cut in various planes and formed by cuboidal epithelium. *Malpighian bodies* lie close to the ventral border while *collecting tubules* near the dorsal border of kidney. A Malpighian body includes a bunch of blood capillaries, called *glomerulus*, enclosed by a close double-walled cup, the *Bowman's capsule.* In an ordinary preparation, the walls of capillaries forming the glomerulus are not distinct, but the blood cells are easily seen. Walls of Bowman's capsule consist of squamous epithelial cells. *Ureter* may be seen close to the lateral border of kidney, cut transversely and lined by columnar epithelium. Tubules and capsules are embedded in connective tissue which also contains muscle and nerve fibres and renal arteries and veins cut at several places. Ventral surface of kidney shows several ciliated funnels, called *nephrostomes*, which communicate coelom with the veins of kidney.

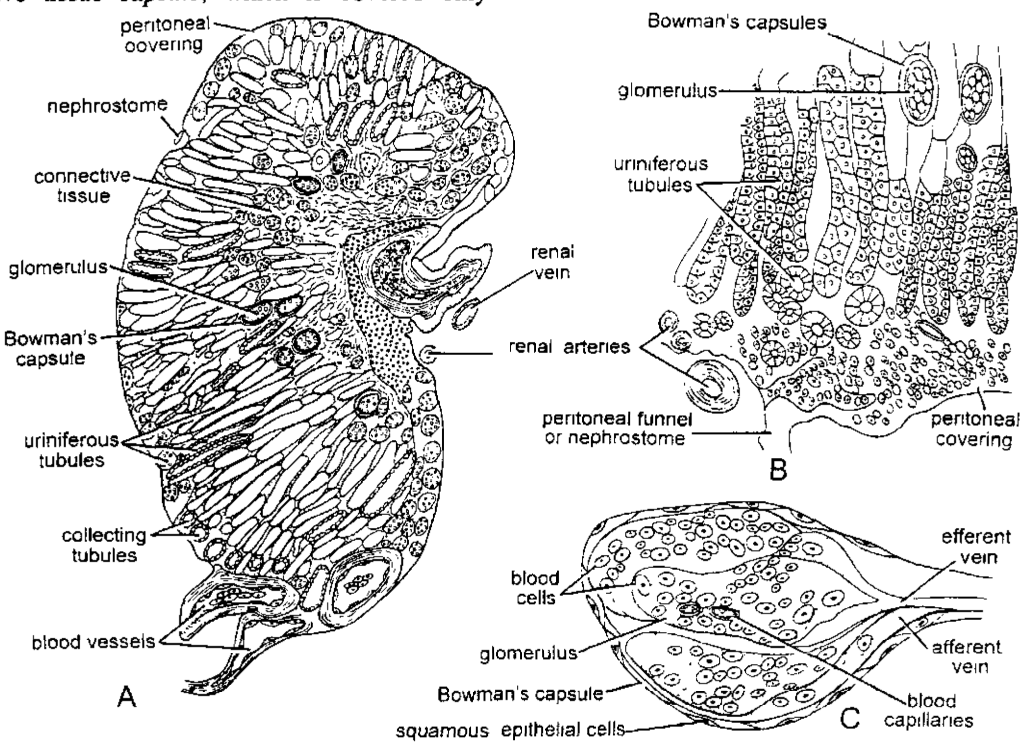


Fig. 31. Kidney of frog. A—T S. under low magnification. B—A portion magnified to show structure of uriniferous tubules. C—A Bowmann's capsule magnified.

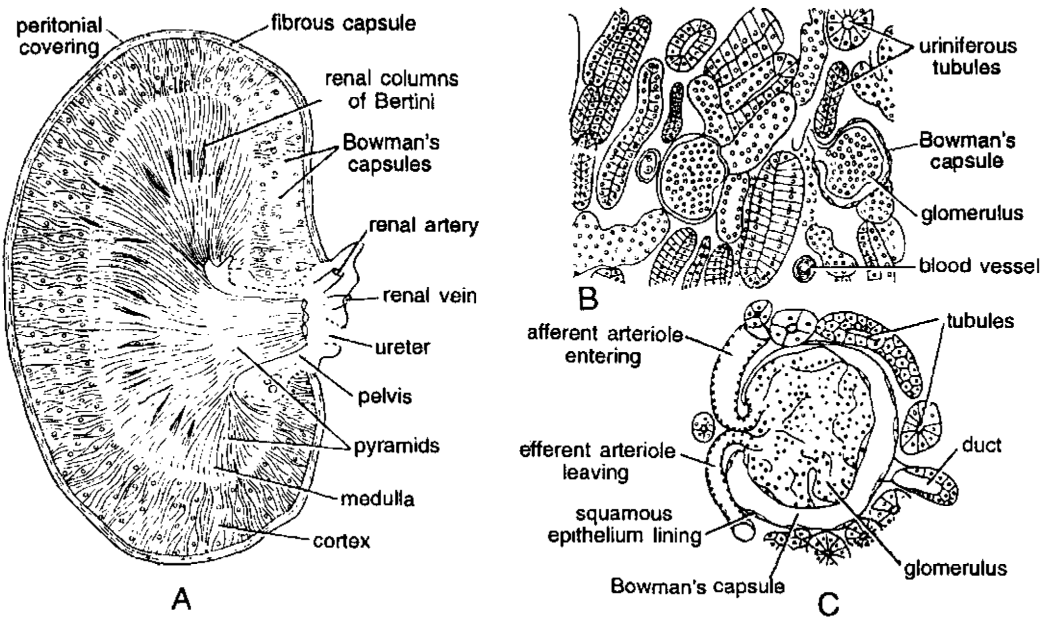


Fig. 32. Kidney of rabbit. A—T.S. under low magnification. B—A portion magnified. C—A medullary body magnified.

Kidney of Rabbit

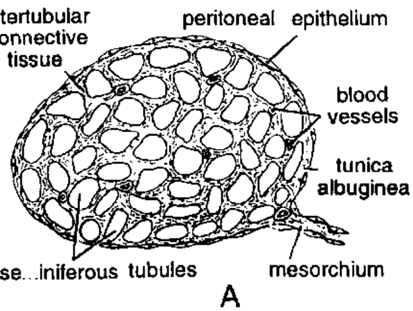
Mammalian kidney is *metanephric* in origin and typically a compact, bean-shaped structure of dark red colour (Fig. 32). It is surrounded by an envelope or *capsule* of tough fibrous connective tissue and covered by peritoneum on its ventral surface only. *Ureter* and *renal vein* leave the median inner concave depression of kidney called *hilum* or *hilus*. A *renal artery* and *nerve* enter the kidney at the hilus. Proximal expanded end of ureter, called *renal pelvis*, occupies a central *renal sinus* which opens externally at the hilus. In a sagittal section, kidney reveals two distinct zones or regions. A narrow peripheral region, striated and lighter in colour, is the *cortex*, while the more deeply stained central region is the *medulla*. The medulla forms large conical processes, the *pyramids*, the apices of which project as renal *papillae* into diverticulae of renal pelvis, called *calyces* (singular *calyx*). The cortex extends between pyramids of medulla as thin *columns of Bertini*. Histologically, the mammalian kidney does not differ materially, from that of frog. The *Malpighian bodies* (glomerulus + Bowman's capsule) and the convoluted portions of *uriniferous tubules* are confined to the cortical region and the collecting tubules to the medullary pyramids.

Testis

The male gonad or testis in all vertebrates is a compact tubular gland (Figs. 33 & 34). In frog it is covered by a fold of peritoneum, called *mesorchium*. In mammals, it has an outer fibrous covering, the *tunica albuginea*, covered externally by *serosa* or *visceral peritoneum*. Histologically, the testis is composed of many coiled microscopic *crypts* or *seminiferous tubules* held together by connective tissue. Unlike uriniferous tubules of kidney, the seminiferous tubules are blind at their inner ends and lined by stratified *germinal epithelium* which produces sperms by spermatogenesis. Most of the germinal epithelial cells are small *spermatogonia* with rounded deeply stained nuclei. They bud off *primary spermatocytes* which are the largest cells. They divide into half-sized daughter cells or *secondary* *spermatocytes*. The smallest cells bordering the central lumen are *spermatids*, while *sperms* or *spermatozoa* occur freely or in bundles in the lumen. All the different stages of spermatogenesis do not usually occur in the same part of the tubule at the same time. In mammals, certain elongated cells, called *Sertoli cells*, are present scattered in the germinal epithelium. They serve to nourish the spermatids or sperms attached to them. The connective tissue in between tubules contains blood vessels, lymphatics, nerve and muscle fibres, and also small patches of *interstitial cells* which secrete the hormone *testosterone* responsible for the development of secondary sexual characters.

Spermatozoa

T e spermatozoa consists of he head, " mi-l- piece and the lail or the flagelium. The anterior lips of the head is differentiated as the acrosome which helps the spermatozoa to penetrate through the egg envelops and to establish connection with the egg cytoplasm. Nucleus forms the major part of the head region. Since the genes are contained in the nucleus, it is responsible for the transmission of hereditary characters from the male parent. The posterior part of the head contains the centriole of the spermetozoa which serves its function during the cell division in the fertilized egg. The middle piece contains the base of the flagellum and around it are mitochondria which supply energy to the flagellum for the propulsion of the spermatozoon with the head foremost.



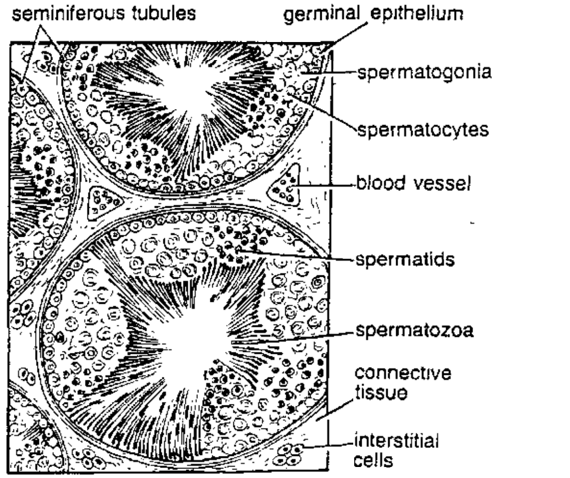
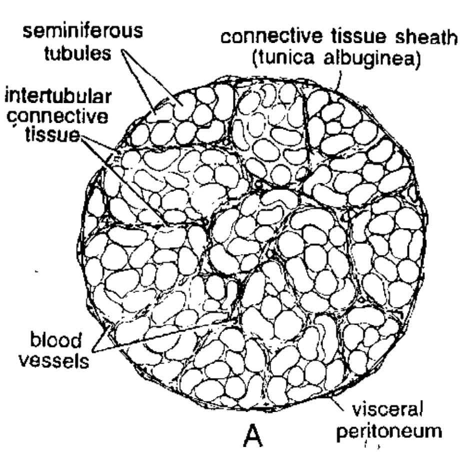


Fig. 33. Testis of frog. A—T.S. of testis in low magnification. B—A portion of testis magnified.



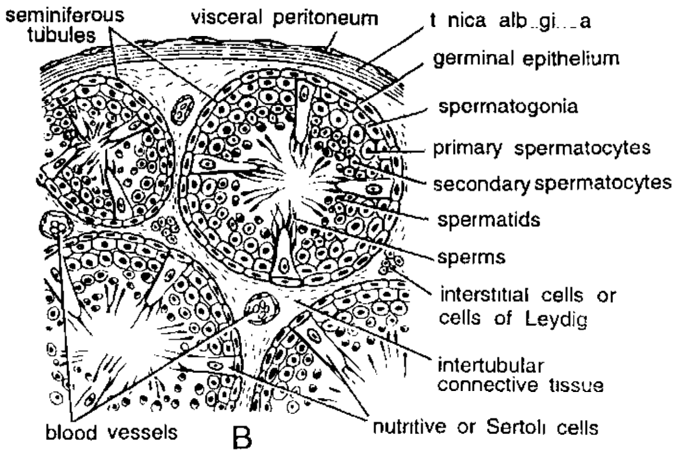


Fig. 34. Testis of rabbit A—T. S under low magnification B—A portion magnified.

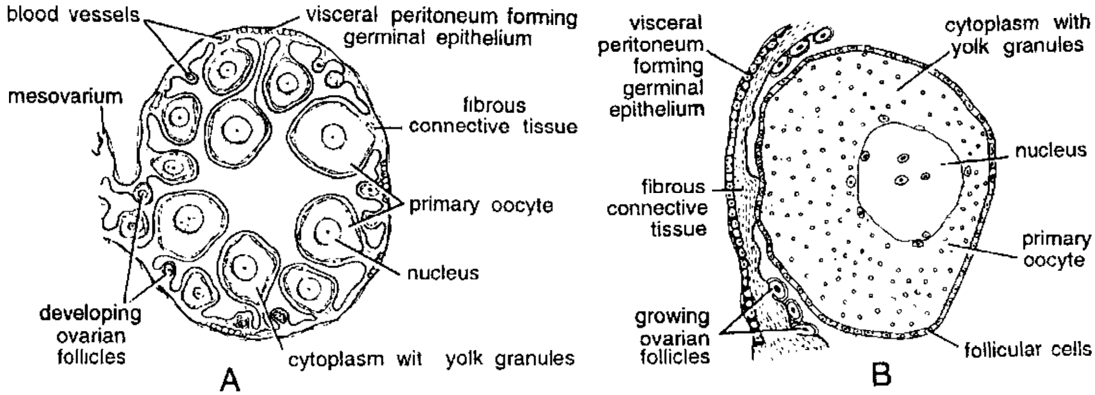


Fig. 35. Ovary of frog. A—T S. of a lobule. B—An ovum under high magnification.

Ovary of Frog

Frog's ovary is an irregular hollow sac composed of several lobules and attached to kidney by a peritoneal fold called *mesovarium* (Fig. 35). The thin wall is made of fibrous connective tissue containing blood vessels, muscle fibres and nerves and externally covered by a simple columnar coelomic epithelium or *germinal epithelium.* In the lumen of each lobule, project several black and white round *ova* in various stages of development. From germinal epithelium are budded off small groups of cells (*oogonia*) forming *ovarian follicles.* In each follicle, one central cell enlarges to become *ovum* containing a *nucleus* and cytoplasm with granular *yolk* for nourishment. Rest of the cells form an outer layer of *follicular epithelium* which also provides nourishment. As ovum grows, follicular cells disappear and become replaced by a thin *vitelline membrane* secreted by the ovum itself. In frog, ova are released from ovary in the *primary oocyte* stage and second maturation division takes place in water.

Ovary of Rabbit

Ovary (Fig. 36) of mammals (e.g. rabbit) is not hollow but a solid oval structure. It is attached with the uterus at *hilus* by a double fold of peritoneum called *mesovarium.* Blood vessels and nerves also enter ovary at hilus. Ovary is invested by *peritoneum* made of cubical cells forming *coelomic* or *germinal epithelium.* Beneath germinal epithelium is a narrow dense layer of connective tissue, the *tunica albuginea.* Internal mass of connective tissue fibres is the *stroma.* It is

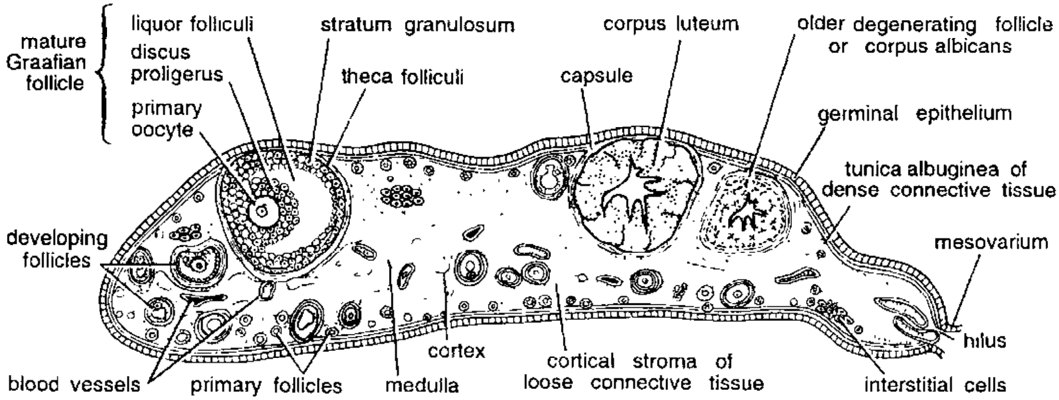


Fig. 36. L. S. Ovary of rabbit.

differentiated into a broad peripheral region, or *cortex*, and a narrow central region or *medulla*. Scattered in peripheral or cortical stroma occur *ovarian follicles, corpora lutea, corpora albicans* and *interstitial cells*, while central or medullary stroma is devoid of follicles but contains many blood vessels. Certain cells from germinal epithelium, called *oogonia*, sink into stroma forming little groups of actively dividing cells, the *ovarian follicles*. A growing or *primary follicle* contains a large central cell or *oocyte* surrounded by a single layer of small cubical *follicle cells*. A *secondary follicle* develops a transparent non-cellular area called *zona pellucida* around the oocyte, several layers thick follicle cells, and a thin connective tissue investment called *theca* containing blood capillaries. Finally, a fully mature stage is termed *Graafian follicle*. It contains a large central *follicular cavity* or *antrum* with a fluid called *liquor folliculi*. The follicle cells lining the cavity are termed *membrana granulosa*. The hillock or mass of cells which surrounds and attaches the primary oocyte to the follicle wall is now called *discuss proligerous* or *cumulus*. Next to zona pellucida, cells of inner margin of cumulus present a characteristic radial arrangement and termed *corona radiata*. After ovulation a ruptured follicle turns into a yellowish solid mass of cells in man, called *corpus luteum*. It secretes the hormone *progesterone*. Corpus luteum disappears leaving a whitish scar tissue called *corpus albicans*. Groups of *interstitial cells* in cortical stroma, few in man but conspicuous in rabbit, also produce sex hormones.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give a detailed account of skin of Frog and Rabbit. Differentiate between the amphibian and the mammalian skin.
2. Compare the structure of skin of *Scoliodon* with that of Frog or Rabbit. Enumerate the functions performed by the integument in a vertebrate.
3. Describe the histological structure of stomach and intestine of Frog or Rabbit.
4. Describe the histology of liver or pancreas of Frog or Rabbit and enumerate its main functions.
5. Describe the microscopic structure of mammalian blood and compare it with that of Frog.
6. Give an account of histological structure of kidney, ovary and testis in Frog and Rabbit.

» *Short Answer Type Questions*

1. Differentiate between transverse sections of — (i) Cartilage and bone, (ii) Stomach and ileum, (iii) Bone of Frog and Rabbit, (iv) Ovary of Frog and Rabbit, (v) Lung of Frog and Rabbit.
2. Make following labelled sketches of Frog and Rabbit — (i) Lung, (ii) Ovary, (iii) Skin, (iv) Spinal cord.
3. Write short notes on — (i) Bowman's capsule, (ii) Glomerulus, (iii) Graffian follicles, (iv) Islets of Langerhans, (v) Pancreas, (vi) Spleen, (vii) Villus.

» *Multiple Choice Questions*

1. Matrix of mucous tissue :
   (a) Barton's jelly (b) Wharton's jelly
   (c) Lymph (d) Karton's jelly
2. Reticular fibers are made from protein :
   (a) Reticuline (b) Pepsin
   (c) Mucin (d) Keratin
3. Reticular connective tissue is predominantly found in :
   (a) Digestive organs (b) Excretory organs
   (c) Lymphoid organs
   (d) Muscles
4. Tendons connect :
   (a) Muscle to muscle (b) Muscle to bone
   (c) Ligaments to bone (d) Bone to bone
5. The ground substance of cartilage consists of :
   (a) Reticuline (b) Wharton's jelly
   (c) Keratin (d) Chondrin
6. Connective tissue around cartilage :
   (a) Epichondrium (b) Perichondrium
   (c) Ectochondrium (d) Endochondrium

7. Type of cartilage in epiglottis :
(a) Elastic (b) Simple
(c) Hyaline (d) Fibrous
8. The lacunae in vertebrate bones are connected to each other by :
(a) Canaliculi
(b) Haversian canal
(c) Bone marrow (d) Lamellae
9. Medium between blood and cells is made by :
(a) Bone marrow (b) Lymph
(c) WBC (d) Muscles
10. Excessive output of urea in sweat :
(a) Urine (b) Uremia
(c) Uric sweat (d) Uridosis
11. Epithelial lining of the internal spaces :
(a) Squamous
(b) Basement membrane
(c) Endothelia
(d) Simple epithelia
12. Squamous epithelium is also called :
(a) Bridge epithelium
(b) Pavement epithelium
(c) Cement epithelium
(d) Cuboidal epithelium
13. Lining of many glands is made up of :
(a) Squamous epithelium
(b) Cuboidal epithelium
(c) Columnar epithelium
(d) Ciliated epithelium
14. Nasal cavity is lined by :
(a) Squamous epithelium
(b) Cuboidal epithelium
(c) Columnar epithelium
(d) Ciliated epithelium
15. Cell junctions forming fluid tight zip lock between cells :
(a) Desmosomes
(b) Gap junctions
(c) Tight junctions (d) Anchoring junctions
16. In the epidermis of Frog, cell multiplication takes place in :
(a) Stratum malphigi
(b) Stratum germinativum
(c) Basement membrane
(d) Stratum corneum
17. Layer separating mucosa from sub mucosa :
(a) Lamina propria (b) Muscularis mucosa
(c) Epithelium (d) Serosa
18. The outermost protective coat of alimentary canal :
(a) Mucosa (b) Sub mucosa
(c) Muscularis (d) Visceral peritoneum
19. The upper end of oesophagus in Rabbit is lined by :
(a) Visceral peritoneum
(b) Tunica adventitia
(c) Mucosa
(d) Sub mucosa
20. Pepsin is secreted by :
(a) Zymogen cells (b) Mucous cells
(c) Oxyntic cells (d) Goblet cells
21. Brunner's glands are characteristic of :
(a) Ileum of frog (b) Ileum of rabbit
(c) Duodenum of frog (d) Duodenum of rabbit
22. Lymphocytes are produced by :
(a) Crypts of Lieberkuhn
(b) Peyer's patches
(c) Paneth cells
(d) Brunner's glands
23. Kupffer cells are characteristic of :
(a) Stomach (b) Intestine
(c) Liver (d) Pancreas
24. Ornithine cycle takes place in :
(a) Liver (b) kidney
(c) Skin (d) Stomach
25. Alpha cells of pancreas secrete :
(a) Insulin (b) Bile
(c) Glucagon (d) Pancreatic juice
26. Largest lymphoid glands in vertebrates :
(a) Liver (b) Pancreas
(c) Thyroid (d) Spleen
27. Reflex activity is under the control of :
(a) Brain (b) Hypothalamus
(c) Medulla oblongata (d) Spinal cord
28. Spermatids take their nourishment from :
(a) Tunica albuginea (b) Sertoli cells
(c) Germinal epithelium (d) Interstitial cells
29. In frog vitelline membrane is secreted by :
(a) Ovum (b) Germinal epithelium
(c) Mesovarium (d) Follicular cells
30. Blood vessels and nerves enter a mammalian ovary at :
(a) Cortex (b) Stroma
(c) Hilus (d) Zona pellucida
31. Progesterone is secreted by :
(a) Corpus albicans (b) Corpus luteum
(c) Corona radiata (d) Cumulus

ANSWERS

1. (b) 2. (a) 3. (c) 4. (b) 5. (d) 6. (b) 7. (a) 8. (a) 9. (b) 10. (d) 11. (c) 12. (b) 13. (b) 14. (d) 15. (c) 16. (a) 17. (b) 18. (d) 19. (b) 20. (a) 21. (d) 22. (b) 23. (c) 24. (a) 25. (c) 26. (d) 27. (d) 28. (b) 29. (a) 30. (c) 31. (b).

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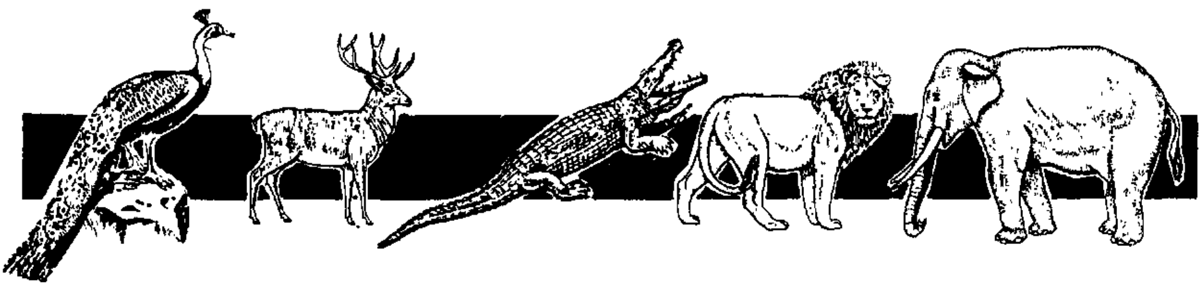

Wild Life of India

What is Wild Life ?

'Wild animal' means any non-domesticated animal found wild in nature. It includes both vertebrates (fish, amphibians, reptiles, birds and mammals) and invertebrates (bees, butterflies, moths, crustaceans, etc.). In *Webster's Dictionary*, 'wild life' is defined as 'living things that are neither human nor domesticated, especially mammals, birds and fishes hunted by man." The term 'wild life' includes animals as well as plants which form part of any habitat in nature.

In the words of late Prime Minister Pandit Jawahar Lal Nehru, "wild life refers to the magnificient animals of our jungles and to the beautiful birds that brighten our lives. But life would become very dull and colourless if we did not have these magnificient animals and birds to look at and to play with. We must try to preserve whatever is left of our forests and the wildlife that inhabits them."

Some wild animals are so characteristic that they become symbols of their home countries. Thus, tiger is associated with India, white bear with Russia, Giant Panda with China, Kangaroo with Australia, Kiwi with New Zealand and springbok with South Africa.

Brief History of Indian Wild Life

Man has been interested in wild animals since the dawn of civilization. He hunted them for food and clothing, observed them for joy and heard the melodious notes of birds for pleasure.

In India, the idea of protection and preservation of wild life has been an integral part of religion and culture since very ancient times. The Vedas include hymns in praise of animals and the Indian Mythology is full of references to several Animal-like Gods such as the monkey-headed *Hanuman*, elephant-headed *Ganesh*, boar-headed *Varahavatar*, lion-headed *Narasinghavatar*, turtle-like *Koormavatar*, fish-like *Matsyavatar*, snake-like *Shesh Nag*, etc. We also learn about snake worship (*Nag Pooja*), eagle worship (*Garud*), cow worship (*Lord Krishna*), and vehicles of Shiva (*Bull Nandi*), Saraswati (*swan*), Ganesh (*rat*), etc. In ancient India, hermitages (ashrams) were the sanctum sanctorums (holy retreats) in the holy environs of which the hunting of animals was totally prohibited. Kautilya's *Arth shastra* of third century B.C. proclaims severe punishment for killing, entrapping or molesting animals in protected areas (sanctuaries). Ashoka the Great enacted laws for the protection of fauna in his kingdom as early as the third century B.C. However, the condition of our wild life rapidly deteriorated first under the Moghul rule and later under the British rule, when mad slaughter of animals became the fashion of the day. Temur and Babar killed thousands of rhinoceroses which were abundant in Kashmir and Northern India. Colonel Pollock, a military engineer of British East India Company in Assam, shot a rhino or buffalo almost daily for breakfast. A former Raja of a state in Madhya Pradesh, probably held the world record for killing the highest number of tigers (1170).

Biodiversity

Biodiversity is the vast array of all species of plants, animals, insects and micro-organism inhabiting the earth either in the aquatic or the terrestrial habitats. To explain the need of the forests and wild life for our survival these days there is much emphasis on understanding biodiversity. Prof. Peter Ravan of Missouri Botanical Garden, St. Louis may be quoted, "Billions of dollars have been spent for the exploration of the moon. We know far more about the moon then we know about the rain forests. The moon will be there for longer than these forests and perhaps than the human race. In the forests are found most complex interacting system on earth, system which might even hold the key to our survival and about which we know practically nothing". Species diversity refers to the various species under the same genus and also the varieties of species within a region e.g., Tiger *Panthera tigris*, lion *Panthera leo persica* and snow leopard *Panthera uncia* all belong to the same genus *Panthera* but they differ from each other at the species level.

The genetic diversity refers to the various kinds of genus which exists in any one individual species. Diversity of genus brings about the changes in an individual species and gives rise to various varieties (in plants) and races (in animals). For example there are many varieties of mango (*Mangifera indica*) and there are several races of human beings.

Socioeconomic benefits of biodiversity

(1) A large part of our daily needs is fulfilled by the harvest of wild species.
(2) Wheat and rice production has increased considerably in last few years by incorporating dwarf genes from wild varieties.
(3) Genes from "wild varieties" may save from the epidemic to some extent disease.
(4) A large number of medicines are prepared from wild products.
(5) Some of the wild species can restore the dwindling species.

Levels of diversity

Biodiversity can be studied at four levels of biological organization :

(1) The ecosystem diversity
(2) The generic diversity
(3) The species diversity
(4) The genetic diversity

Ecosystem diversity refers to the various types of habitats in various types of ecosystems namely terrestrial (e.g. forest, desert), aquatic (fresh water and marine ecosystems), wetlands (Mangroves and estuarine ecosystems etc.).

The generic diversity refers to the diverse plant groups from algae to angiosperms, the diverse animal groups from fishes to amphibians, reptiles, birds and mammals of many other forms of animal life.

With the increasing depletion of forests and wild life about 26 biologically sensitive areas have been identified in India where preservation of biodiversity is required. In the "Earth Summit" held in 1992 at Rio de Janeiro an agreement on biological diversity was developed. Several recommendations have been made for the preservation of biodiversity in the welfare of the mankind. After 10 years, in 2002 next "Earth Summit" was held at Geneva to review the progress made in this direction.

Importance (Values) of Wild Life

Why do we need to protect our wild life from extinction? Wild life is a source of danger to human life. It is a nuisance to a farmer because it often destroys his crops. The domestic livestock is denied grazing ground in sanctuaries and reserves for wild life. Similarly, the hunters are denied recreation by shooting wild life. Even then conservation of wild life becomes necessary and of great importance due to its many values to mankind.

1. Ecological value. For a millennium, man and wild animals have evolved together on this planet, called Earth. All life on earth is one and all living things are inextricably interlinked (food chains) forming ecosystems. Destruction of wild life may cause upset in the ecological balance or equilibrium resulting in severe consequences. Thus, protection of every animal species is of great importance to the quality of life and to the survival of man himself. By rendering the planet uninhabitable for animals, we will not be able to avoid extinction ourselves.

2. Commercial value. Wild life forms an important natural resource. Unlike coal or petroleum which is nonrenewable, wild life is also a renewable resource. With proper care and management, it can yield good dividends and even earn foreign exchange. The commercial value of wild life is best seen in the world's marine fisheries, with an annual output of about 100 million tons of sea food worth billions of rupees. Freshwater fish and other aquatic creatures also provide large amount of food for people. Wild life of dry land mainly contributes to the food of the so-called primitive people of the world. An entire industry, the fur trade is supported by fur-bearing animals. Trade in live as well as dead animals supports thousands of people and also earns foreign exchange. For example, an Indian rhino may fetch equivalent of Rs. 1,25,000 in the world market. Similarly, the ivory of elephants, the horns of rhinoceros, the glands of musk deer, the antlers of deer etc., all command high prices. Wild life of a country may even attract people from abroad and earn foreign exchange. Thus, the tourist industry of Kenya (East Africa), based on its wild life, ranks third after coffee and sisal.

3. Game value. Wild life has its worth as game also. In several European and American countries, millions of people hunt or fish for recreation, spending billions of dollars on these sports.

4. Scientific value. Scientific studies of many of the wild life species are of direct value to humans. Thus, sea urchins have helped greatly in the understanding of human embryology. A desert toad has helped in early determination of pregnancy. Rhesus monkeys have contributed to the present knowledge of human blood groups. Antlers of deer help in determining the degree of radioactive contamination of natural environments. Armadillo contributed to the development of vaccine for Leprosy. We do not know when some obscure wild animal species may be shot to prominence by providing a clue to human health and survival.

5. Asthetic value. There is a great worldwide aesthetic value of wild life because of their sheer beauty and appeal to the human spirit. A world without melodious birds, graceful beasts and rupturous forests would be a poorer place for humans to live in. Without wild animals, a countryside looks dead, static monotonous and like a picture postcard. People feel pleasure, satisfaction and happiness in the presence of wild life.

6. Ethical value. Generally people think that they have no right to destroy wild animals, rather they feel an obligation for the conservation of nature and protection of wild life. In fact all religions preach a healthy respect and reverence for life and consider it wrong to take the life of an animal.

The Vanishing Wild Life

Animal species were subject to natural causes of extinction even before the arrival of man about 2 million years ago. Some familiar examples are the extinct ammonites, large cephalopods and branchiopods (Devonian) and the dinosaurs (Mesozoic). However, the tempo of extinction of species has been at its height in the last 2 or 3 centuries mainly due to thoughtless action of man. In his pursuit of 'progress', and with the growing human population, agriculture and urbanization, man has thoroughly exploited wild life and their natural habitats. He has cut down forests, drained marshes and polluted rivers and seas. As if inspired by a divine mission, he has attempted to create a desert around himself. As a result, many animal species have altogether vanished, while several others, that are living today, are on the verge of extinction.

According to one estimation, the number of species of wild fauna disappeared during the last 4 centuries had been as follows :

Seventeenth century	(1600-1700)	— 7 species extinct
Eighteenth century	(1700-1800)	— 11 species extinct
Nineteenth century	(1800-1900)	— 27 species extinct
Twentieth century	(1900-1988)	— 67 species extinct

[I] Causes of destruction

The ways and means of extermination of wild life by man fall into two broad categories : *direct* and *indirect*.

1. Direct destruction. The main causes of direct physical elimination of wild animal species by man include hunting, capturing and indiscriminate killing for amusement, meat, fur, feathers, trophies etc. Thus, in North America, 60 million heads of bison (*Bison*) were relentlessly and brutally hunted, in a few years, to feed the workers of the Transamerican Railway. Only the animal's tongue was consumed and the rest of the body left to rot. The European Bison now survives only in Polish and Russian parks. Predators like Asiatic lion (*Panthera leo*), tiger (*Panthera tigris*), leopard (*Panthera pardus*), wolf (*Canis lupus*), coyote, cougar, white bear (*Ursus*), etc., were hunted down, trapped or poisoned because they occasionally eat livestock. 60,000 to 70,000 individuals of blue whale (*Balaenoptera musculus*) and other whales are killed every year for fat used in cosmetics and soap industry, and for meat used in dog food. Millions of fur seals, sea otters, beavers, snow leopards, ocelots, etc., are slaughtered for their pelts by luxury fur trade for the sake of clothing and fashion business. India's hunting leopard (*Acinonyx*), which was the fastest animal on the earth, has become extinct in living memory. Man is also responsible for the recent extinction of the migrating dove or passenger pigeon (*Ectopistes migratorius*, 1914), Carolina parakeet (1920), heath hen (1932), great auk (1844), Labrador duck (1850-70), and others of North America. The dodo *(Rephus)*, a peaceful bird of Mauritius vanished around 1681.

The other direct causes leading to the drastic reduction of many animals are the mania for souvenirs (ivory yielding elephants, walruses, hippopotami, etc.), for trophies and stuffed animals (rare birds), for superstitions and medicines (rhinoceros horn), and for supplying living animals to private zoos, laboratories, etc. Nearly 47,000 elephants were killed annually in Africa between 1850 and 1890, for the London ivory market alone.

2. Indirect destruction. The indirect causes for destruction of wild life are also numerous. The chief causes are deforestration, destruction of habitats, spread of deserts, pollution, insecticides, etc.

3. Wildlife diseases. Khera (1980) pointed out that prevalence of epizootic diseases among wildlife has also been a major factor associated with decline in number of some species of wildlife population. Some of the important diseases encountered among different species of wild animals are— *Rinder pest, foot and mouth disease, Rabies, Anthrax, African horse sickness, Surra, Leptosporiasis, Influenza, Parasitic infections, Encephalitis, Salmonellosis, Shigellosis, Tuberculosis* etc.

[II] Protected Indian wild life

Table 1, 2 and 3 provides a list of some common Indian mammals, birds and reptiles which are endangered or threatened with extinction. They have been declared as protected species so that their hunting (capturing, killing, poisoning, injuring, etc.) is illegal under the provisions of the Wild Life (Protection) Act, 1972.

Indian threatened mammals. There are nearly 372 species of mammals found in India including various species listed in threatened categories (IUCN[1] Red List of Threatened Animals Table 1). This database provides information on the distribution of mammalian species in various protected areas of India.

Indian threatened reptiles : There are 447 species of reptiles found in India (Murthy, 1994) including number of species listed in threatened categories Table 2. This database provides information on the distribution of reptiles in Indian protected areas. Large number of information related to species distribution on various protected areas has been linked with various protected areas including tiger reserves.

Threatened Indian birds : There are 1,228 species of birds found in India including 65 species listed in various threatened categories according to IUCN (Table 3). This database provides information on the distribution of birds in various protected areas of India. Large number of information related to species distribution on various protected areas have been collected and documented in the form check lists and linking with each PAs of India is under process.

Important Indian Wild Life

The wild life of India is unique in the richness of its variety (Fig. 1). From the great sweep of Himalayas in North to the virgin forests of South, and from the mangrove swamps in east to the sprawling deserts of west, India abounds in natural habitats having different terrains and varied climatic conditions. On account of this, oriental region is divided into four eco-climatic divisions—(i) Himalayan mountain system (ii) Peninsular India, (iii) Tropical Indo-Malayan evergreen Belt and (iv) Andaman Nicobar Islands. These house some of the rarest species of wild life in the world. It comprises about 350 species of mammals, 2,100 species and subspecies of birds and about 20,000 species of insects. Some of the most famous Indian wild animals are described as follows :

1. Indian crocodiles. Three types of crocodilians occur in India : (i) The gharial (*Gavialis gangeticus*), (ii) Salt water or estuarine crocodile (*Crocodylus porosus*), and (iii) The fresh-water or marsh crocodile or mugger (*Crocodylus palustris*). Once abundant in all the major rivers and even ponds, they are among threatened animals today. Their population declined because of uncontrolled and all season hunting for skin, flesh and sport. Loss of habitat due to construction of dams, diversion of rivers and human interference were other factors. In the wake of declining population, 'save the Crocodile' projects were launched in 1974 under the guidance of Dr. H.R. Bustard as the chief technical adviser. These aim at conservation and management of crocodilians through incubation of eggs, rearing and release in preserves. Their breeding farms presently run in nine Indian states including Andhra Pradesh, Bihar, Gujarat, Kerela, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. The first crocodile farm was started in 1975 in Orissa on Bhitar Kanika island. Uttar Pradesh set up crocodile sanctuaries at Katarniaghat in district Bahraich and Kukrail, near Lucknow, in 1976. At these centers crocodiles, *C. palustris* and Gharials are provided natural habitat. The eggs are protected and hatchlings are transferred to suitable tanks, where they grow into young gharials/crocodiles. These young crocodiles when attain size of 1-1.2 m are released in ideal habitat and care is taken that they are not disturbed by man. To conserve the gharial (*Gavialis gangeticus*) a 400 km long gharial sanctuary was established in and along river Chambal in 1978. This sanctuary is managed by forest departments of Madhya Pradesh, Rajasthan and Uttar Pradesh states. As a result, the

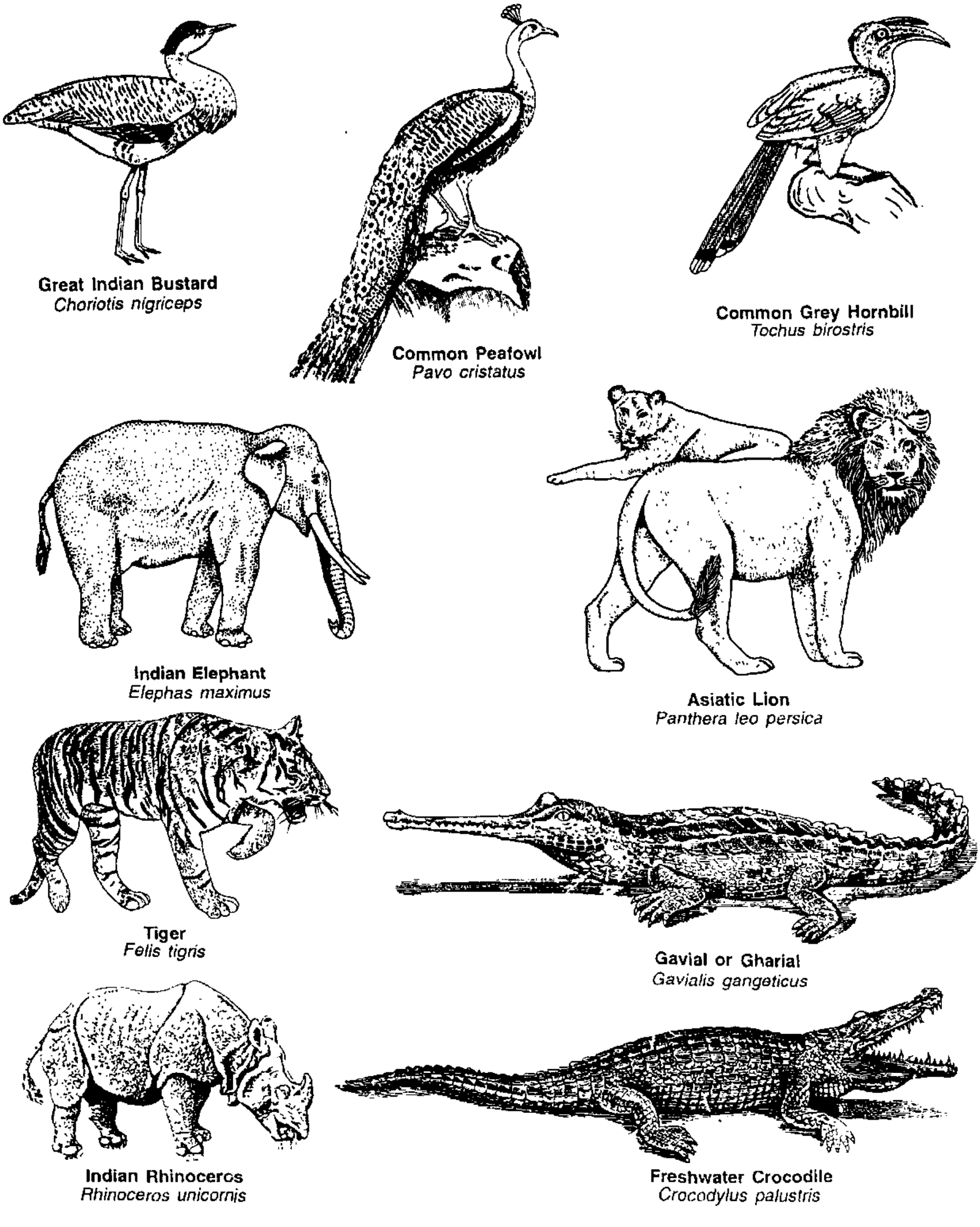

Fig. 1. Important wildlife of India.

Table 1. **IUCN Red List of Some Indian Threatened Mammals.**

Common name	Scientific name	Threatened category
Asiatic golden cat	*Felis temmincki*	I
Asiatic lion	*Panthera leo persica*	E
Asiatic wild dog/dhole	*Cuon alpinus*	V
Asiatic black bear	*Selenarctos thibetanus*	E
Banteng	*Bos javanicus*	V
Bengal fox	*Vulpes bengalensis*	I
Bharal	*Ovis nahura*	T
Bison or gaur or mithun	*Bos gaurus*	T
Black buck	*Antelope cervicapra*	T
Brow-antlered deer	*Cervus eldi eldi*	V
Brown bear	*Ursus arctos*	V
Brown palm civet	*Paradoxurus jerdoni*	V
Capped langur	*Presbytis pileatus*	T
Caracal	*Felis caracal*	T
Chinkara or Indian gazelle	*Gazella gazelle bennetti*	T
Chital	*Axis axis*	T
Clawless otter	*Anonyx cinerea*	K
Clouded leopard	*Neofelis nebulosa*	V
Common otter	*Lutra lutra*	V
Crab eating macaque	*Macaca irus umbrosa*	T
Desert cat	*Felis libyca ornate*	E
Dugong/seacow	*Dugong dugon*	V
Fishing cat	*Felis viverrina*	T
Flying squirrels	*All species*	T
Four-horned antelope	*Tetraceros quadricornis*	T
Ganges river dolphin	*Platanista gangetica*	V
Giant squirrels	*Ratufa macroura, R. indicus*	T
Golden langur	*Trachypithecus geei*	R
Goral	*Nemorhaedus goral*	V
Great Indian rhinoceros	*Rhinoceros unicornis*	E
Grey/Indian wolf	*Canis lupus*	V
Himalayan ibex	*Capra ibex*	T
Himalayan crestless procupine	*Hystrix hodgsoni*	T
Himalayan W-toothed shrew	*Crocidura attenuata*	V
Himalayan marten	*Martes flavigula*	I
Himalayan musk deer	*Moschus chrysogaster*	V
Himalayan shrew	*Soriculus nigrescens*	V
Himalayan tahr	*Hemitragus jemlahicus*	T

(Contd.)

Common name	Scientific name	Threatened category
Hoolock gibbon	*Hylobates hoolock*	E
Hyaena	*Hyaena hyaena*	T
Indian elephant	*Elephas maximus*	E
Indian pangolin	*Manis crassicaudata*	T
Indian wild ass	*Equus hemionus khur*	T
Jackal	*Canis aureus*	V
Kashmir stag/hangul	*Cervus elaphus hanglu*	E
Leopard	*Panthera pardus*	T
Lesser panda	*Ailurus fulgens*	V
Lion-tailed macaque	*Macaca silenus*	T
Loris	*Loris tardigradus*	T
Malabar civet	*Viverra megaspila*	T
Markhor	*Capra falconeri*	T
Musk deer	*Moschus moschiferus*	T
Nilgai	*Boselaphus tragocamelus*	E
Nilgiri langur	*Presbytis johni*	T
Nilgiri tahr	*Ilemitragus hylocrius*	T
Otter	*Lutra perspicillata,*	T
Pallas's cat	*Felis manul*	T
Pig-tailed macaque	*Macaca nemestrina*	T
Pigmy hog	*Sus sulvanius*	T
Red fox	*Vulpes valpes*	T
Sambar	*Cervus unicolor*	T
Sloth bear	*Melursus ursinus*	T
Slow loris	*Nycticebus coucang*	T
Snow leopard	*Panthera uncial*	T
Swamp deer or gond	*Cervus duvauceli*	T
Tibetan antelope or chiru	*Panthelope hodgsoni*	T
Tibetan fox	*Vulpes ferrilatus*	T
Tibetan gazelle	*Procapra picticaudata*	T
Tibetan wild ass	*Equus heminonus kiang*	T
Tiger	*Panthera tigris*	T
Wild buffalo	*Bulbalus bubalis*	T
Wild pig	*Sus scrofa*	T
Wild yak	*Bos grunniens*	T

crocodilians which were once thought to be on the verge of extinction in 1970, have regained their lost habitat in the perenial rivers and now they are well out of danger.

2. Great Indian bustard. (Fig. 2) (Family Otididae). The great Indian bustard (*Choiotis* or *Ardeotis nigriceps*) is one of the largest flying bird in the world. Once quite abundant in the arid zones of India, as far south as the Malabar coast and Sri Lanka, it is now rare and restricted mainly to the deserts of Rajasthan. It is locally called 'Hukna', 'Tuqdar' or 'Gorawan', in Hindi. It is a splendid looking bird, about one meter tall, having long sturdy yellow legs without hind toe. Its plumage is dull brown above and white below. It is found in parties of 5 or 6. One male might

Table 2. IUCN Red List of Some Indian Threatened Reptiles.

English name	Scientific name	Threatened categories
Asian Giant Tortoise	*Manouria emys*	V
Assam Roofed Turtle	*Kachuga sylhetensis*	T
Black Pond Turtle	*Geoclemys hamiltonii*	I
Central Asian/Oxus Cobra	*Naja naja oxiana*	K
Cochin Forest Cane Turtle	*Geoemyda silvatica*	V
Elongated Tortoise	*Indotestudo elongata*	K
Estuarine Crocodile	*Crocodylus porosus*	V
Gharial (Long-snouted Crocodile)	*Gavialis gangeticus*	E
Green Sea Turtle	*Chelonia mydas*	E
Hawksbill Turtle	*Eretmochelys imbricata*	E
Indian Egg-eating Snake	*Elachistodon westerwanii*	R
Indian Python	*Python molurus molurus*	V
Leathery Turtle	*Dermochelys coriacea*	E
Loggerhead	*Caretta caretta ? ?*	V
Mugger (Marsh Crocodile)	*Crocodylus palustris*	V
Monitor lizards	*Varanus griseus, V. flavescens, V. salvator*	T
Olive Ridley Turtle	*Lepidochelys olivacea*	E
Pythons	*Python molurus, P. reticulatus*	T
Red-crowned Roofed Turtle	*Kachuga kachuga*	I
Three-keeled land Tortoise	*Melanochelys tricarinata*	I
Travancore Tortoise	*Indotestudo forstenii*	R
Yellow Monitor Lizard	*Varanus flavescens*	I
?	*Oligodon nikhili*	R

Table 3. IUCN Red List of Threatened Indian Birds.

English name	Species name	Threatened categories
Andaman serpent eagle	?	R
Asian dowitcher	?	R
Baer's pochard	*Aythya* sp.	V
Beautiful nuthatch	*Sitta* sp.	R
Bengal florican	?	E
Black breasted parrotbill	?	I
Blacknecked crane	*Grus nigricollis*	V
Bristled grass warbler	*Dendroica* sp.	K
Brown chested jungle flycatcher	?	V
Cheer pheasant	*Catreus wallichii*	T

(Contd.)

English name	Species name	Threatened categories
Cinereous vulture	?	V
Comb duck	*Anas* sp.	E
Dalmatian pelican	*Pelecanus* sp.	V
Darkrumped swift	*Apus* sp.	I
Forest owlet	*Glaucidium radiatum*	I
Grass warbler	*Cisticola* sp.	R
Great Indian bustard	*Choriotis nigriceps*	V
Great Indian hornbill	*Buceros bicornis*	T
Great adjutanat	?	E
Green avadavat	?	R
Grey sided thrush	*Anas poecilorhyncha*	K
Himalayan quail	?	Ex
Hume's pheasant	*Fhasianus* sp.	R
Imperial eagle	*Aquila heliaca*	R
Jerdon's babbler	?	V
Jerdon's/double banded courser	*Cursorius bitorquatus*	I
Large falcons	*Falco peregrinus, F. biarmicus, F. chicquera*	T
Lesser white fronted goose	?	R
Lesser florican	?	E
Long billed bush warbler	*Dendroica* sp.	R
Manipur bush quail	?	R
Marbled teal	?	V
Marsh babbler	?	K
Masked fin foot	*Heliopais personata*	V
Mishmy wren	*Toglodytes* sp.	I
Mountain quail	*Oppassia superciliosa*	T
Narcondam hornbill	*Rhyticeros narcondami*	R
Nicobar scrubfowl	*Atrichornis* sp.	R
Nicobar parakeet	*Psittacula* sp.	I
Nicobar pigeon	*Caloenas nicobarica*	R
Pale capped pigeon	*Columba* sp.	R
Peafowl	*Pavo cristatus*	T
Pink headed duck	*Rhodonessa caryophyllacea*	Ex
Plain pouched hornbill	?	I
Rufous headed parrot bill	?	R
Rufous vented prinia	?	R
Rufousnecked hornbill	?	R
Rusty throated wren babbler	*Turdoides* sp.	I
Rusty bellied short wing	?	I
Sclater's monal	*Lophophorus sclateri*	R
Siberian crane	*Grus leucogeranus*	V

(*Contd.*)

English name	Species name	Threatened categories
Snowy throated	?	R
Sociable lapwing	?	R
Spoon billed sandpiper	*Platalea leucorodia*	I
Swamp francolin	*Fracolinus* sp.	V
Swamp partridge/kyah	*Perdix* sp.	V
Tawny breasted wren babbler	*Turdoides* sp.	K
Wedge billed wren babbler	*Turdoides* sp.	R
Wedge billed wren	*Troglodytes* sp.	R
Western tragopan	*Tragopan* species	T

International Union for Conservation of Nature and Natural Resources
Ex = Extinct, E = Endangered, V = Vulnerable, I = Indeterminate, K = insufficiently known, T = Threatened.

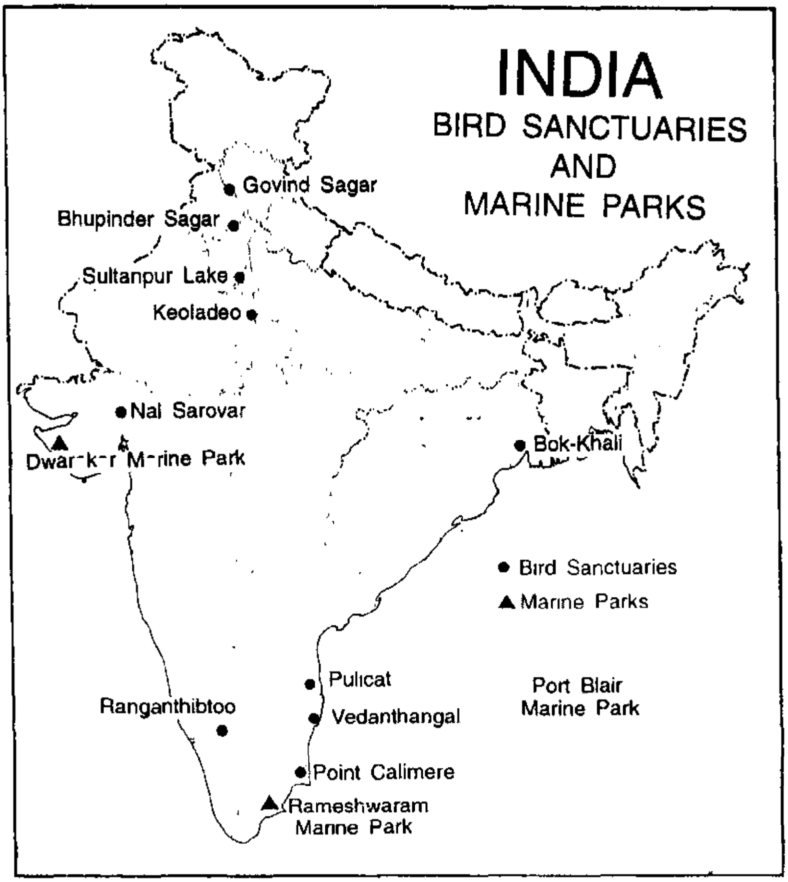

Fig. 2.

have 3-5 hens. The bird is extremely shy and wary normally but has a queer habit of hiding behind bush rather than take to wings when disturbed. Normally they lay one egg or rarely two. It is a great friend of farmers as it feeds mainly on arthropods, lizards, snakes and mice, besides grains and young shoots of plants. Large areas of the Desert National Park in Rajasthan have been fenced so that bustards may not be disturbed during breeding season (July to October) as they are extremely shy of human presence. As a result of this timely action, their number has increased in natural habitat at Sokhalia village of Ajmer district in Rajasthan. It is no longer an endangered species in Rajasthan and has also been located in Gujarat, Maharashtra, Madhya Pradesh and Karnataka.

3. Common peafowl. (Family Phasianidae). The common peafowl or peacock of India is *Pavo cristatus*, called 'Mor' or 'Mayur' in Hindi. It occurs throughout India upto 1650 metres in the Himalayas. It displays a well-marked sexual dimorphism, the male having a gorgeous ocellated tail. Peacock is not threatened but it is the Nationai Bird of India. For details, readers may refer to Chapter 28.

4. Hornbills. (Family Bucerotidae). Hornbills are large birds, with broad curved bills having peculiar prominent protuberance or casque, rounded wings and long graduated tail. Several species are found in India (Table 4).

They are usually found in pairs or in small parties of 3-5. They nest in tree hollows during breeding season. They are threatened by deforestration because of dearth of suitable nesting trees. Tribal people also kill them for good taste of flesh and the alleged medicinal value of their fat and bones. Their peculiar casque is also used in witchraft as charm or ornament.

5. Indian elephant. Elephants are the largest living mammals found on land. The Asiatic or Indian elephant, (*Elephas maximus*) is widely distributed in the Himalayan Terai in Northern India, and in Karnataka, Kerala and Tamil Nadu in Southern India. But, strangely enough, it is not found in central India particularly in Madhya Pradesh, Andhra and Maharashtra. It lives in dense tropical and subtropical forests near water. The Indian elephant differs from the African elephant (*Loxodonta africana*) in several features, In India, elephants have long been domesticated and trained for shikars (hunting), transportations, processions, travelling, inspections, circuses, and sundry heavy works. Elephant-killing is normally forbidden because the pious Hindus consider it a symbol of Lord Ganesha. Apart from heavy poaching for ivory, the elephant has suffered most severely from

Table 4. **Endangered Species of Indian Hornbills.**

	Common name	Zoological name	Distribution
1.	Common grey hornbill 'Dhanesh' in Hindi	*Tochus birostris*	Throughout N. India in semi-open forests
2.	Malabar grey hornbill	*Tochus griseus*	Western Ghats. Lacks casque
3.	White-throated brown hornbill	*Ptilolaemus tickelli*	Everygreen forests. 300-1500 m. altitude Eastern India.
4.	Rufous-necked hornbill	*Aceros nipalensis*	Deciduous evergreen forests of Sikkim, Arunachal Pradesh, Manipur and Mizoram
5.	Wreathed hornbill	*Rhyticeros (undulatus)*	Evergreen forests along Himalayan foothills south of Brahmaputra
6	Narcondam hornbill	*Rhyticeros (undulatus) narcondarni*	Narcondam Island of Andaman group
7	Giant hornbill	*Buceros bicornis homri*	Heavy forests of Terai upto 2,000 m altitude. Western Ghats.
8	Indian pied hornbill	*Anthracoceros malabaricus*	Terai and lower foot hill forests
9	Malabar pied hornbill	*Anthracoceros coronatus*	Plains to 300m. altitude forests of South India.

destruction of its habitat (deforestration) for agriculture. It is feared that they are doomed to become extinct even in the parks and sanctuaries reserved for them because their increasing numbers may cause destruction of vegetation leading to malnutrition. Periyar Wild Life Sanctuary, situated in Kerala having an area of 777 sq. km was established in 1940 behind dam built on river Periyar for elephant and other wildlife.

6. Indian lion. The Indian or Asiatic lion (*Panthera leo persica*) once roamed from Greece across Arabia and Middle East to North-East India. It is now practically extinct from Asia and restricted to a small pocket of Gir forest of Gujarat State in Western India. Like its African cousin, it is also an animal of the open savannah. Moghul emperor Jahangir hunted male lions and tigers only. During the Sepoy Mutiny in India (1857), Col. Smith killed 300 lions of which 50 were from Delhi alone. By twentieth century, the population of lions was drastically reduced to a mere 15. Recorded history shows that the last lion was killed at Anadra and Jaswantpura, Rajasthan in 1876. The Gir Lion Sanctuary Project was started in 1972. Total area of this sanctuary is about 1412.12 sq. km. As a result of conservation measures the lion population grew to about 177 in 1968, 180 in 1974, 200 in 1977 and 250 at present. Still much is needed for their conservation and they will need to be rehabilitated in other regions also.

7. Indian tiger (Fig. 3) The most famous animal of Indian Wild life is perhaps the tiger (*Panthera tigris*). It is famous for its phantom-like

Fig. 3.

grace, beauty, strength and courage. Since 1972 it has also become India's National Animal. It lives in a variety of habitats, throughout the country, from thorny jungles to dense Terai forests, even up to 3000 m altitude in the Himalaya. The tiger population of India was supposed to be not less then 40,000 in the beginning of twentieth century. But, unrestricted killing for trophies, skins, flesh and fat reduced their number to about 1,800 in early 1970s. To save them from extinction, a 'Project Tiger' was launched in 1973 by the Government of India with the assistance of the World Wild Life Fund (W.W.F.) under the instructions of Late Prime Minister Mrs. Indira Gandhi. Today, the project is in progress in 12 selected reserves in 17 states of India (Table 5). The tiger population in these reserves, estimated at 268 in 1972, has increased to 757 in 1982. It can be stated with confidence now that the tiger has been saved.

8. Indian rhino. The great Indian one-horned rhinoceros (*Rhinoceros unicornis*) was once extensively distributed in the plains of Indus river (Pakistan) and Ganges in Northern India. Temur once killed several of them with sword and spears on the frontiers of Kashmir. Babar once went to a hunting of rhinos which were then found in different parts of Northern India. Wanton hunting

***Table 5.* Showing Details of Tiger Reserves of India.**

	Tiger reserves	Year of establishment	Total area	State
1.	Bandhavgarh	1993-1994	1162	Madhya Pradesh
2.	Bandipur	1973-1974	866	Karnataka
	Nagarhole (extension)	1999-2000	643	Karnataka
3.	Bhadra	1998-1999	492	Karnataka
4.	Bori Satpura	1999-2000	1486	Madhya Pradesh
5.	Buxa	1982-1983	759	West Bengal
6.	Corbett	1973-1974	1316	Uttaranchal
7.	Dampo	1994-1995	500	Mizoram
8.	Dudhwa Katerniaghat	1987-1988	811	Uttar Pradesh
9.	Indravati	1982-1983	2799	Chhattisgarh
10.	Kalakad Mundanthurai	1988-1989	800	Tamil Nadu
11.	Kanha	1973-1974	1945	Chhattisgarh
12.	Manas	1973-1974	2840	Assam
13.	Melghat	1973-1974	1677	Maharashtra
14.	Nagarjunsagar-Srisailam	1982-1983	3568	Andhra Pradesh
15.	Namdapha	1982-1983	1985	Arunachal Pradesh
16.	Pakhui-Nameri	1999-2000	1206	Arunachal Pradesh
17.	Palamau	1973-1974	1026	Jharkhand
18.	Panna	1994-1995	542	Madhya Pradesh
19.	Pench (M.P.)	1992-1993	758	Madhya Pradesh
20.	Pench	1992-1993	257	Maharashtra
21.	Periyar	1978-1979	777	Kerala
22.	Ranthambhore	1973-1974	1334	Rajasthan
23.	Sariska	1978-1979	866	Rajasthan
24.	Simplipal	1973-1974	2750	Orissa
25.	Sunderbans	1973-1974	2585	West Bengal
26	Tadoba-Andhari	1993-1994	620	Maharashtra
27	Valmiki	1989-1990	540	Bihar

and reduction of natural habitat eliminated them in the west and restricted them to Nepal, Assam and some of the adjacent regions. Every part of its body has a surreptitious market. Its flesh and blood are considered highly acceptable food in Nepal and offered as libation. Urine is considered antiseptic and also used as a charm. But rhinos are mostly poached and killed for their horn which is alleged to be a strong aphrodisiac and an antidote for poison. A single horn of rhino fetches and exhorbitant one to one-and-a-half lakh rupees in some Asian countries. In 1904, only a dozen individuals were left in Assam and fewer in North Bengal. As a result of strict anti-poaching methods and conservation measures adopted, the rhinos have become around 1,654 in Kaziranga National Park (Assam) and seven other sanctuaries. Efforts are also being made to transfer them to other regions having suitable conditions.

9. Bison. Bison commonly known as Gaur is confined to India, Mayanmar and Malaya. In India it is found throughout the peninsula of India and as far as Assam. It requires unbroken forests and accommodates itself in either open or dune jungle. In Mandla district they are permanent resident of jungles north of the river Narmada. In this region they are found in the districts of Khandwa, Hoshangabad, Betul, Chhindwara, Seoni Chanda, Balaghat, Mandla, Bilaspur and Raipur. Some epidemic diseases (render pest and enteric virimea) caused death of individuals some years ago. Now a few animals are confined to Bandipur in Karnataka. Bison is a huge black animal. The legs are small to carry the heavy weight. The tail is short or a small back tassel. Both sexes carry horns. During the winter season, they are found in grass maidans and slopes of hills and in summer months they are found at low elevation near water resources. Their food consists of coarse grasses and they also eat the bark of a variety of trees. They also eat some fruits. The breeding season varies considerably in different regions. Newly born calves can be seen from first week of May to first week of October. The majority of breeding takes place in cold weather. Gestation period is 8-9 months. One or two calves are born at a time. They live in herds consisting of 8-12 individuals.

10. Wild buffalo. The wild buffalo of the genus *Bubalus bubalis* is distributed from the east of Assam in the plane or Brahamputra to eastern portion of Tara and thence into Midnapur and Orrisa. They are found in fair number in the forests of district Balaghat, Mandla, Raipur and Bastar. They prefer large grass plains with plentiful of water supply. In appearance the buffalow is a large black or scaly animal, much resembling the tame buffalo but it is much taller. Horns are black and triangular in section. The adult buffalo weights about 800 kg. They eat grass and lie in herd of 8-15 animals. They perfer to lie in water. Breeding starts in autumn. Gestation period is ten months.

11. Bear. It is a large black shaggy animal with a white horse shoe on his breast. It has hairless rums round his eyes and large dirty grey protruding lips and snout. The fore legs are bowed. The claws are white and extraordinarily powerful. They have short tail.

Bears breed in the hot weather and the 2-3 cubs are born after 7 months in the cold weather. At birth the cubs are blind for three weeks. They live in caves when the cubs are small otherwise they live in forests. They are noctural and move long distances in search of fruits, roots, flowers, tubers, berries, insects and honey.

They are distributed upto North Assam and in other parts of the country like Madhya Pradesh, Uttar Pradesh and wherever suitable condition exist.

12. Musk deer. The Himalayan musk deer, *Moschus moschiferous* was wide spread from Pakistan through N. India and Nepal to Bhutan, Mayanmar, Tibet and South West China. Now they are found in isolated pockets of Nepal and are near extinction. In India only 25% of the Oriental population is left which is confined to Jammu and Kashmir, Himachal Pradesh and Uttaranchal State (Kedarnath and Badrinath). Musk deer is hunted for musk gland or pod. However, it is not required to kill the deer for musk, it can be obtained without killing it with the help of injections. Musk is a precious article costing about 60,000-80,000 $/kg. Project musk deer was started in Kedarnath Sanctuary.

Sanctuaries and National Parks

Definitions

One of the best methods to save a wild life species, which is on the road to extinction, is to put it in a special enclosure to reproduce. This is best illustrated by sanctuaries and national parks whose legal definition varies from country to country. A *Sanctuary* or a *National Park* may be defined "as an area, declared by statute, for the purpose of protecting, propagating or developing wild life therein, or its natural environment, for their scientific, educational and recreational value."

The difference between a sanctuary and a national park is subtle and even confusing. Hunting without permit is prohibited and grazing or movement of cattle regulated in a sanctuary. But hunting and grazing are absolutely prohibited in a national park which may be established within or outside a sanctuary.

Famous national parks of world

The first national park in the world, the *Yellostone National Park*, was founded in 1872 in U.S.A. Since then, about 2,000 parks have been established all over the world. These offer protection to thousands of endangered species in their natural habitats. Some parks have been created for specific and very rare endangered species to be saved from extinction. Table 6 provides a list of some of such famous parks of the world.

Table 6. **Famous National Parks of World created for Specific Endangered Species.**

	Name of national park	Country	Specific endangered animal
1.	Alberta National Park	Congo, Africa	Mountain Gorilla
2.	Mt. Simien National Park	Ethiopia, Africa	Abyssinian Ibex or Steinbok
3.	Bontebok National Park	South Africa, Africa	Bontebok antelope
4.	Everglades National Park	Florida, U.S.A.	Puma
5.	Rifugio di Los Padres	California, U.S.A.	Californian Condor
6.	Ordesa National Park	Spain, Europe	Steinbok of Pyrenees
7.	Bialowieska National Park	Poland, Europe	Europian Bison
8.	Corbett National Park	Uttar Pradesh, India	Indian Tiger
9.	Dachigam National Park	Kashmir, India	Kashmir Stag
10.	Gir National Park	Gujarat, India	Asiatic Lion
11.	Kaziranga National Park	Assam, India	One-horned Rhinoceros
12.	Ghana bird sanctuary (Keoladeo National Park)	Bharatpur, Rajasthan, India	Avifauna

Indian sanctuaries and national parks

There area 493 existing wildlife sanctuaries in India covering an area of 117,291.03 km^2, which is 3.57% of the geographical area of the country. Another 217 sanctuaries are proposed in the Protected Area Network Report covering an area of 16,669.44 km^2. Maximum number of sanctuaries exists in size class less than 10 km^2 and there are only 2 sanctuaries, having more than 5,000 km^2. The network of sanctuaries will go up 709 after full implementation of the above report (Rodgers *et. al.*, 2002) (Table 7 and Figure 4).

Table 7. **Showing State-wise break up of Wildlife Sanctuaries.**

State/UTs	Area of state (km^2)	No. of WLS	Area covered (km^2)	% of state area
Andhra Pradesh	275068	22	12600.09	4.58
Arunachal Pradesh	83743	11	7606.37	9.08
Assam	78438	15	883.16	1.13
Bihar	94163	11	2949.17	3.13
Chhattisgarh	135194	10	3419.46	2.53
Goa	3702	6	647.96	17.50
Gujarat	196024	21	16422.72	8.38
Haryana	44212	9	279.92	0.63
Himachal Pradesh	55673	32	5770.85	10.37
Jammu & Kashmir	222235	15	10312.25	4.60
Jharkhand	79714	10	1862.75	2.34
Karnataka	191791	21	3888.22	2.03
Kerala	38863	12	2143.36	5.52
Madhya Pradesh	308252	25	7158.40	2.32
Maharashtra	307690	35	14376.66	4.67
Manipur	22327	3	393.30	1.76
Meghalaya	22429	3	34.20	0.15
Mizoram	21081	4	771.00	3.66
Nagaland	16579	3	20.34	0.12
Orissa	155707	18	6969.15	4.48
Punjab	50362	10	316.73	0.63
Rajasthan	342239	24	5712.83	1.67
Sikkim	7096	5	265.10	3.74
Tamil Nadu	130058	19	2539.82	1.95
Tripura	10486	4	603.62	5.76
Uttar Pradesh	240926	23	5222.47	2.17
Uttaranchal	53485	6	2395.52	4.48
West Bengal	88752	15	1203.28	1.36
		Union Territories		
Andaman & Nicobar	8249	96	377.95	4.58
Chandigarh	114	1	25.42	22.30
Dadra & Nagar Haveli	491	1	92.16	18.77
Daman & Diu	112	1	2.18	1.95
Delhi	1483	1	13.20	0.89
Lakshadweep	32	1	0.01	0.03
Pondicherry	493	0	0.00	0.00
India	3287263	493	117291.03	3.56

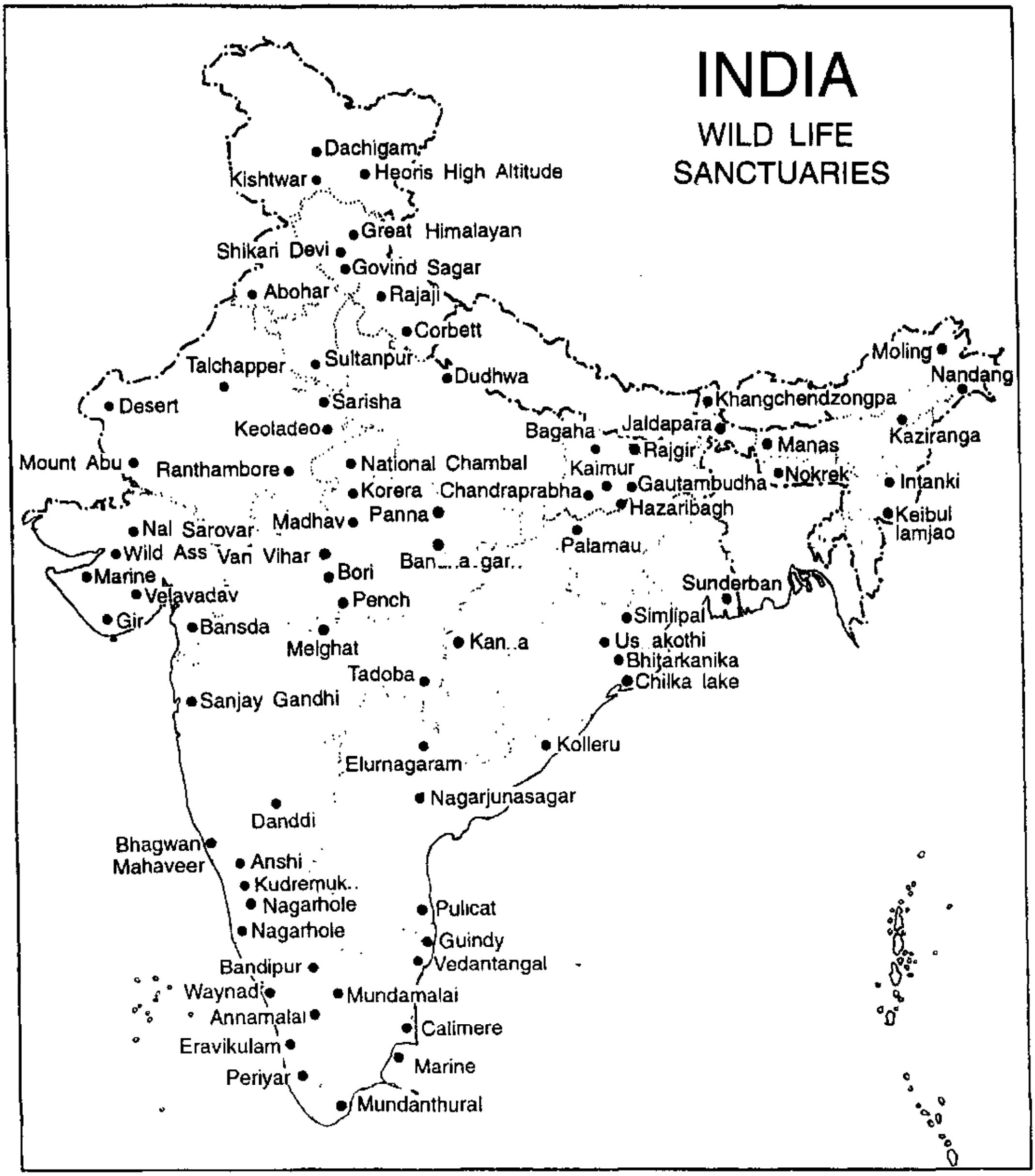

Fig. 4.

There are 89 existing national parks in India covering an area of 37,526.90 km^2, which is 1.14% of the geographical area of the country (National Wildlife Database, 2003). In addition to the above 74 national parks covering an area of 16,630.08 km^2 are proposed in the Protected Area Network Report (Rodgers *et. al.* 2002). The network of parks will go up 164 after full implementation of the above report. Maximum number of parks exist in size class less 100-500 km^2 and there are 7 parks, having more than 5,000 km^2 (Table 8 and Figure 5).

Table 8. Showing State-wise break up of National Parks of India.

State/UTs	Area of state (km^2)	National parks	Area covered (km^2)	% of state area
Andhra Pradesh	275068	4	373.23	0.14
Arunachal Pradesh	83743	2	2290.82	2.74
Assam	78438	5	1968.60	2.51
Bihar	94163	1	335.65	0.36
Chhattisgarh	135194	3	2929.50	2.17
Goa	3702	1	107.00	2.89
Gujarat	196024	4	479.67	0.24
Haryana	44212	1	1.43	0.00
Himachal Pradesh	55673	2	1429.40	2.57
Jammu & Kashmir	222235	4	4680.25	2.09
Jharkhand	79714	1	231.67	0.29
Karnataka	191791	5	2435.14	1.27
Kerala	38863	3	536.52	1.38
Madhya Pradesh	308252	9	3656.36	1.19
Maharashtra	307690	5	955.93	0.31
Manipur	22327	1	40.00	0.18
Meghalaya	22429	2	267.48	1.19
Mizoram	21081	2	250.00	1.19
Nagaland	16579	1	202.02	1.22
Orissa	155707	2	990.70	0.64
Punjab	50362	0	0.00	0.00
Rajasthan	342239	4	3856.53	1.13
Sikkim	7096	1	1784.00	25.14
Tamil Nadu	130058	5	307.84	0.24
Tripura	10486	0	0.00	0.00
Uttar Pradesh	240926	1	490.00	0.20
Uttaranchal	53485	6	4077.00	7.62
West Bengal	88752	5	1693.25	1.91
		Union Territories		
Andaman & Nicobar	8249	9	1156.91	14.02
Chandigarh	114	0	0.00	0.00
Dadra & Nagar Haveli	491	0	0.00	0.00
Daman & Diu	112	0	0.00	0.00
Delhi	1483	0	0.00	0.00
Lakshadweep	32	0	0.00	0.00
Pondicherry	493	0	0.00	0.00

However, a comprehensive list of various wild lives found in different sanctuaries and national parks are appended in Table 9.

Fig. 5.

Biosphere Reserves

UNESCO in 1971 started Biosphere Reserve Programme with following important objectives :

- Conservation of representative animal samples of the ecosystem.
- Provide long term *in situ* conservation of genetic diversity.
- Extend opportunities for education and training.
- Promote international co-operation.

It is one of the best methods for implementation of World Conservation Strategy. Upto 1985 there were 243 Biosphere Reserves world over in 65 different countries. Biosphere

Table 9. **Some Wild Life Sanctuaries and National Parks of India.**

	Name and location	Area in Sq. km.	Important animals found
1.	**Nagarjuna Sagar (Ikshawaka Sanctuary)** Guntur, Prakasham, Karnool, Mahbubnagar & Nalgonda Distt. Andhra Pradesh	3568	Tiger, panther, slothbear, wild bear, nilgai, chital, sambar, black buck, jackal, fox, wolf, muggar crocodile
2.	**Pulicat (Lake) Sanctuary** Nelore Distt., Andhra Pradesh	500	Flamingo, pelican, duck, teal, stork, crane, heron
3	**Kaziranga National Park** Sibsagar, Jorhat Distt., Assam	430	Rhinoceros, elephant, wild buffalo, gaur, sambar, swamp deer, hogdeer, wild boar, tiger, leopard, gibbon, python, pelican, stork, florican
4.	**Manas Sanctuary** Barpeta Distt., Assam	80	As in Kaziranga. Also wild dog, panther, golden langur, water monitor, great pied hornbill
5.	**Hazaribagh Sanctuary** Hazaribagh, Bihar	186	Tiger, leopard, hyaena, wild boar, gaur, samabar, chital, nilgai, peafowl
6.	**Palamau Sanctuary** Daltongunj, Bihar	980	Elephant, panthor, leopard, wild boar, barking deer, gaur, chital, sambar, peafowl
7.	**Kaimur Sanctuary** Rohtas, Bihar	1342	Tiger, leopard, chinkara, sambar, nilgai, crocodiles
8	**Gir National Park** Sasan-Gir, Junagarh Distt, Gujarat	1412	Asiatic lion, panther, striped hyaena, sambar nilgai, chital, 4-horned antelope, chinkara
9.	**Sultanpur (Lake) Bird Sanctuary** Gurgaon, Haryana	1.2	Wild boar, crocodiles, python, green pigeon Sarus crane, spot bill, ducks, ruddy shell
10.	**Dachigam Sanctuary** Srinagar, Jammu and Kashmir	89	Snow leopard, black & brown bears, hangul, musk deer, serow.
11.	**Shikari Devi Sanctuary** Mandi, Himachal Pradesh	213	Black bear, panther, snow leopard, goral, barking & musk deers, serow, flying fox, monal, chir, chukor, partridge
12.	**Govind Sagar Bird Sanctuary** Bilaspur, Himachal Pradesh	100	Teal, ducks, goose, crane
13.	**Bandipur National Park** Mysore Distt. Karnataka	874	Elephant, tiger, panther, wild boar, wild dog, sloth bear, gaur, barking deer, 4-horned antelope, sambar, chital, malabar squirrel, green pigeon
14.	**Periyar Sanctuary** Idukki Distt. Kerala	777	Elephant, tiger, panther, wild boar, wild dog, sloth bear, gaur, nilgai, sambar, barking deer, black nilgiri langur, grey hornbill, egret
15.	**Kanha National Park** Mandla & Balaghat, Madhya Pradesh	940	Tiger, panther, wild boar, wild dog, gaur, barasingha, sambar, chital, black buck, nilgai, barking & mouse deers
16.	**Tadoba National Park** Chandrapur, Maharashtra	116	Tiger, panther, sloth bear, gaur, sambar, chital, nilgai, chinkara, crocodiles.
17.	**Pench National Park** Nagpur, Maharashtra	257	Tiger, panther, sloth bear, gaur, sambar, chital, nilgai, chinkara, barking deer, peafowl
18.	**Bhitar Kanika Sanctuary** Cuttack, Orissa	170	Salt water crocodile, leopard, hyaena, chital, sambar, giant squirrel, water monitor, king cobra, python, storks, ibis.
19.	**Chilka Lake Bird Sanctuary** Balagaon, Orissa	900	Flamingo, pelican, egret, ibis, cormorant crane, duck, sandpiper, curlew
20.	**Simlipal Sanctuary** Baripad, Mayurbhanj, Orissa	303	Tiger, leopard, elephant, wild boar, gaur, sambar, mouse deer, flying squirrel, mugger.
21.	**Sariska (Project Tiger)** Alwar, Rajasthan	195	Tiger, panther, wild boar, hyaena, sambar, chinkara, nilgai, 4-horned antelope, langur
22.	**Keoladeo Ghana Bird Sanctuary** Bharatpur, Rajasthan	29	Siberian crane, storks, herons, cormorant, spoon bill, egret, ibis, etc., sambar, chital, boar, python

(Contd.)

	Name and location	Area in Sq. km.	Important animals found
23.	**Desert National Park** Jaiselmer, Barmer, Rajasthan	3000	Great Indian bustard, black buck, chinkara
24.	**Annamalai Sanctuary** Coimbatore, Tamil Nadu	958	Elephant, tiger, panther, sloth bear, wild dog, gaur, chital, sambar
25.	**Corbett National Park** Nainital Distt., Uttar Pradesh	525	Elephant, tiger, panther, sloth bear, wild boar, nilgai, sambar, chital, crocodiles, python, king cobra, peafowl, partridge.
26.	**Jaldapara Sanctuary** Madarihat, West Bengal	115.5	Rhino, elephant, tiger leopard, gaur, deers, sambar, variety of birds
27.	**Sajnakhali Sanctuary** 24-Parganas, West Bengal	362	Tiger, Wild boar, chital, storks, cormorant, herons, ibis, pelican, bittern, darter
28.	**Sundarbans (Tiger Reserve)** 24-Pargana, West Bengal	2585	Tiger, wild boar, deers, estuarine crocodile, gangetic dolphin

***Table 10.* Showing Biospheres Reserves of India.**

	Name of reserve	Date of established	Area (sq. km.)	State
1.	Nilgiri	1-9-86	5,520.00	Karnataka, Kerala, Tamil Nadu
2.	Nanda Devi	18-1-88	5,860.00	Uttaranchal
3.	Nokrer	1-1-88	80.00	Meghalaya
4.	Great Nicobar Islands	6-1-89	885.00	Andaman & Nicobar Island
5.	Gulf of Mannar	18-2-89	10,500.00	Tamil Nadu
6.	Manas	14-3-89	2,837.00	Assam
7.	Sunderbans	29-3-89	9,630.00	West Bengal
8	Simlipal	22-6-94	4,374.00	Orissa
9.	Dibru-Saikhowa	28-7-97	765.00	Assam
10.	Dehang-Debang	2-9-98	5,111.50	Arunachal Pradesh
11.	Panchmarhi	3-3-99	4,926.00	Madhya Pradesh
12.	Khangchendzongpa	7-2-2000	2,619.92	Sikkim
13.	Agasthyamalai	12-11-2001	1,701.00	Kerala

Reserve includes natural, least disturbed, man-modified degraded ecosystems. Biosphere reserves are divided into different zones for management purposes :

1. Core zone. Representing natural and least disturbed ecosystem.

2. Manipulation zone I. Includes man made forests and felling areas.

3. Manipulation zone II. Includes area marked for tourism, education, training and research activities.

4. Manipulation zone III. Includes tribal settlements and agriculture activity lands.

5. Restoration zone. Includes degraded areas, selected for restoration to natural or equal conditions.

In India first biosphere reserve was established in 1986, *Nilgiri Biosphere Reserve* having area of 5520 km. The second biosphere reserve was established in 1988, *Nanda Devi Biosphere* reserve. In this very year (1988) third reserve, Nokrek was set up. Till 2001 following biosphere reserves were established as shown in Table 10 and Fig. 6.

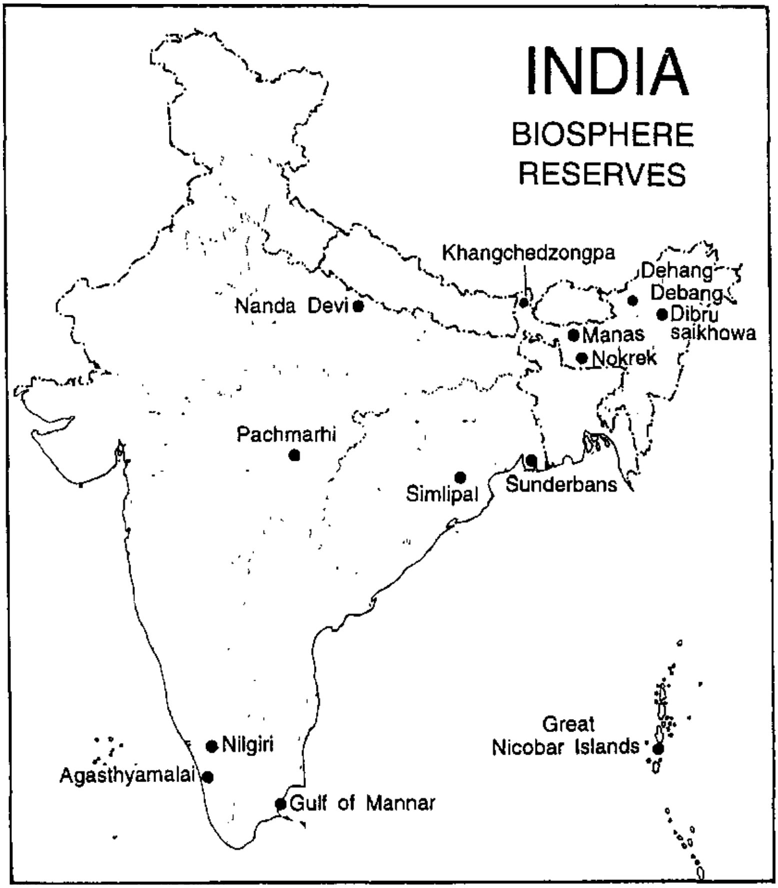

Fig. 6.

Zoological Gardens and Museums

Several zoological gardens and museums were also established to conserve the species in their wild state, to provide scientific educational and recreational opportunities and to earn revenue. Some important zoological gardens and museums of India are shown in Table 11 and Fig. 7.

1. **Natural history museum, Mumbai** has excellent collection of animals, particularly fishes and birds.

2. **Zoological garden.**

3. **Tarapore varsova aquarium Mumbai** attached to sea and has beautiful collection of marine fishes and crustaceans.

4. **Indian museum Kolkata** is biggest in India.

5. **Zoological garden Kolkata** is famous for talking parrots.

6. **Zoological garden,** has good species collection.

7. **Zoological garden, Delhi, Lucknow, Kanpur** has some rare species of animals.

8. **Geological museum, ISI, Kolkata** is known for complete skeleton of Indian Dinosaurs.

9. **Zoological garden Hyderabad** has rich collection of lions, tigers, crocodiles and monkeys.

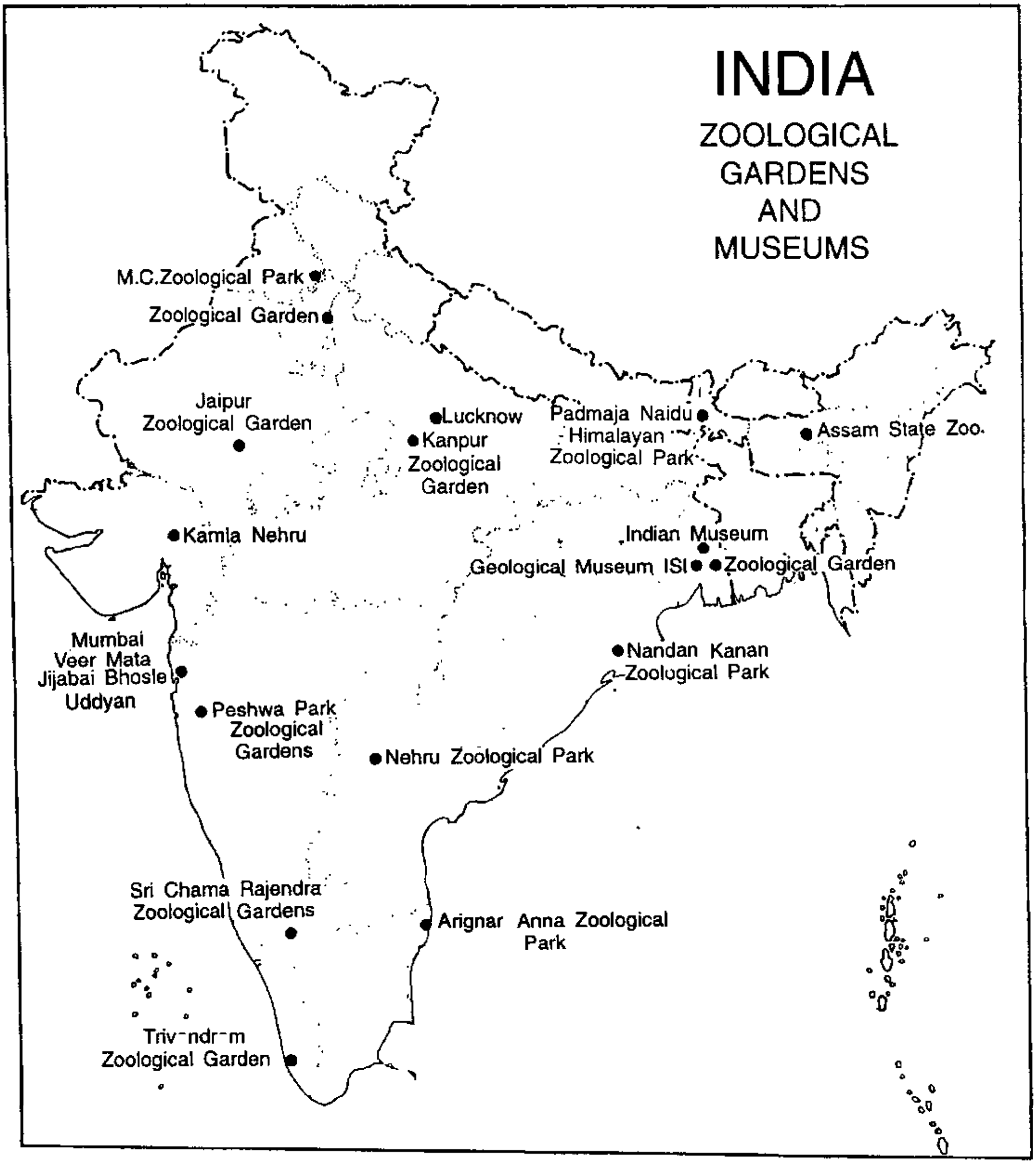
INDIA
ZOOLOGICAL GARDENS AND MUSEUMS
M.C.Zoological Park
Zoological Garden
Jaipur Zoological Garden
Lucknow
Kanpur Zoological Garden
Padmaja Naidu Himalayan Zoological Park
Assam State Zoo.
Kamla Nehru
Indian Museum
Geological Museum ISI
Zoological Garden
Mumbai Veer Mata Jijabai Bhosle Uddyan
Nandan Kanan Zoological Park
Peshwa Park Zoological Gardens
Nehru Zoological Park
Sri Chama Rajendra Zoological Gardens
Arignar Anna Zoological Park
Triv-ndr-m Zoological Garden

Fig. 7.

Table 11. **Showing Some Indian Zoological Gardens and Museums.**

Zoo	Locality	Town
Kamla Nehru Zoological Gardens	Kankaria	Ahmedabad
Nandankanan Zoological Park	Shaeed Nagar	Bhubaneswar
Veermata Jijabai Bhosle Udyan	Byculla	Mumbai
Natural History Museum	-	Mumbai
Zoological Garden	-	Mumbai
Tarapore Varsova Aquarium	-	Mumbai
Kolkata Zoological Garden	Alipore	Kolkata
Indian Museum	-	Kolkata
Geological Museum	-	Kolkata
M. C. Zoological Park	Chhat-Bir	Chandigarh
Padmaja Naidu Himalayan Zoological Park	Darjeeling	Darjeeling
Delhi National Zoological Park	New Delhi	New Delhi
Assam State Zoo	Guawahati	Assam
Nehru Zoological Park	Hyderabad	Hyderabad
Jaipur Zoological Gardens	Jaipur	Jaipur
Sakkarbaug Zoo Junagadh	Junagadh	Junagadh
Kanpur Zoological Park	Azadnagar	Kanpur
Angnar Anna Zoological Park	Chennai	Chennai
Zoological Garden		Chennai
Sri Chamarajendra Zoological Gardens	Indirinagar	Mysore
Peshawe Park Zoological Gardens	Peth	Pune (Poona)
Trivandrum Zoological Gardens	Trivandrum	Trivandrum

Wild Life Organizations

In recent years man has interfered with nature as never before. He has destroyed forests, drained swamps, polluted rivers and oceans and annihilated whole species of animals. In the beginning of this century, a realization dawned that the presence of wild fauna in the human environment is of great importance for the quality of life and survival of man himself.

1. I.U.C.N. With the birth of the protectionist, conscience, an international scientific organization was formed in 1948 with headquarters at Morges in Switzerland. It is called the *International Union for the Conservation of Nature and Resources* (IUCN).

2. W.W.F. The *World Wild Life Fund* (WWF), international, was founded in 1961, and, like the IUCN, based at Morges in Switzerland. Its principal goal is to collect and distribute funds for wild life conservation operations throughout the world. A sort of United Nations, it embraces hundreds of organizations all over the world. Its multifarious activities deal with education and training with propaganda and publicity, and with conservation itself. The *World Wild Life Fund*, (W.W.F.) India, was launched in 1969, with headquarters at Bombay. The same year, the W.W.F. also launched the 'Project Tiger' India. It was most spectacular and the biggest ever single largest conservation compaign of its kind in the world.

3. Red Data Books. These are directories and schemes compiled by the IUCN. They provide uptodate information about the animal species which are rare or in danger of extinction.

4. I.B.W.L. In 1952, the Government of India constituted an advisory body on country's wild life, called the *Central Board for Wild Life*. Later, it was named as the *Indian Board for Wild Life* (IBWL). Several Indian states followed by forming their own *Wild Life advisory Boards*.

5. B.N.H.S. The Bombay *Natural History Society* is a non-government organization dedicated to the cause of wild life conservation in the country. It was founded by 7 resident of Bombay in 1881. The society conducts research and educational activities and field work and brings out a journal on the wild life of India.

6. W.P.S.I. The *Wild Life Preservation Society of India* is also a non-government body. It was founded in 1958, at Dehradun. The society conducts tours of students and members to nearby sanctuaries and parks, carries out research on vanishing flora and fauna, organizes a Corbett Memorial Essay Competition for school students, and bring forth a bilingual quarterly journal, called *Cheetal*.

Wild Life Institute of India

To train people and expand the activities in wild life, Government of India has established a wild life institute of India at Dehradun. This institute is engaged in Management and extension of wild life. It runs several courses at post graduate level along with diploma and other short term courses in specialized fields. As a result of training by this institute a number of trained persons are now engaged in conservation and extension of wild life in India.

Methods of Wild Life Conservation

The most commonly adopted methods for the conservation of wild life, in brief, are as follows :

1. Habitat management. This includes ecological study of the habits and habitats of wild life species, protection, preservation and improvement of habitats, census and statistical data regarding species to be conserved, etc.

2. Establishment of parks, reserves and sanctuaries. The establishment of National Parks, Wildlife Reserves, Sanctuaries, Zoological Gardens etc., serves many purpose : (i) to conserve the species in their wild state, (ii) to provide scientific, educational and recreational opportunities, and (iii) to earn revenue by attracting tourists.

3. Breeding in captivity. Tree species, such as ginko and metasequoia, have survived only in captivity. Mountain Gorilla is protected in the National Park of Alberta. Tiger, White Tiger and Indian Lion today live in national parks. The European Bison, saved at the eleventh hour, survives in the National Park of Biolowieska in Poland. Similarly Pere David's Deer, Whooping Crane, Hawaiian Goose, Parma Wallaby and Arabian Gazelle, once threatened with extinction, are considered to be already 'on the way back,' as a result of captive breeding.

4. Reintroduction. Several animal species which were almost extinct, such as the Arabian Oryx, Vicuna of High Andes. Russian antelope or Saiga, Trumpeter Swan, Black Buck, Flamingos, etc. were allowed to reproduce and flourish in suitable places similar to the original ones. Later these were reintroduced in several parks and sanctuaries and areas of their original natural habitats.

5. Mass education. For any conservation programme, there is a great need of education to the people to achieve their participation. The methods adopted are : (i) celebration of wild life week every year, (ii) publicity through media and film shows, (iii) holding conducted tours, essay competitions, lectures, seminars, etc., (iv) setting up nature clubs in educational institutions, (v) publication of wild life books and journals, (vi) establishment of Natural History Museums, etc.

6. Promulgation of laws. All countries have promulgated laws for the protection and conservation of Wild Life. In India, comprehensive central legislation was enacted in 1972, called 'The Wild life (Protection) Act, 1972'. Killing, capturing and hunting of wild life without prior permission from suitable authority, and poaching have become punishable under the law. In 1976, 42nd amendment in the Indian constitution, protection of wildlife have been included in concurrent list. Further amendment in law is required for heavier and deterrant punishment to poachers.

Problems of Wildlife Management in India

Mitra (1980) pointed out that management of wild life in India is beset with several problems. The most important of which is that people living near forest do not know the value of conservation of nature. Government is hard pressed with steady increase in human population, superstitions and illiteracy among general mass. Due to all this government is bound to take projects to accommodate these people, boot industries, hydroelectric projects, construction of reservoirs etc. In addition to these, cultivation of cash crops like tea, coffee, rubber, eucalyptus etc. has also disturbed the normal ecological set up significantly for wild life.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. What do you understand by wild life ? What are its values for man kind ?
2. "Wild life is an asset to be protected and preserved to our own advantage and to benefit future generations" Discuss.
3. What are sanctuaries and national parks ? Give a detailed account of wild life of your state.
4. Write essay on — (i) Vanishing wild life of India (ii) Methods of conservation of wild life, (iii) Wild life organizations.

» *Short Answer Type Questions*

1. Write notes on — (i) Importance of wildlife, (ii) Vanishing wild life, (iii) Importance of Indian wildlife, (iv) Zoological gardens and museums, (v) Biosphere reserves, (vi) Musk deer, (vii) Project tiger.

» *Multiple Choice Questions*

1. Which of the following is national animal of India ?
   (a) Elephant (b) Deer
   (c) Bear (d) Tiger
2. Crocodile project is in which of the following state ?
   (a) Uttar Pradesh (b) Bengal
   (c) Madhya Pradesh (d) Assam
3. Armadillo contributed to the development of vaccine for :
   (a) Tuberculosis (b) Hepatitis B
   (c) Aids (d) Leprosy
4. Periyar wild life sanctuary, situated in which state?
   (a) Uttar Pradesh (b) Meghalya
   (c) Kerala (d) Manipur
5. In India first biosphere reserve was established at :
   (a) Nanda Devi (b) Nilgiri
   (c) Corbett national park (d) Manas
6. Project tiger was launched in India in :
   (a) 1973 (b) 1975 (c) 1978 (d) 1990
7. In which of the following national park Indian rhino is conserved :
   (a) Corbett national park
   (b) Kajiranga national park
   (c) Manas sanctuary
   (d) Kaimur sanctuary

ANSWERS

1. (d) 2. (a) 3. (d) 4. (c) 5. (b) 6. (a) 7. (b).

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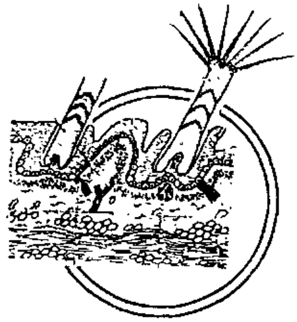

Integument and its Derivatives in Vertebrates

Comparative Anatomy, its Meaning and Purpose of Study

Study of the structure of animals is termed *anatomy*, whereas a comparative study of structure of different animal groups, or animals, is known as *comparative anatomy.* In fact the study of comparative anatomy is more purposeful and dynamic than mere study of the location and structure of different organ systems in different animals. It also determines the phylogenetic origin and modification of their various homologous structures. In a sense, it is the history of the struggle of animals, striving for compatibility with an ever changing environment in the past. Despite their differences, all vertebrates, past as well as present, are built according to the same basic architectural plan. Thus, comparative study of various homologous vertebrate structures offers special evidence in support of the doctrine of organic evolution with the premise that species have been changing.

Integument or Skin

Definition. The term *integument* is applied to the outermost protective covering of the animal body, the *skin*, and its various *derivatives*. Skin also includes the conjunctiva of eyeballs and external surface of eardrums. It is directly continuous with the mucous epithelial lining of mouth, rectum, nostrils, eyelids and urinogenital ducts.

[I] Functions of integument

The integument or skin of vertebrates is truly a 'jack-of-all-trades' since it performs several important functions —

1. Protection. The integument or skin separates the animal from its external environment and helps to maintain a constant internal environment. It has several protective devices—

(1) It protects the body against a variety of mechanical and chemical injuries which may result from pressure, friction, blows, harmful gases and fluids.

(2) Protective derivatives such as scales, bony plates, fat, feathers, hairs, etc. reduce the force of injury, prevent excessive loss of body moisture and do not allow entry of harmful bacteria and fungi, and other foreign bodies.

(3) Pelage (fur), plumage (feathers), bristles or spines, claws, nails, hoofs, antlers, horns, etc. serve for offence and defence.

(4) Protective colouration or camouflage serves to escape detection by enemies.

(5) Skin pigments also protect against solar radiation.

2. Locomotion. Dermal fin rays in the fins of fishes and skin webs in the feet of frogs, turtles, aquatic birds, etc., help in swimming in water. Adhesive pads (Amphibia) and claws (amniotes) on digits assist in climbing. Feathers on wings and short tail of birds and cutaneous patagia or wings of bats and flying lizards and squirrels help in flying.

3. Dermal endoskeleton. Skin contributes to bony dermal armour such as in extinct ostracoderms and placoderms and living sturgeons, crocodiles and turtles. Dermal endoskeleton in head, shields the brain and sense organs. Elsewhere it prevents compression of soft internal organs and also forms parts of teeth.

4. Secretion. Skin glands secrete substances having several uses. (i) Mucous glands in aquatic forms (e.g., fish, frog) keep the skin moist and slippery. (ii) Poisonous, bitter or offensive secretions ward off potential enemies. (iii) Uropygial glands in birds secrete oil for preening feathers. (iv) Oil from sebaceous glands of mammals lubricates the skin and hairs. Moreover, *sebum* contains *fatty acids* and *lactic acids* in it which bring down the pH of skin to 3-A and creates a hostile environment for growth, multiplication and survival of microbes. (v) Mammary glands manufacture milk for nourishment of the young. (vi) Odours of scent glands attract the opposite sex. (vii) Tears from lacrymal glands wash the conjunctiva of mammalian eye ball. (viii) Glands of auditory meatus secrete an carwax, the cerumen, to grease eardrums and to entrap insects that enter the canal.

5. Food storage. Thick fatty layer of blubber under skin of seals and whales serves as insulation as well as reserve food. Animals also accumulate subcutaneous fat prior to hibernation and migration.

6. Temperature control. In warm-blooded animals, fur, feathers and scales insulate and conserve body heat in cold climate. Sweat glands of mammals provide cooling by evaporation in summer. For elimination of heat, integumentary blood vessels dilate so that skin becomes a radiator. For conservation of heat, the vessels constrict. These devices help in homoiothermy or in the maintenance of constant body temperature.

7. Excretion. Excess of water, salts and urea are also eliminated in sweat. Gills of marine fishes contain chloride-secreting cells. Shedding of skin during ecdysis also gets rid off of some metabolic wastes.

8. Sensation. Cutaneous nerve endings and other sense organs are stimulated by touch, pain, changes in pressure and moisture, extremes of heat and cold and chemicals, etc. In their absence, these animals may starve or destroyed by an enemy.

9. Sexual selection. Brilliantly coloured skins, antlers of male deer, long tail coverts of peacock, etc. lead to sexual dimorphism and also serve to attract the females for mating.

10. Miscellaneous. Skin has many other functions not cited above. (i) Vitamin D is synthesized in mammalian skin from sebum of sebaceous glands in ultra-violet light. (ii) Brood pouches under the skin of some fishes and amphibians protect unhatched eggs. (iii) Nasal glands of tetrapods keep nostrils free of water and dirt. (iv) Amphibians and other aquatic animals carry on considerable respiration through their richly vascular skin. (v) Skin shows selective absorption of oils, ointments, iodine, beneficial sun-rays, etc. (vi) Special types of enzymes are produced by larvae of some fishes and frogs.

[II] Structure of integument in general

The skin of all vertebrates is built according with the same basic plan. It is multicellular and differs from that of the invertebrates in having two layers— (i) an outer *epidermis* developed from ectoderm, and (ii) an inner *dermis* derived from the mesoderm. The related abundance of the two layers differs according to the environment.

1. Epidermis. Epidermis is a stratified epithelium and normally quite thin in comparison to dermis. It is further distinguished into two regions— (i) The outermost region of many layers of dead usually flattened (squamous) cells forms a horny, resistant covering or *stratum corneum* on the skin surface. Its cells accumulate a horny protein, called *keratin*, gradually die and eventually wear off in the form of scurf or dandruff. Since keratin is tough and insoluble in water, the keratinized stratum corneum provides protection against mechanical injuries, fungal and bacterial attacks and loss of body moisture. (ii) The innermost or basal region of epidermis includes a single row of living columnar cells, the *Malpighian layer* or *stratum germinativum*, which is separated from the underlying dermis by a basement membrane. Its cells actively divide and continually replace the worn out cells of the cornified layer.

Epidermis is thin in aquatic vertebrates and rich in mucous glands. It is thicker in land vertebrates and structures such as scales, feathers, hairs, nails, claws, horns and enamel of teeth are derived from its Malpighian layer.

2. Dermis. Dermis or *corium*, which is the inner layer of skin, is comparatively thicker than epidermis. It is composed of fibrous connective tissue and contains many blood capillaries, lymph vessels, muscle fibres, nerve fibres, sense organs and elastic fibres which bring the skin back to its normal shape. Pigment cells or *melanocytes* are mostly located in dermis, although sometimes pigment granules are also found in epidermis. Fat may accumulate as reserve food in special cells, called *adipocytes*, in deeper parts of dermis and in the subcutaneous tissue.

Derivatives of Integument

The skin itself is relatively simple but its derivatives are numerous and complex. Depending on the layer of skin from which they are derived, these structures fall under two broad categories : *epidermal* and *dermal*.

1. Epidermal derivatives. These are formed by the epidermis and comprise : (i) *epidermal glands* and (ii) *hard horny structures* including *epidermal scales, scutes, beaks, horns, claws, nails* and *hoofs, feathers* and *hairs*, etc. All the hard horny structures together form the *exoskeleton* of an animal.

2. Dermal derivatives. These arise from dermis and comprise *bony* or *dermal scales*, *plates* or *scutes, fin-rays* and *antlers*, etc.

[I] Epidermal glands

Integumental or epidermal glands are formed by the Malpighian layer of epidermis. They arise in epidermis but often invade the dermis. They may be unicellular or multicellular, tubular or alveolar in shape, and simple, compound or branched. They are lined by cuboidal cells or columnar epithelium. They are usually named after their nature or function. The 9 major types described below are : mucous, poison, luminescent, femoral, uropygial, sweat, sebaceous, scent and mammary.

1. Mucous glands. They secrete *mucin* which forms slimy or sticky mucous on coming in contact with water. Mucous keeps the skin moist and slippery and protects against harmful bacteria and fungi. They are abundant in amphibian skin. They may be unicellular or multicellular eg., granular cells, beaker cells of amphioxus, cyclostomes, fishes etc.

2. Poison glands. Many fishes and amphibians have poison glands. These are modified multicellular cutaneous glands, larger but fewer than mucous glands. The parotid glands behind the head of toads are aggregations of poison glands. Secretion of poison glands may be bitter, irritating and even dangerous to the predators. Poison glands of amphibians are granular glands collected into masses called, *Parotid glands*. The poison secreted by it is *alkaloid* and similar in action like digitalis.

3. Luminescent glands or photophores. In deep sea luminous teleost fishes, certain multicellular epidermal glands serve as light-emitting organs, known as *photophores*. In one type of photophore, the superficial layer of mucous cells forms a magnifying lens, lower or basal part consists of luminous cells surrounded below by reflecting pigment cells. The reflector is made of *guanine* crystals. Light emitted is not intense, may be of many hues, and serves to attract preys. They can be flashed on and off, by *sympathetic nerves*. Injections of *adrenaline* produce flashes in some species like *Spinax*.

4. Femoral glands. These are found in male lizards (e.g. *Uromastix*) on the ventral surface of each thigh, in a single row 12-18 *femoral pores* from knee to cloacal aperture. Their sticky secretion hardens in air to form temporary tiny spines that serve to hold the female during copulation.

5. Uropygial gland. It is one of the few integumentary glands found in birds, forming a prominent swelling just above the tail or uropygium. It is branched and alveolar and exudes an oily secretion used for lubricating beak, preening feathers and attracting the opposite sex during breeding season due to odoriferous nature. The oil secreted by it contains *pomatum* which is picked up by beak and used for preening and water proofing.

6. Sweat glands. Sweat glands or sudoriferous glands (*sudor* = sweat) are abundant in the skin of most mammals. They are slender coiled tubes embedded deep in the dermis, with their long ducts opening on skin surface. A little urea and some salts are eliminated dissolved in water in the sweat produced by these glands. Evaporation of watery perspiration also helps to cool and regulate body temperature in hot environments.

Sweat glands are absent in spiny scaly anteaters and marine forms such as Sirenia and Cetacea. In many mammals their distribution is restricted. They may occur only on the soles of feet (cats and mice), lips (rabbits), muzzle and skin between toes (ruminants), sides of head (bats), ears (hippopotamus), etc. Male giant Kangaroo (*Macropus rufus*) and hippopotamus secrete red-coloured sweat. *Ciliary glands* in eyelashes and along margins of eyelids are modified sweat glands.

7. Sebaceous glands. These are branched alveolar glands opening into hair follicles of mammals. They may open directly onto skin surface such as around the genital organs, tip of nose or edges of lips. Their oily secretion, called *sebum* (=grease), keeps the skin and hairs soft, greasy, water-proof and glistening.

Sebaceous glands absent in pangolins and marine mammals (Sirenia, Cetacea) which are practically devoid of hairs. *Ceruminous glands* of external ear canals are modified sebaceous glands. Their waxy or greasy secretion, called *cerumen*, helps trap insects or dust particles. Similarly, *meibomian glands* of eyelids, which spread their oily secretion over the exposed surface of eyeball, are modified sebaceous glands.

8. Scent glands. These are modifications either of sebaceous or sudoriferous glands of mammals. Their odorous secretions serve to repel foes or attract members of opposite sex. Scent glands may occur between toes on feet (goat, rhino, horse), near eyes on head (deer family), navel on abdomen (musk deer), mid-dorsally on back (Kangaroo rats *Dipodomys*), around anus (skunks, many carnivores and rodents), etc.

In a zoo, many foul odours may not be due to unhygienic conditions but caused by the scent glands of mammals in the pens and cages.

9. Mammary glands. Characteristic of mammals, these are compound tubular glands that produce milk during lactation period for feeding the young ones. Usually they occur only on females, but are also present on males in monotremes, primates and some others. In monotremes, the mammary glands lack nipples or teats and resemble modified sweat glands. In other mammals, they possess nipples and are modifies sebaceous glands.

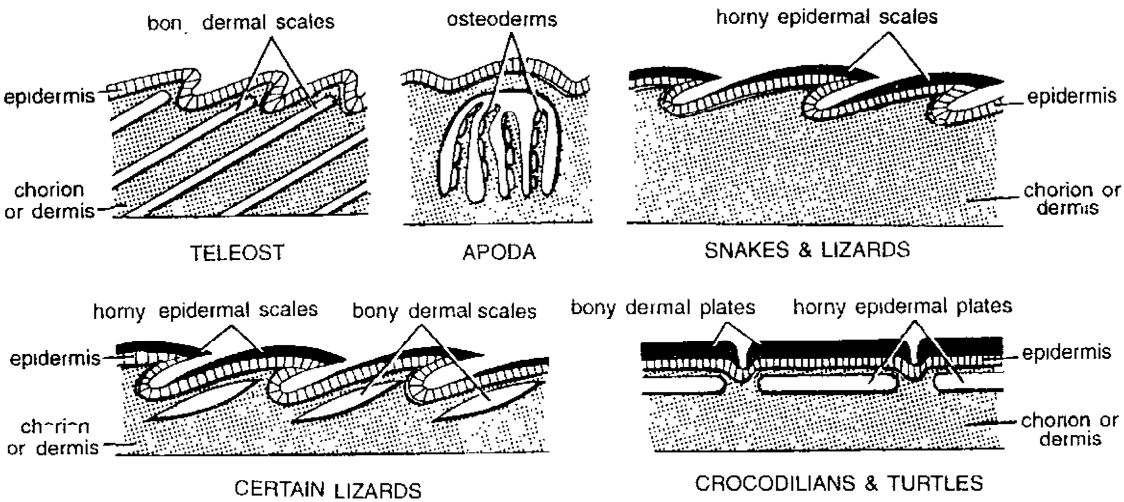

Fig. 1 Diagrammatic V.S through skins of various vertebrates showing relationship of various types of scales.

Distribution and number of mammary glands and nipples vary with the species. A *nipple* is a raised conical or elongated elevation of body surface bearing the opening of milk gland. In *true teats* (man, apes), ducts of mammary glands open separately on the nipple. In *false teats* (ungulates), all ducts empty into one cistern from which a single tube leads to the tip of the nipple.

[II] Epidermal scales and scutes

All the hard horny structures develop by the accumulation of a scleroprotein, known as *keratin*, in the cells of epidermis. Such cells are said to be keratinized or cornified, and they become dead. All stratum corneum cells are cornified and form hard horny exoskeletal structures like scales, beaks, horns, claws, nails, hoofs, feathers, hairs, etc. in different vertebrates.

Reptiles have a continuous outer covering of horny epidermal scales that prevents water loss through skin surface. In lizards, scales are thin, small, overlapping and periodically moulted in small pieces. In snakes also the scales are overlapping, enlarged on head, called *shields*, and on ventral surface, called *scutes*, which aid in locomotion. In most snakes and some lizards, the stratum corneum of entire body is periodically shed in one piece at the time of ecdysis or moulting. Crocodilians and turtles have large, thick, rectangular *scutes*, not overlapping but touching each other, and supported beneath by dermal bones. Scutes of crocodilians are sloughed or shed in patches at intervals. The toothless horny *beak* of turtles, the *rattle* at the end of the tail of rattle snakes and *horns* of the horned toad (a lizard) are other modifications of stratum corneum in reptiles.

In birds, small epidermal scales are present on the lower leg, foot and base of beak. The sheath of beak (*rhamphotheca*) is also a modification of stratum corneum.

Reptile-like epidermal scales occur in some mammals also, such as on the feet and tails of rats and beavers, etc. The *large scales* on the body of a scaly anteater undergo ecdysis individually. In armadillos, large body scales become fused into *plates* and *bands*. They are supported beneath by dermal bony scales and do not moult.

[III] Dermal scales and scutes

Bony structures develop within the dermis and are mesodermal in origin (Fig. 1). Thick bony scales and plates formed a heavy armour in the extinct ostracoderms. But they have been retained in reduced form in most living fishes, reptiles and others. In contrast to the horny epidermal scales, the bony dermal scales are not shed but increase in size during life by the addition of new bone.

1. Dermal scales of fishes. As mentioned above bony or dermal scales develop in the dermis. In fishes, the overlying epidermis wears off so that the scales become exposed forming the *exoskeleton.* Five types of dermal scales are known, depending on their structure, in fishes. (i) *Cosmoid* scales occurred in extinct lobe-finned fishes (Crossopterygii). (ii) *Placoid* scales are characteristic of elasmobranchs (Chondrichthyes). (iii) *Ganoid* scales are present in ganoid fishes (chondrosteans and holosteans). (iv) *Cycloid* and (v) *Ctenoid* scales are characteristic of modern teleosts. For more details, readers may refer to Chapter 18 and Figure 5.

2. Dermal scales and scutes of tetrapods. Dermal scales or bony plates measuring 1 to 2 mm, called *osteoderms,* are found embedded in the pockets of dermis below epidermis, in some caecilians or Apoda (Amphibia). They also occur in the back of some tropical toads.

In addition to epidermal scales and scutes, reptiles also retain traces of bony dermal armour of their ancestors. A few lizards exhibit small *dermal scales.* Crocodiles and alligators have many oval *bony plates* embedded in the dermis of their back and neck. In turtles, below horny epidermal scutes, are present large *bony plates* or *osteoderms,* forming a box-like continuous rigid dermal skeleton around trunk and including a dorsally arched *carapace* and a ventral flattened *plastron.*

Amongst mammals, bony plates or osteoderms occur in armadillos and whales.

3. Dermal fin rays. Supporting the fins of fishes are long, flexible fin rays embedded in dermis. In Chondrichthyes, they are horny, hair-like, made of fibrous connective tissue and called *ceratotrichia* (*cerato* = horn + *tricho* =hair). In Osteichthyes, they are branched, made of a series of segments or scales, and called *lepidotrichia* (*lepido* = scale). Unsegmented, sharp and spine-like fin rays are termed *actinotrichia.*

[IV] Digital cornifications

All digital cornifications, that is, claws, nails and hoofs, are built on the same plan (Fig. 2). They are modification of stratum corneum at the tips of digits and grow parallel to the skin.

1. Claws. Claws of reptiles, birds and mammals are identical in structure. A claw is made by a hard, pointed, narrow, curved, horny dorsal plate, called *unguis,* and a less hard ventral plate, called *subunguis,* both enclosing the tip of the digit covering the last tapering phalanx.

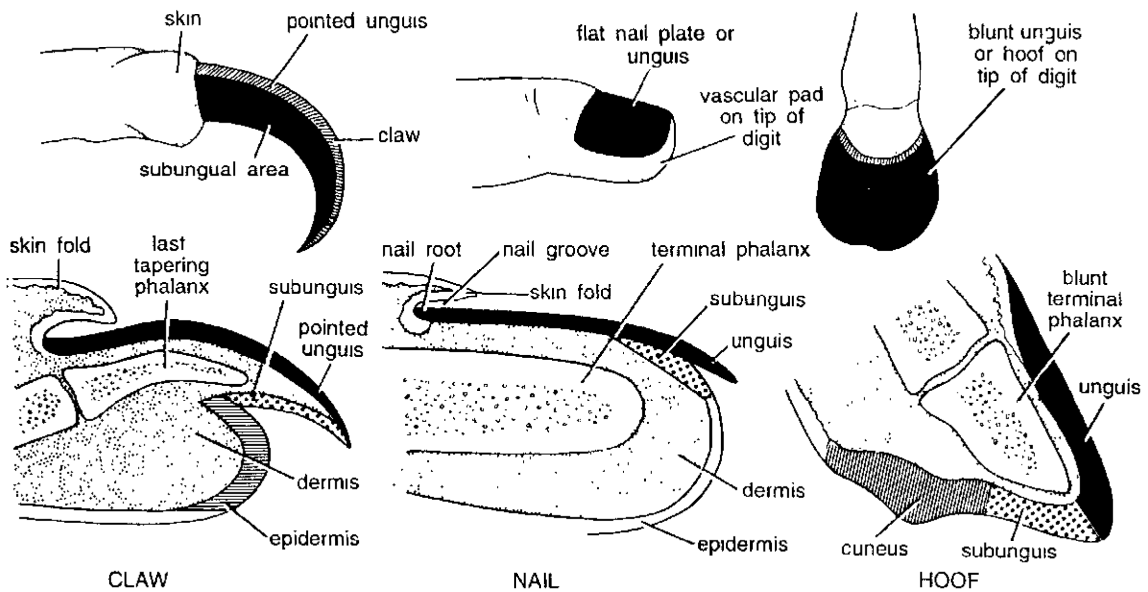

Fig. 2. Relation between claw (eagle), nail (human) and hoof (horse). Digital tips shown complete above and in sagittal sections below

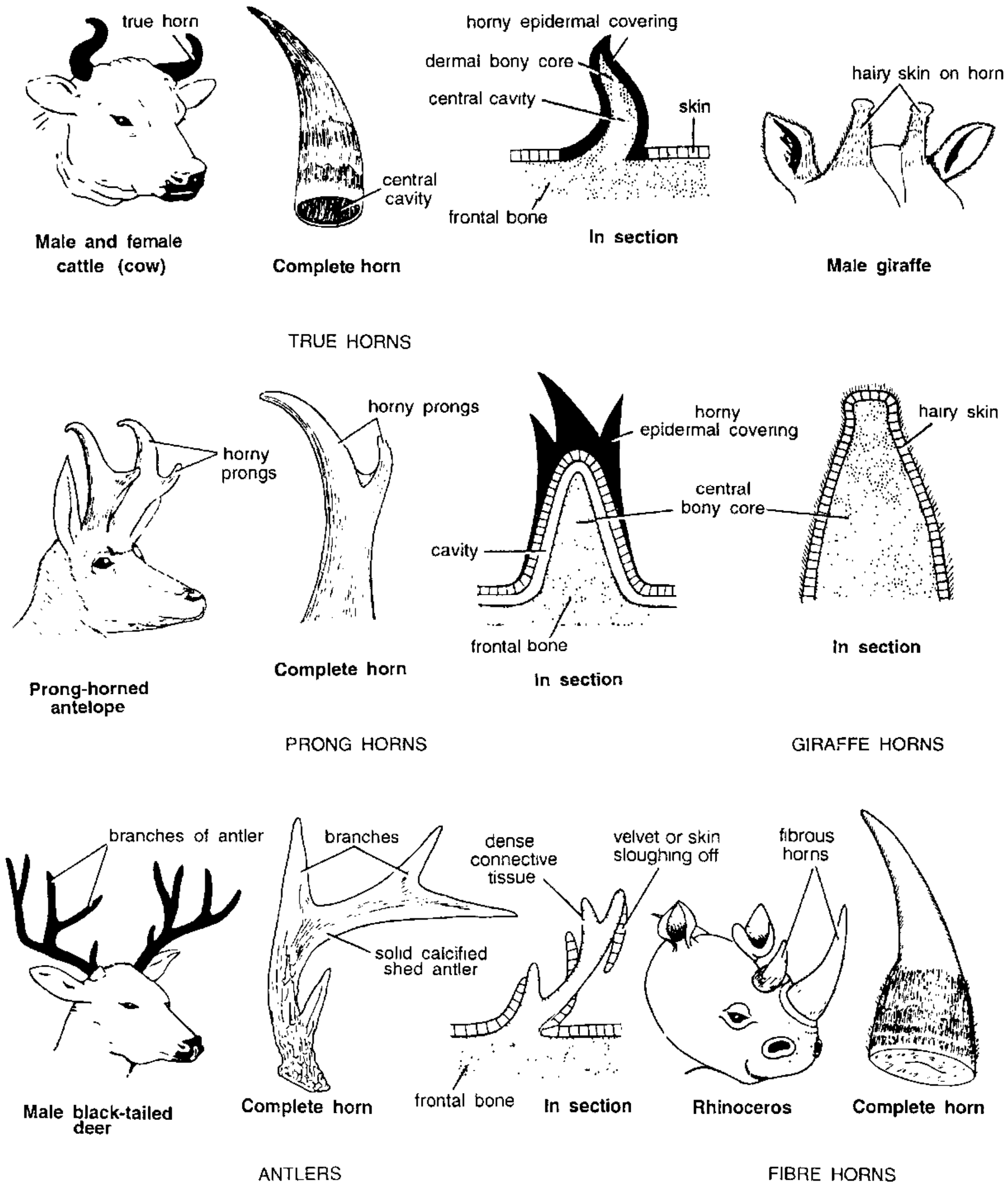

Fig. 3. Types of mammalian horns and antlers.

2. Nails. Claws are modified into nails which are characteristic of Primates (mammals). Dorsal plate or unquis is broad and flat, while subunguis is softer and much reduced. The tip of the digit forms a greatly sensitive and highly vascular *pad* over which the epidermis invaginates to form a *nail groove* containing the nail root.

3. Hoofs. Hoofs are characteristic of ungulates (hoofed mammals). The horny unguis is neither pointed nor flat, but U- or V-shaped. Subunguis is also U-shaped, greatly thickened and touching ground. The horse's shoe can be nailed into it. Subunguis surrounds a softer horny substance, the *cuneus*. The tip of digit forms a pad and contains a blunt phalanx.

Other modifications of stratum corneum include the *whalebone plates* of toothless whales, and the *horny coverings* of horns of sheep and cattle and prong horns of antelopes.

[V] Horns

Horns are found in hoofed mammals (Artiodactyla and Perissodactyla) only (Fig. 3). They are present on their head and form organs of offense and defense. At least 5 types of horns are recognized, but all are not true horns, that is, product of stratum corneum.

1. True horns. True or hollow horns usually occur in both the sexes in goats, sheep, cattle and others. They are unbranched, cylindrical and tapering. They are permanent structures that continue to grow throughout life and are never shed. The true horn is made of a hollow dermal bony core arising from frontal bone of skull, and covered by an epidermal horny hollow cap.

2. Prong horns. The horns of prong-horned antelope (*Antilocapra*) are also true horns. It is formed by a small central permanent bony core arising from frontal bone and covered by a thin hollow and horny epidermal horn. But the horny sheath of a prong horn bears 1 to 3 branches or prongs, and it is shed every year. The permanent bony core becomes the base around which a new horn is developed the following year.

3. Antlers. Antlers are characteristic of deer family. They are found only on males but on both the sexes in reindeer and caribou. Antlers are annual growths and not true horns. An antler is a branching solid outgrowth of dense connective tissue connected basally to the frontal bone of skull. Deposition of calcium salts makes the antler hard. During growth, it is covered on the surface with typical hairy and vascular skin, or 'velvet'. When growth is complete, the velvet wears off, exposing the naked, branched antler. After the breeding season is over, the antlers are also shed and new antlers develop the following year.

4. Giraffe horns. Horns of giraffes are stunted, unbranched and permanent antlers present in both sexes. Each consists of a short bony dermal core, projecting from frontal bone and remains covered with simple unmodified skin or velvet which is never shed.

5. Hair horns. Hair horns or fibre horns are found in rhinoceros of both sexes. Perched upon a roughened area of nasal bones. Indian rhino has a single horn, while the African species has two, one behind the other. These horns are entirely made of thick hairy and keratinized epidermal fibres fused together. These are permanent structures and if broken they again grow out. Rhinoceroses are still slaughtered illegally because these horns are in great demand in Oriental countries as a love charm.

[VI] Feathers

Birds are covered by feathers which are not found in any other group of animals. They are dry, non-living and cornified products of stratum corneum of epidermis. These unique structures are light in weight, but strong, elastic and water-proof. They show different colours due to presence of pigments of various shades and structural arrangement. They mainly streamline and protect the body, conserve body heat and make broad surfaces of wings and tail used for flight. The mode of development of feathers is like that of scales. Feathers are moulted and replaced seasonally.

Generally, three types of feathers are recognized : countour, down (plumules) and filoplumes (hair-like). For a detailed treatment of the structure, development, kinds and uses of feathers, readers may refer to Chapter 27.

[VII] Hairs

Hairs are characteristic of mammals. They may cover the entire body (furred animals) or may be reduced to patches (man) or to scattered hairs (whales). Like scales and feathers, hairs are also cornified epidermal products of the integument. Collectively, all the hairs covering the body of a mammal, are known its *pelage*. It is periodically lost by moulting and replaced by a new one.

Each hair originates from the bottom of a tubular invagination, or *hair follicle*, of germinative layer of epidermis into dermis. A *dermal* or *hair papilla*, containing blood vessels and nerves, nourishes the swollen *root* or *bulb*, adding new cells forming the *shaft* of the hair. The cells of the shaft become keratinized, har ened and soon d e, so that the hair protruding above the skin is a dead structure. It is lubricated by the only secretions of a *sebaceous gland* into follicle. A smooth arrector pili muscle is associated with each follicle. Typically, the hair shaft consists of three layers : an external *cuticle* made up of overlapping microscopic scales, middle *cortex* containing shrivelled cells and pigments, and inner *medulla* containing air spaces in larger hairs.

Chief functions of hairs seem to serve for insulation of body and as sensitive tactile organs (e.g. vibrissae). Hairs have several modifications (bristles, quills or spines, scales, horns, etc.) and variously used in industry.

Integument in Different Classes of Chordates

Although fundamental structure of skin remains similar in all vertebrates, yet variations occur in different classes involving : (i) presence or absence of dermal bones, (ii) relative abundance of glands in aquatic forms, and (iii) specializations of stratum corneum or surface layer of epidermis in terrestrial forms.

1. Lower chordates (Protochordata). In *Balanoglossus* and *Branchiostoma*, the integument

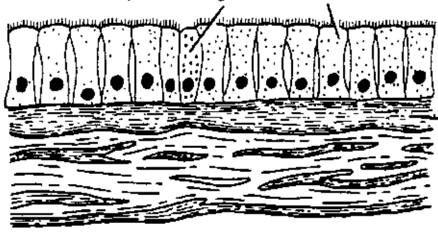

Fig. 4. Skin of a young *Amphioxus* in V. S.

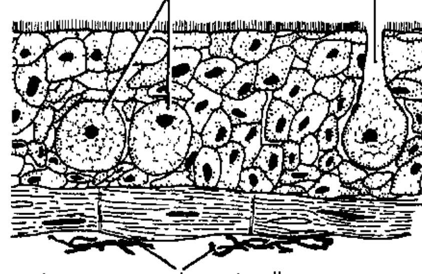

Fig. 5. Skin of a larval cyclostome in V. S.

or skin is quite simple and lacks keratin (Fig. 4). The outer epidermis is thin, made of a single layer of tall or columnar and often ciliated cells. Thus it is similar to that of invertebrates because it is stratified in all higher chordates. There are numerous unicellular epidermal gland cells, secreting a thin cuticle in amphioxus. Dermis or corium is gelatinous in amphioxus.

2. Cyclostomata. Keratin does not occur in epidermis which differs from that of protochordates (*Branchiostoma*) but resembles that of higher chordates in being multi-layered and more durable (Fig. 5). Epidermis contains three types of secretory cells or unicellular glands : *mucous glands* secrete slime, elongated *club cells* with hyaline cytoplasm are probably neural or scab-forming, and *granular cells* are of unknown function. Below epidermis, a layer of collagen and elastic fibres forms *cutis*, which also contains star-shaped *pigment cells*. They have power of migration and also present in dermis.

3. Fishes. The epidermis is several-layered but simple, thin and without a typical stratum corneum

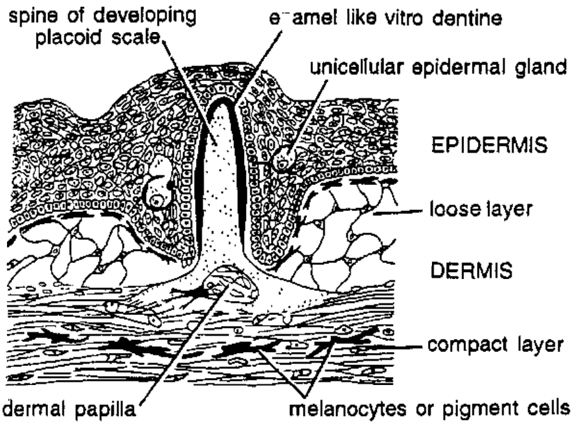

Fig. 6. Skin of dogfish embryo in V. S.

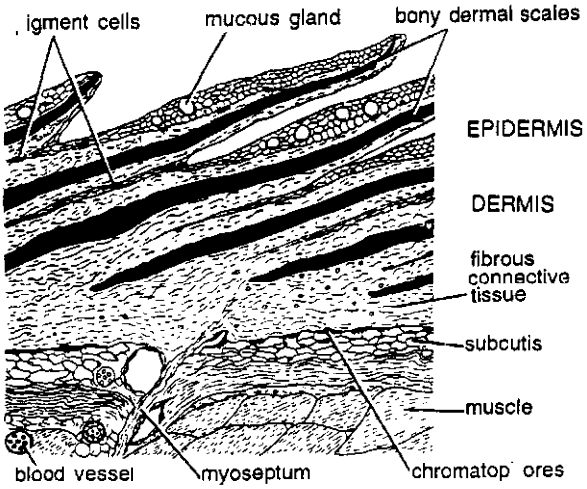

Fig. 7 Skin of a teleost fish in V. S.

as an adaptation to life in water (Figs. 6, 7 & 8). Epidermis is quite rich in unicellular *goblet* or *mucous gland cells* secreting mucous which reduces friction between body surface and water, protects from fungal or bacterial infections and controls osmosis. A few multicellular epidermal *glands*, such as *poison glands* and light-emitting organs or *photophores*, may also be found.

Dermis is typical but all the connective tissue fibres forming it run parallel to the surface. A peculiarity is the presence of atleast 5 types of *dermal scales* projecting above the surface. Of these -cartilaginous fishes (elasmobranchs) have *placoid scales*. Chondrostei and Holostei have

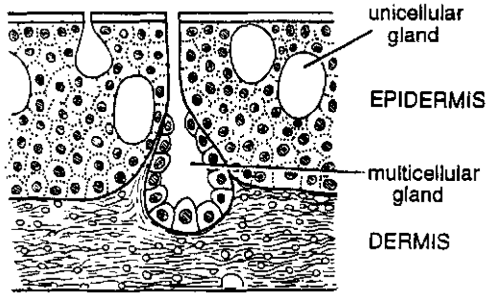

Fig. 8. Skin of a dipnoan (*Protopterus*) in V. S.

ganoid scales, while Teleostei have *cycloid* and *ctenoid scales*. *Cosmoid scales* are known from extinct Crossopterygii. Patterns and brilliance of colouration are perhaps greatest in fishes than in any other group of chordates. This is because of -i—e-t -ell- --lled *ch----at--h--e-* --d *iridophores* containing guanin, which are found in the dermis.

4. Amphibians. Typical amphibian skin is shown by frog (Figs. 9 & 10). It is thin and less intimately attached to the underlying muscles due r rg *ubcutane u ly p pace* b-n--t- d—is. T--ic-l ---hibi-- ski- is modified from that of fishes in atleast 3 rimar respects. (i) In aquatic forms, stratified epidermis often exhibits a *thin stratum corneum* of flat and dead keratiniz cells w ic co y g shed in patches and replaced. (ii) Amphibians are the lowest vertebrates having abundant *multicellular skin glands*, rather than unicellular. The mucous secreted keeps the skin moist and also permits respiratory gaseous exchange through richly vascular skin thus compensating for the poor development of lungs. However, the warty skin of land forms, such as toads, with heavier stratum corneum and less number of glands, resembles that of reptiles. Many amphibians have cutaneous *poison glands* (parotid glands of toad) whose toxic secretions serve toward off enemies. (iii) Skin of extinct Labyrinthodontia (stem Amphibia) was heavily armoured with *dermal scales* which are absent in modern Amphibia. However, remnants of dermal bony scales are found embedded in the skin of some

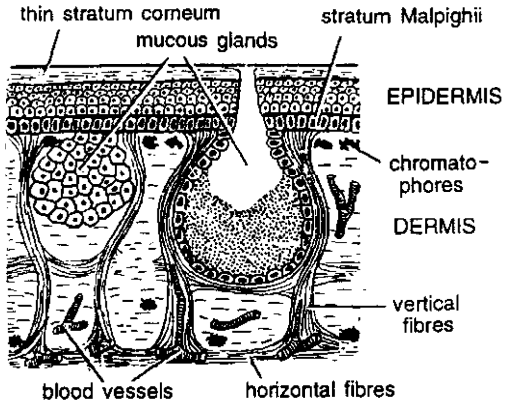

Fig. 9. Frog. V. S. skin.

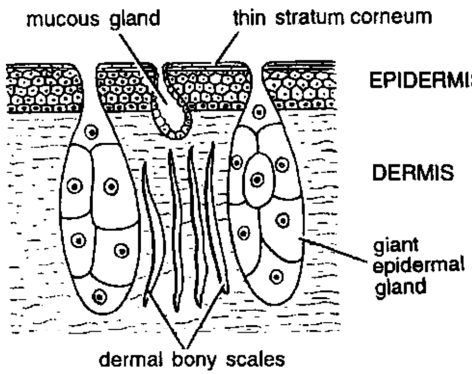

Fig. 10. *Ichthyophis*. V. S. Skin showing structure and dermal scales.

Gymnophiona and a few tropical toads. Some amphibians have the power to change body colour with the help of pigment cells or chromatophores present in dermis.

5. Reptiles. Reptiles are the first true land vertebrates and their integument shows many terrestrial adaptations (Fig. 11). (i) *Stratum corneum* is relatively thicker making the skin dry and prevent any loss of body moisture. It is variously modified to form overlapping horny *epidermal scales* covering the body, *spines, shields, scutes, plates, claws, horns, beaks, rattles* etc., forming the *exoskeleton*. These are periodically shed in small bits or even in a single piece (ecdysis or moulting). (ii) In addition to horny epidermal structures, reptiles also retain the bony dermal armour of their ancestors, in the form

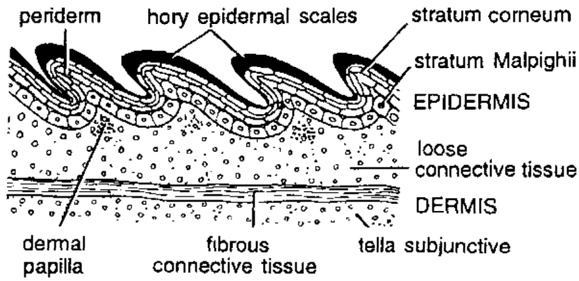

Fig. 11. Lizard. V. S. skin.

of *bony dermal scales, scutes* or *plates* called *osteoderms*, in their dermis. (iii) Reptiles exhibit relatively few *integumentary glands*, with the exception of *scent glands* for sexual attraction near cloaca in some snakes, *femoral glands* on the thighs of male lizards, and *musk glands* of musk-turtles and alligators. (iv) Some lizards and snakes exhibit elaborate *colour patterns* for concealment from predators and preys, or as warning signals. Some lizards (e.g. chamaeleons) have marked capacity to change their body colouration with the help of *chromatophores* present in dermis.

6. Birds. Skin of birds, Fi_. 12 like that of ot er verte rates, s compose o strati e epidermis and dermis. But, skin is thin and loosely attached to achieve maximum freedom of movement for flight. Modifications of stratum corneum, other than feathers, include horny sheaths of beaks. *Scales* are restricted to lower legs, feet, webs and base of beaks. *Claws* usually present on toes may also occur on one or two fingers (ostrich, hoatzin, geese, etc.). Like beaks, claws are also diversified and adapted to different habitats. Rest of the body is covered with *feathers* which undoubtedly evolved from epidermal scales. They protect and insulate the body. Feathers are shed and replaced seasonally. Three usual types of feathers are contour, down and filoplumes. No skin glands occur in birds with the exception of a *uropygial* or *preen gland* on tail, which is particularly well developed in aquatic birds. Its oily or waxy secretion is coated on feathers and beaks during preening. Bird skin has no chromatophores. *Melanocytes* containing pigments

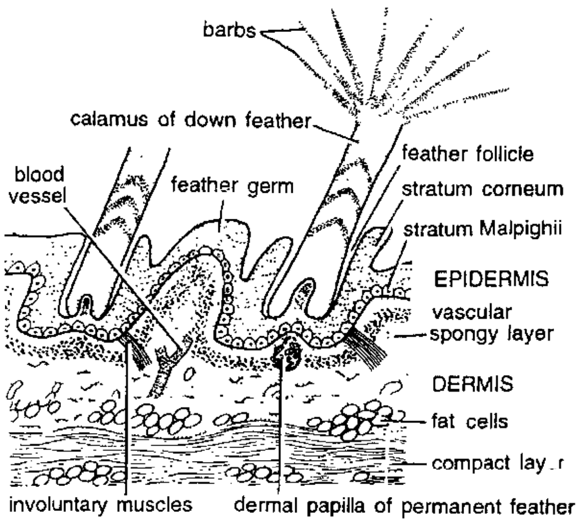

Fig. 12. Skin of a bird in V. S.

migrate into feathers and scales. Body colours are mainly due to reflection and refraction of light from feathers.

7. Mammals. Skin of mammals is elastic, water-proof, thickest of all vertebrates and variously modified (Fig. 13). The two layers, epidermis and dermis, have reached their highest specialization in mammals. The thick epidermis is differentiated into 5 layers from outside. These are *stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum germinativum* or *Malpighian layer.* Stratum corneum containing keratin is particularly thicker on palms and soles having maximum friction and wear and tear. Modifications of stratum corneum include horny epidermal *scales, hairs, bristles, claws, nails, hoofs, horns,* etc.

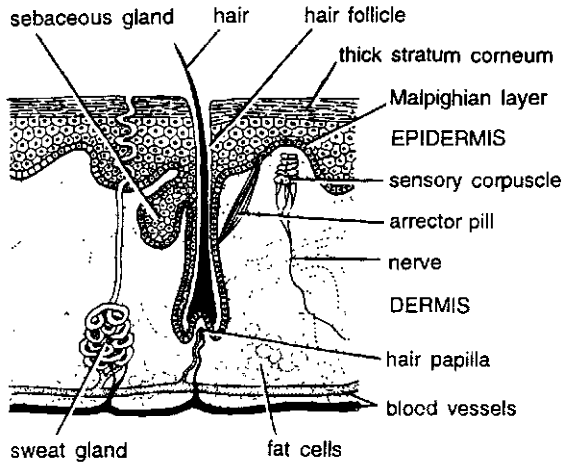

Fig. 13. Skin of a mammal in V. S.

Mammalian skin has a wide variety of *glands* which are all multicellular. Based on function there are 5 major types : *sebaceous, sweat, mammary, lacrimal* and *scent.* Of these mammary, sebaceous and sweat glands are found only in mammals. *Mucous glands* do not occur in the epidermis of mammals.

Dermis of mammals is proportionately much thicker than in other vertebrates. Except in armadillos, *dermal scales* do not occur in mammals. *Hair colour* is due to the presence of varying intensities of brown or black pigment granules between and within the hair cells. *Skin colour* is due to varying concentrations of melanin granules in basal layers of epidermis, or due to pigment-containing melanocytes located in dermis just beneath the epidermis. *Albinism* results from lack of pigments, while *melanism* results from the presence of an excess of black pigments.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. What is integument? Describe the integument and its derivatives in vertebrates.
2. Give an account of the integument in vertebrate you have studied and explain its functions.
3. Discuss how the integuments of reptiles and birds are adapted to their respective modes of life.
4. Give a comparative account of integument of reptiles, birds and mammals.
5. Describe the exoskeletal structures in vertebrates you have studied.

» Short Answer Type Questions

1. Draw labelled diagram of vertical section of the skin of — (i) Lizard, (ii) Bird, (iii) Frog, (iv) Mammals.
2. Write notes on — (i) Epidermal glands, (ii) Horns, (iii) Keratinization, (iv) Osteoderms.

» Multiple Choice Questions

1. Study of structure of animals :
   (a) Anatomy (b) Histology
   (c) Morphology (d) Physiology
2. Outermost protective covering of animals :
   (a) Feathers (b) Integument
   (c) Scales (d) Hairs
3. Which is not a function of skin?
   (a) Protection (b) Locomotion
   (c) Secretion (d) Digestion
4. Integumentary gland secreting tears :
   (a) Mammary gland (b) Sebaceous gland
   (c) Lacrymal gland (d) Uropygial gland
5. In presence of sunlight vitamin D is synthesized in mammalian skin from :
   (a) Sweat (b) Earwax (c) Sebum (d) Tears
6. Dermis of vertebrate integument is derived from :
   (a) Ectoderm (b) Mesoderm
   (c) Endoderm
   (d) Ecto-mesoderm
7. Melanocytes are located in :
   (a) Stratum corneum
   (b) Stratum germinativum
   (c) Stratum lucidum
   (d) Dermis
8. Poison secreted by parotid glands of amphibians is :
   (a) Alkaloid (b) Alcohol
   (c) Fatty acid (d) Carbohydrate
9. Reflecting pigment cells in luminescent glands contain :
   (a) Guanine crystals (b) Adenine crystals
   (c) Cytosine crystals (d) Thymine crystals
10. In birds uropygial gland is present just above the :
    (a) Beak (b) Eye (c) Tail (d) Ear
11. In Hippopotamus, sweat glands are restricted to :
    (a) Ears (b) Muzzle
    (c) Lips (d) Soles of feet
12. Digital cornifications are modifications of :
    (a) Stratum corneum (b) Stratum germinativum
    (c) Stratum lucidum (d) Dermis

ANSWERS

1. (a) 2. (b) 3. (d) 4. (c) 5. (c) 6. (b) 7. (d) 8. (a) 9. (a) 10. (c) 11. (a) 12. (a)

52

Endoskeleton in Vertebrates

What is Skeleton?

The hardened tissues of the body together form the *skeleton* (*sclero* = hard). Organism will remain small and slow moving if there had been no skeleton for support and to serve as levers on which muscles can act. Skeleton of invertebrates is most often secreted on the surface, forming a lifeless or dead *exoskeleton*. Whereas skeleton of vertebrates develops most often underneath the surface forming a living or growing *endoskeleton*.

Types of Vertebrate Skeletons

Three types of skeletons develop in vertebrates :

1. Epidermal horny exoskeleton. These include hard and horny or keratinized derivatives of epidermal layer of skin, such as claws, reptilian scales, bird feathers and mammalian hairs, horns, nails and hoofs, etc. All living amphibians lack an exoskeleton. Epidermal horny exoskeletal structures of vertebrates have already been discussed in Chapter 51.

2. Dermal bony skeleton. Dermal bony skeleton is derived from the dermis of skin. It includes bony *scales* and *plates* or *scutes* (*osteoderms*), *finrays* and *antlers* of fishes, reptiles and mammals. In fishes, dermal scales become exposed due to wearing out of epidermis, and form exoskeleton.

3. Endoskeleton. Greater part of vertebrate skeleton lies more deeply, forming the endoskeleton. It develops from mesenchyme. At early embryonic stage, endoskeleton is composed of *cartilage*, which is replaced by *bone* in most adult vertebrates. Such bones deposited in place of preexisting cartilages, are called *cartilage* or *replacement bones*. Thus, they are distinguished from the *dermal* or *membrane bones* which directly form more superficially in dermis without any preexisting cartilage. Despite this difference in the mode of their development, the two types of bones are similar histologically.

Functions of Endoskeleton

Chief functions of vertebrates can be enumerated as follows :

(1) To provide physically support to body by forming a firm and rigid internal framework.
(2) To give definite body shape and form.
(3) To protect by surrounding delicate internal organs like brain, heart, lungs, etc.
(4) To permit growth of huge body size (whale, elephant, extinct dinosaurs), since it is living and growing.
(5) To provide surface for attachment of muscles.
(6) To serve as levers on which muscles can act.
(7) To manufacture blood corpuscles in bone marrow.
(8) To aid in hearing (ear ossicles).
(9) To help in breathing (tracheal rings, ribs).

Subdivisions of Vertebrate Endoskeleton

For convenience of study, endoskeleton of vertebrates is further subdivided into 3 major categories on the basis of their location in body—axial, appendicular and heterotopic. Each of these categories includes several elements as given in Table 1.

According to another scheme, endoskeleton can be divided first into somatic and visceral skeletons, as follows :

1. Somatic skeleton. Skeleton of body wall.

*(a) **Axial skeleton.*** Vertebral column, ribs, sternum and most of the skull (neurocranium and dermatocranium).

*(b) **Appendicular skeleton.*** Girdles and limb bones.

2. Visceral skeleton. Skeleton of pharyngeal wall (splanchnocranium).

Skull

The skeletal structure forming the framework of the vertebrate head is called *skull*. It is an important structure which is derived from three

Table 1. **General Divisions of Endoskeleton in a Land Vertebrate.**

I. Axial skeleton (median)			**II. Appendicular skeleton (lateral, paired)**		**Heterotopic bones (miscellaneous)**
Skull	**Vertebral column**	**Thoracic basket**	**Girdles**	**Limb bones**	**Develop in association with certain organs**
A. Neurocranium 1. Cranium or brain box surrounding brain 2. Sense capsules (i) *Olfactory*–nose (ii) *Optic*–eyes (iii) *Auditory* ears	**Vertebrae** 1. Cervical–neck 2. Thoracic–chest 3 Lumbar–lower back 4. Sacral–hip 5. Caudal–tail	**A. Ribs** Paired; bony or cartilaginous **B. Sternum** Breast bone	**A. Pectoral** Anterior or shoulder girdle. Includes : 1. Scapula–dorsal 2. Clavicle–anterior 3. Coracoid–posterior	**A. Forelimb** 1. Humerus-upper arm 2. Radius and ulna-forearm 3. Carpals-wrist 4. Metacarpals-palm 5. Phalanges-fingers	**1. Os cordis**—Inter ventricular septum of heart in deer and bovines **2. Rostral**– Pig's snout
B. Dermatocranium Membrane or dermal bones of skull **C. Splanchnocranium** Includes visceral arches or pharyngeal skeleton 1. Upper jaw 2. Lower jaw 3. Hyoid 4. Larynx			**B. Pelvic** Posterior or hip girdle. Includes : 1. Ilium-dorsal 2. Pubis-anterior 3. Ischium-posterior	**B. Hind limb** 1. Femur– thigh 2. Tibia & fibula–shank 3. Tarsals– ankle 4. Metatarsals–sole 5. Phalanges – toes	**3. Os penis**–Penis of bats, rodents, marsupials, carnivores, insectivores, whales, lower primates. **4. Os clitoridis**–Clitoris of otters, rabbits, several rodents. **5. Pessulus**–Syrinx of birds. **6. Epipubic**–Ventral abdominal wall of monotremes and marsupials. **7. Sesamoid**–Pisciform in hand, patella (kneecap), etc.

major embryonic components— (i) *neurocrancium* or *chondrocranium,* (ii) *dermatocranium* and (iii) *splanchnocranium.*

1. Neurocranium or chondrocranium. It includes (i) the *cranium* or *brain box* that houses the brain, and (ii) three pairs of *sense capsules* containing special sense organs of smell (*olfactory*), sight (*optic*) and hearing (*otic*).

2. Dermatocranium. It includes membrane or dermal bones attached to neurocranium and splanchnocranium.

3. Splanchnocranium. It includes the visceral or pharyngeal skeleton, originally forming a series of paired arches providing jaws, support for tongue (hyoid), and support for gill region.

Table 2 lists all the different types of bones found in different regions in the skull of vertebrates.

***Table 2.* Types of Bones in Skull of Vertebrates.**

Region of skull	Cartilage or replacement bones	Membrane or dermal bones	Bones of mixed origin
A. Chondrocranium 1. *Occipital*	* Supraoccipital Exoccipital * Basioccipital	Parietal * Interparietal Postparietal	
2. *Parietal*	* Basisphenoid Pleurosphenoid		
3. *Frontal*	Orbitosphenoid * Presphenoid	Frontal Postfrontal Lacrimal	Prefrontal
4. *Olfactory capsule*	* Mesethmoid Turbinals } Ethmoid Cribriform } Ectethmoid	Nasal Vomer Septomaxillary	
5. *Otic capsule*	Epiotic Prootic Opisthotic	Squamosal Supratemporal	Sphenotic Pterotic
6. *Optic capsule*	Sclerotic		
7. *Palate*		* Parasphenoid Vomer (in mammals) Endopterygoid or Pterygoid Ectopterygoid	Palatine
B. Splanchnocranium *1. Upper jaw*	Quadrate (incus) Epipterygoid Alisphenoid Metapterygoid	Premaxilla Maxilla Jugal Quadratojugal	
2. *Lower jaw*	Articular (malleus) Mentomeckelian	Dentary (mandible) Coronoid Splenial Angular Supra angular	
3. Hyoid arch	Hyomandibular Columella (stapes) Symplectic Inter- epi-, hypo-, cerato-, * basihyal		
4. Gill cover		Preopercular Opercular Subopercular Interopercular Gular	

N.B.—All bones are paired. Single bones are marked with an asterisk (*).

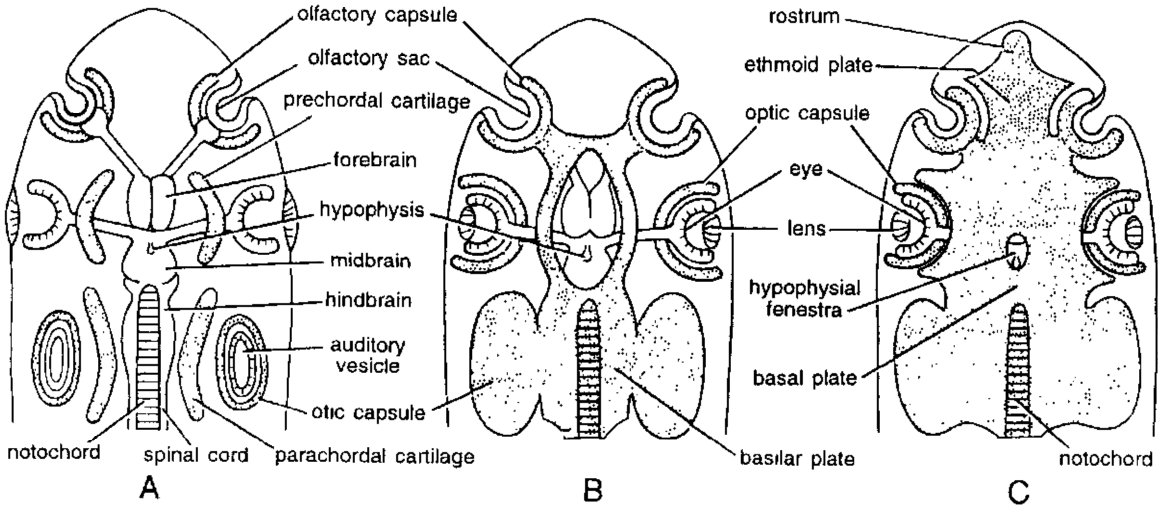

Fig. 1. Stages to show diagrammatic development of chondrocranium or cartilaginous neurocranium in ventral view A—Cartilages appear in head of embryo B—Formation of ethmoid and basilar plates. C—Chondrocranium completed

[I] Morphogenesis (history and development) of skull

1. Development of chondrocranium. Skull formation commences in the embryo soon after the formation of central nervous system and notochord (Fig. 1). A pair of curved cartilaginous plates, called *prechordals*, forms parallel to and below the forebrain. Similarly, another pair of *parachordal cartilages* forms beneath the midbrain and hindbrain, and parallel to the anterior end of notochord. The two prechordals expand towards each other and unite in the midline to form an *ethmoid plate*. Similarly, the two parachordals unite across the midline forming a *basilar plate*. Later, the ethmoid and basilar plates also grow towards each other and fuse to form a single *basal plate*, or floor upon which the brain rests. A large opening in the basal plate, the *hypophyseal fenestra*, lodges the pituitary gland.

Meanwhile, paired capsules of cartilage are also formed around the developing sense organs. The *olfactory capsules* around the nasal epithelium, and *auditory* or *optic capsules* surrounding the membranous labyrinths or internal ears, fuse with the basal plate forming the *neurocranium*. In its cartilaginous stage, the neurocranium is often termed *chondrocranium*, which means 'cartilaginous braincase'. The *optic capsules* or *sclerotic coats* around the eyes do not fuse with the chondrocranium, so that eyeballs can move independently of skull.

Further development involves formation of cartilaginous walls along lateral sides of brain. In lower forms, such as elasmobranches and lower bony fishes (e.g. *Amia*), the sidewalls further grow forming a complete cartilaginous roof over brain. Some openings remain uncovered for cranial nerves and blood vessels. The largest of all is foramen magnum at the posterior end of chondrocranium for spinal cord. In most bony fishes and tetrapods, however, the brain is not roofed over by cartilage except above the foramen magnum. Later membrane or dermal bones form a roof over the brain.

2. Development of splanchnocranium. It develops partly from neural crest cells and from splanchnic mesoderm. It includes visceral or pharyngeal skeleton consisting of a series of horseshoe-shaped paired cartilaginous arches (usually 7 pairs) encircling and supporting the pharynx between gill clefts. The arches remain united and interconnected ventrally, but are free dorsally. In jawed vertebrates or gnathostomes, the *first* or *mandibular arch* on either side is divided into a dorsal *palatopterygoquadrate cartilage* forming the *upper jaw*, and a ventral *Meckel's cartilage* forming the *lower jaw*. The *second* or *hyoid* arch on either side gives out a dorsal *hyomandibular* cartilage to support and connect jaws to chondrocranium below auditory region, and ventrally forming the *hyoid apparatus* supporting tongue. The remaining or *branchial arches* support the gills or larynx.

[II] Skull in different vertebrates

A comparative study shows that the basic architectural pattern of the three major components of skull (viz., neurocranium, dermatocranium and splanchnocranium) is essentially the same in all the vertebrates. However, there are many differences in general form and detailed structure of skull, including reduction in the number of bones.

1. Cyclostomata. Skull is most primitive (or specialized?) among living cyclostomes. It retains cartilaginous embryonic neurocranium with an imperfect fibrous roof without dermal plates or bones. Visceral skeleton, modified as a branchial basket, is not comparable with that of higher vertebrates.

2. Chondrichthyes. In elasmobranchs, neurocranium is cartilaginous. Brain is completely roofed. Olfactory and otic capsules are fused with the chondrocranium, but optic capsules remain free. Dermal bones are absent.

3. Osteichthyes. In ganoids or primitive bony fishes, such as gar, sturgeon, spoonbill, *Amia*, etc. and earlier crossopterygians, neurocranium is flat,

***Table 3.* Major Skeletal Derivatives of Visceral Arches in Representative Vertebrates.**

Visceral arch	Dogfish (*Scoliodon*)	Teleost (Bony fish)	Amphibian (*Necturus*)	Amphibian (Frog)	Reptile & Bird (*Uromastix* & Pigeon)	Mammal (Rat or rabbit)
I.	Meckel's cartilage Pterygoquadrate	Articular Quadrate Epipterygoid Metapterygoid	Articular Quadrate Cartilage in lateral Roof of mouth	Articular Mentomeckelian in some species Quadrate Annulus tympanicus	Articular Quadrate Epipterygoid —	Malleus Incus Alisphenoid —
II.	Hyomandibula Ceratohyal Basihyal	Hyomandibula Symplectic Interhyal Epihyal Ceratohyal Hypohyal Entoglossal	Rudimentary — Ceratohyal — — Hypopyal	Columella — Anterior horn — — Body of hyobranchial apparatus	Columella — Anterior horn — — Body of hyobranchial apparatus Entoglossus	Stapes — Anterior horn — — Body of hyoid
III.	Pharyngobranchial Epibranchial Ceratobranchial Hypobranchial	Pharyngobranchial Epibranchial Ceratobranchial Hypobranchial	Epibranchial Ceratobranchial	Body of hyobranchial apparatus	Second horn Body of hyobranchial apparatus	Posterior horn Body of hyoid
IV.	Branchial elements (as in III)	Branchial elements (as in III)	Branchial elements (as in III)	Posterior horn Body of hyobranchial apparatus	Posterior horn	Thyroid cartilage
V.	Branchial elements	Branchial elements	Epibranchial only Homologies of laryngeal cartilages remain in doubt	Not clearly delineated		Thyroid Cricoid Arytenoid
VI.	Branchial elements	Branchial elements	Missing or not clearly delineated			
VII.	Bears no gill Some reduction	Reduced	Missing			

completely roofed, cartilaginous and partially ossified forming many sculptured dermal bones by the fusion of dermal scales. In *Polypterus*, neurocranium is extensively ossified.

In some primitive teleosts (trout, salmon), chondrocranium is mostly cartilaginous. But, in higher teleosts, skull is highly specialized, laterally compressed and well ossified. Dermal bones are smooth, without ganoin, and not scale-like. Cartilaginous visceral arches have been changed to bones or replaced by dermal bones. Palatoquadrate cartilages do not meet anteriorly. Upper jaw is formed by premaxilla and maxilla, which are dermal bones. Lower jaw (Meckel's cartilage) has three bones—dentary, angular and articular-the last hinging on quadrate which attaches to cranium.

4. Amphibia. Modification in skull of Amphibia over that of fishes are correlated with the shift from water to land. There are fewer bones and much more embryonic cartilage in skull of modern amphibians, which is markedly platybasic and flattened. Basioccipital, supraoccipital, basisphenoid and presphenoid are absent. Hyomandibular becomes columella of the middle ear. Ventral wall of otic capsule bears a membrane covered aperture, fenestra ovalis, into which columella articulates for transmitting sound waves. Two occipital condyles, one on each exoccipital, are present. Visceral skeleton is essentially bony fish-like except that the number of gill-bearing arches is reduced.

5. Reptilia. In modern reptiles, neurocranium shows extensive ossification except in naso-ethmoidal region. There is one occipital condyle and more dermal bones than in Amphibia. Skull is tropibasic. One or two temporal fossae occur behind the orbits, except in Chelonia. Pineal foramen is lost, except in *Sphenodon* and many lizards. Prootic, epiotic and opisthotic of otic region remain separate. A quadratojugal is absent. Quadrate is movable at both ends showing streptostylism. There is tendency to form a Turbinal element in nasal passage, and to form a secondary palate. A transverse ectopterygoid and a vertical epiterygoid are present. Hyomandibular is modified into columella of middle ear. Lower jaw exhibits a large toothed dentary, angular, supraangular, splenial, coronoid and articular bones.

6. Aves. Bird skull is essentially reptilian in structure. Neurocranium is well ossified. A single occipital condyle occurs. Modifications are associated with flight and altered feeding habits. Skull is large, penumatic and light, with very thin dermal bones and practically without sutures. Premaxillary and dentary are elongated to form a toothless beak necessary for feeding. Cranium is large and its roof domed to accommodate the larger brain. Orbits are large, separated by a thin interorbital septum, and each with a ring of dermal sclerotic bones. Foramen magnum faces downwards. Like reptiles, there is a columella in the middle ear. Quadrate is streptostylic. Lower jaw has one cartilage bone (articular) and four dermal bones.

7. Mammalia. Mammalian skull has two occipital condyles, a condition inherited from ancestral synapsid reptiles. Prefrontals, postfrontals, transpalatines, supraorbitals, postorbitals, parasphenoid, quadratojugals, quadrates and all lower jaw bones except dentary are absent. Occipital bones fuse into a single piece enclosing foramen magnum. Otic bones become fused into a petrosal or periotic. Middle ear cavity has 3 ear ossicles - malleus (articular), incus (quadrate) and stapes (columella or hyomandibula). A complete secondary palate is present. Teeth are heterodont and present on premaxillae, maxillae and dentaries. Pterygoids are insignificant. Lower jaw on either side is made of a single dentary, there being no trace of Meckel's cartilage. Hyoid arch mainly contributes to hyoid apparatus. Remaining visceral arches contribute to thyroid, epiglottis, arytenoids, cricoid, tracheal rings, etc.

[III] Suspensoria or jaw suspensions

As mentioned earlier, the vertebrate skull has three major parts - neurocranium, dermatocranium and splanchnocranium. The splanchnocranium includes the visceral arches. The first or *mandibular arch* consists of a dorsal *palatopterygoquadrate bar* forming the upper jaw, and a ventral *Meckel's*

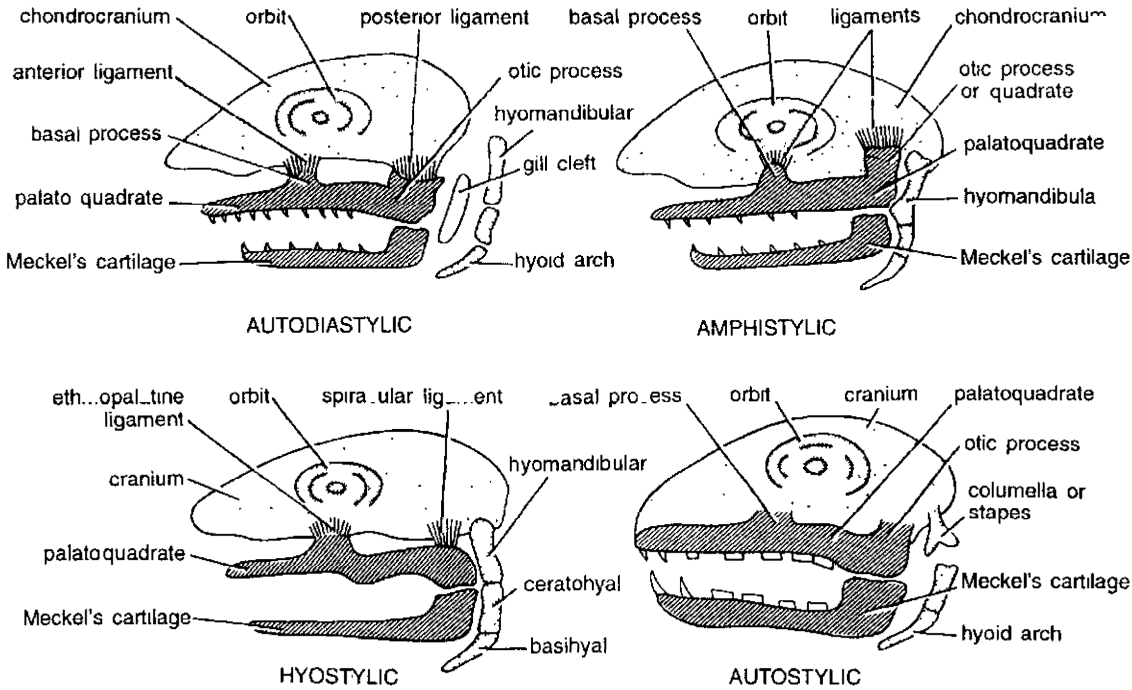

Fig. 2. Types of jaw suspensoria in vertebrates

cartilage forming the lower jaw. The second or *hyoid arch* consists of a dorsal *hyomandibular* which supports and suspends the jaws with the cranium, and a ventral *hyoid proper*. The remaining arches support the gills and are known as branchial arches.

Thus, we find that splanchnocranium plays an important role in the formation of jaws in gnathostomes, and in their suspension with the chondrocranium. The method of attachment or suspension of jaws from the chondrocranium is termed *jaw suspension* or *suspensorium*. There are 5 principal variants or types of suspensoria as follows (Fig. 2) :

1. Autodiastylic. This condition was found in some earliest gnathostomes such as acanthodians. The jaws are attached to the cranium by anterior and posterior ligaments. Hyoid arch remains completely free or independent and does not support the jaws. The gill cleft in front of hyoid arch bears a complete gill and does not form any spiracle.

2. Amphistylic. This is a rather primitive arrangement found in Crossopterygii and some primitive sharks (e.g. *Heptanchus, Hexanchus*). The quadrate or the basal and otic processes of upper jaw (mandibular arch) are attached by ligaments to chondrocranium. Similarly, the upper end of hyomandibula (hyoid arch) is also attached to chondrocranium, while the two jaws are suspended from its other end. This arrangement makes a double suspension (*amphi* = both+*style* = bracing) since both the first and second arches participate in bracing the jaws against the chondrocranium.

3. Hyostylic. It is found in most elasmobranchs and all bony fishes. Upper jaw (palatoquadrate) is loosely attached by anterior ethmopalatine to cranium. Both the jaws are braced against hyomandibular, the upper end of which fits into auditory region of skull. Since only hyoid arch braces or binds the two jaws against cranium, this jaw-suspension is termed *hyostylic*. It provides the jaws a wider movement and helps in swallowing larger preys.

4. Autostylic. This condition is found in extinct placoderms, chimaeras, lung fishes and most tetrapods (amphibians, reptiles and birds). Hyomandibular does not participate but becomes modified into columella or stapes of middle ear for transmitting sound waves. Upper jaw (palatoquadrate) is directly and intimately bound to cranium by investing dermal bones (*auto* = self). The articular of lower jaw articulates with the quadrate of the upper jaw.

Autostylic suspensorium is widespread and has at least 3 variation or subtypes.

(a) Holostylic. In Holocephali (chimaeras), upper jaw is firmly fused with skull and lower jaw suspended form it. Hyoid arch is complete, independent and not attached to skull.

(b) Monimostylic. In many tetrapods, hyomandibular forms columella and articular articulates with quadrate. However, the quadrate remains immovably attached with skull.

(c) Streptostylic. In some reptiles (lizards, snakes) and birds, quadrate is loosely attached and is movable at both ends, a condition known as *streptostylism*.

5. Craniostylic. This type of jaw-suspension is characteristic of mammals and some consider it as a modification of autostylic suspension. Upper jaw fuses throughout its length with cranium, and hyomandibular forms the ear ossicle stapes. But articular and quadrate also become modified into ear ossicles malleus and incus, respectively. Consequently, two dermal bones, dentary of lower jaw and squamosal of skull, provide the articulation between jaw.

Vertebral Column

Notochord. In all chordate embryos, the first axial endoskeleton to appear is a slender, stiff, unsegmented, gelatinous rod, the *notochord*. It is present below the nerve cord and above the digestive tract. Its ancestral predecessor is not known but it probably originated from endoderm. Typically, notochord is covered by inner and outer elastic fibrous connective tissue sheaths, called *elastica interna* and *elastica externa*, respectively.

In protochordates (amphioxus) and cyclostomes (lamprey), notochord persists throughout life and continues to grow with the animal. But in fishes and higher types, notochord is later on surrounded by cartilaginous or bony rings, called *vertebrae*. In most fishes and aquatic amphibians, the adult notochord is constricted within each vertebra. It is not constricted in lungfishes and sturgeon. In tetrapods, it is practically obliterated.

Vertebrae. Backbone or vertebral column of all vertebrates is formed of a metameric series of many small and essentially similar pieces, called *vertebrae*. Thus, a vertebra is the unit of vertebral column. Vertebrae are named after the region of body in which they occur. Vertebral column of fishes comprises only *trunk* (abdomen) and *caudal* (tail) vertebrae (Figs. 3A–B). In tetrapods, vertebral column includes five regions : *cervical,*

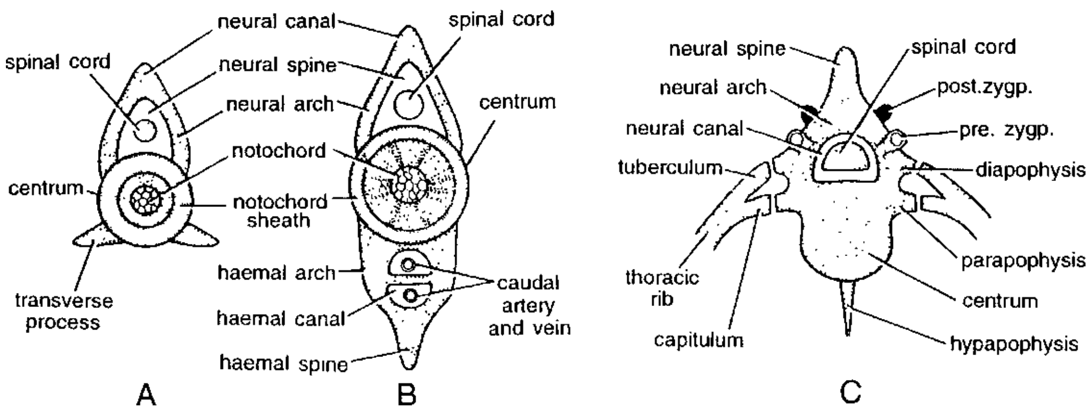

Fig. 3 Structure of a vertebra showing processes in cephalic view. A—Trunk vertebra of shark. B—Caudal vertebra of shark C—Typical tetrapod vertebra

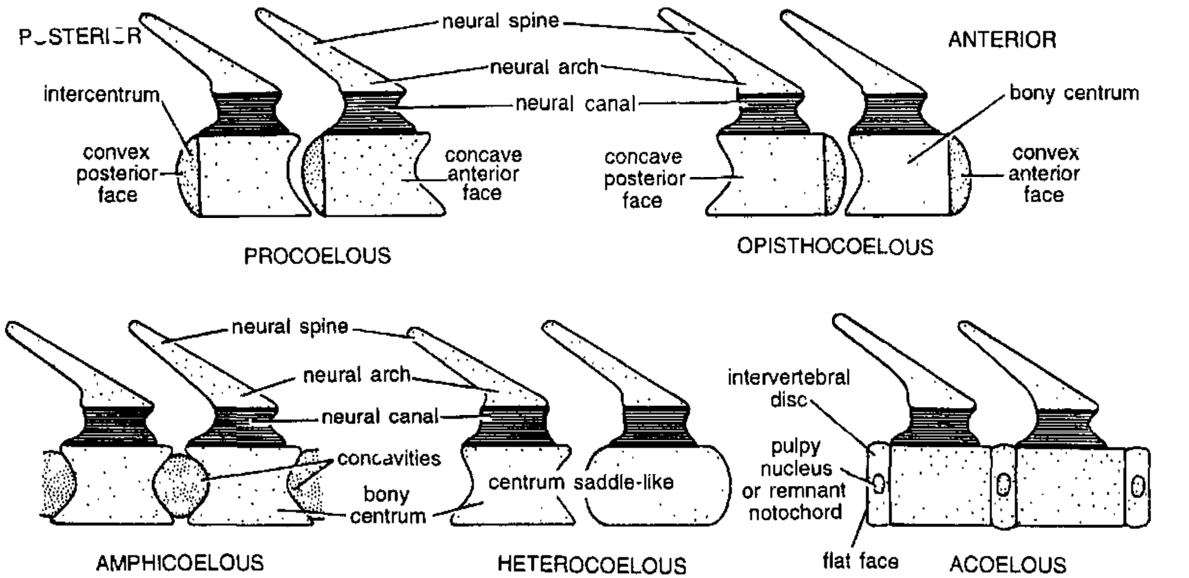

Fig. 4. Types of vertebrae based on shape of centra, in sagittal section.

thoracic, lumbar, sacral and *caudal*, each having usually several vertebrae. Amphibians have a single cervical (atlas) and only one sacral (9th) vertebra. Morphologically, vertebrae differ in different vertebrates or even in different regions of the same vertebrate, but all vertebrae are built according to a similar basic pattern.

Basic structure of a vertebra. Typically, a vertebra has a cylindrical, spool-like body or *centrum*, which encloses or replaces the embryonic notochord (Fig. 3C). Above the *centrum* is a *neural arch* produced dorsally into a *neural spine*. Successive neural arches enclose a *vertebral* or *neural canal* in which the *spinal cord* lies. The caudal vertebra in fishes also has a ventral *haemal arch* enclosing a *haemal canal* through which the caudal artery and vein pass. Haemal arch also carries a ventral *haemal spine*.

Types of processes. Various kinds of processes (*apophyses*) arise from the arches or centra of vertebrae.

(a) Zygapophyses. In vertebrates, from anterior and posterior faces of neural arch project paired articular facets, the *pre-* and *post- zygapophyses*. These serve for articulation between adjacent vertebrae. Zygapophyses do not occur in fish vertebrae.

(b) Transverse processes. Lateral transverse processes arise from centrum and serve for attachment of ligaments and muscles.

(c) Diapophyses. Each projects laterally from centrum or neural arch and articulates with dorsal head (tuberculum) of thoracic rib.

(d) Parapophyses. Each projects laterally from centrum and articulates with ventral head (capitulum) of rib.

(e) Basapophyses. These project ventro-laterally from centrum or haemal arch, or meet ventrally to form haemal arch.

(f) Pleurapophyses. These are lateral transverse processes fused with short ribs at their tips.

(g) Hypapophysis. It is a single prominent mid-ventral projection of centrum in certain vertebrae.

Types of centra and vertebrae. An intervertebral disc or intercentrum is often present between centra of successive vertebrae in embryo. This may fuse with anterior or posterior end of a centrum changing its shape to convex or flat. On the basis of the particular shape of centra, the following main types of vertebrae occur (Fig. 4) :

(a) Procoelous (*pro* = in front + *coelous* = hollow). Anterior face of centrum is concave and posterior face convex. e.g. typical vertebrae of frog and most reptiles.

(b) Opisthocoelous (*opistho* = at the back). Centrum is concave posteriorly and convex anteriorly. e.g. cervical vertebrae of some large ungulates.

(c) Amphicoelous (*amphi* = both). Centrum is concave at both ends. e.g. vertebrae of most fishes and tailed amphibians, 8th vertebra of frog.

(d) Acoelous or amphiplatyan (*a* = absent; *platy* = flat). Centrum is flat at both ends, without a concavity or a convexity. e.g. vertebrae of mammals.

(e) Biconvex (*bi* = two). Centrum is convex at both ends. e.g., sacral or 9th vertebra of frog.

(f) Heterócoelous (*hetero* = asymmetrical). Ends of centra are shaped like a saddle. e.g. vertebrae of modern birds.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Compare the skull of lizard with bird.
2. Give an account of different types of jaw suspensorium in vertebrates.
3. Describe the pectoral and pelvic girdles of frog, *Varanus, Gallus* and rabbit. Show how the structure of girdle is suited to the mode of life in these animals.

» *Short Answer Type Questions*

1. Give a brief account of the following — (i) Basic structure of vertebra, (ii) Jaw suspensorium, (iii) Development of chondrocranium.

» *Multiple Choice Questions*

1. In living amphibians exoskeleton is :
   (a) Hairy (b) Horny
   (c) Nails (d) Absent
2. Which of the following is a pelvic bone?
   (a) Ilium (b) Scapula
   (c) Clavicle (d) Coracoid
3. Cartilage bone :
   (a) Parietal (b) Lacrimal
   (c) Quadrate (d) Prefrontal
4. Cranium is a constituent of :
   (a) Dermatocranium (b) Splanchocranium
   (c) Visceral skeleton (d) Neurocranium
5. Pituitary gland is housed in :
   (a) Hypophyseal fenestra (b) Olfactory capsule
   (c) Ethmoid plate
   (d) Basal plate
6. Skull in cyclostomes is made of :
   (a) Replacing bones (b) Cartilage
   (c) Membrane bones (d) Dermal plate
7. In modern amphibians the collumella of middle ear is modified :
   (a) Basisphenoid (b) Sphenoid
   (c) Hyomandibular (d) Mandibular
8. Foramen magnum in birds faces :
   (a) Upwards (b) Downwards
   (c) Left (d) Right
9. The jaw suspensorium in elasmobranchs :
   (a) Autodiastylic (b) Amphistylic
   (c) Autostylic (d) Hyostylic
10. A single prominent mid-ventral of centrum in vertebrates :
    (a) Hypapophysis (b) Zygapophysis
    (c) Diapophysis (d) Parapophysis

ANSWERS

1. (d) 2. (a) 3. (c) 4. (d) 5. (a) 6. (b) 7. (c) 8. (b) 9. (d) 10. (a).

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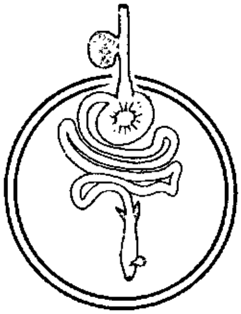

Digestive System in Vertebrates

Oxygen, water and food are necessary for the continuance of life. O_2 enters the body through the agency of respiratory system, but water and food are first taken into the *digestive tract* of every living being. Associated with the tract are its *derivatives* or *accessory organs*, such as tongue, teeth, oral glands, pancreas, liver, gall bladder, etc. The digestive tract and associated accessory organs together constitute the *digestive system.* The basic pattern of digestive system is similar in all vertebrates.

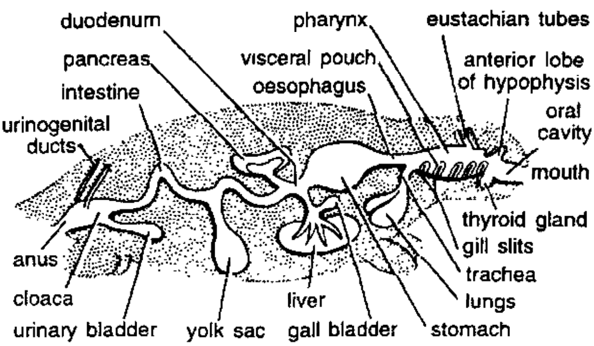

Fig. 1. Alimentary canal and its chief derivatives in a vertebrate.

Embryonic Digestive Tract

Archenteron. The digestive system is one of the earliest to form during embryonic development of vertebrates. The embryonic digestive tract or alimentary canal is endodermal in origin and termed the *primitive gut, archenteron* or *mesenteron* (Fig. 1). Its part containing yolk or connected by a narrow stalk with yolk sac is called *midgut.* The part anterior to midgut is *foregut* and posterior to it is *hindgut.* Foregut differentiates into oral cavity, pharynx, oesophagus, stomach and most of the small intestine of the adult. Hindgut forms the large intestine and cloaca. Only the linings of these organs are endodermal, while connective tissue and muscles in their walls are derived from mesoderm.

A midventral invagination of ectoderm of head, called *stomodaeum*, opens into oral cavity.

Thus, anterior portion of oral cavity is ectodermal, while its posterior portion is endodermal. A similar ectodermal midventral caudal invagination, called *proctodaeum*, leads into hindgut. It gives rise to the terminal ectodermal part of cloaca in lower vertebrates, and to rectum in mammals. Ectoderm of oral cavity gives rise to enamel of teeth, epithelial covering of tongue and anterior part of oral cavity, several types of oral glands (poison, salivary, mucous, etc.), and to Rathke's pouch forming adenohypophysis.

Mesenteries. Embryonic gut from stomach to cloaca is attached to mid-dorsal body wall by a continuous double fold of peritoneum, the *dorsal mesentery*, and to mid-ventral bodywall by a *ventral mesentery*. Much of dorsal mesentery persists throughout life, but most of ventral mesentery disappears except near liver and urinary bladder. Nerves and blood vessels connect to the organs through mesenteries.

Cilia. Cilia often occur in the digestive tract of vertebrates. It is entirely ciliated in adult *Branchiostoma* and in many larval vertebrates commencing with ammocoetes. Cilia are retained in the oral cavity, pharynx, oesophagus and stomach of amphibians, in stomach of many teleosts, in caeca of some birds and in many other parts in various species. They occur temporarily in stomach of human foetus.

Alimentary Canal

The term *alimentary canal* or *digestive tract* in vertebrates refers to an internal tube, seldom straight and often tortuously coiled, running from an anterior mouth opening in head to a posterior anal or cloacal aperture at the base of tail. It is designed for ingestion, digestion and absorption of food stuffs and egestion of undigested wastes. Major parts of alimentary canal are : oral cavity, pharynx, oesophagus, stomach, and small and large intestines (Figs. 2 & 4). Chief accessory organs associated with the alimentary canal are : tongue, teeth, oral glands, pancreas, liver, gall bladder, etc. Various modifications of alimentary canal in different vertebrates include : (i) lengthening of various parts by looping or coiling, (ii) formation of diverticula or enlargements (e.g. crop, caecum, stomach compartments), and (iii) development of internal folds (e.g. spiral valve, villi, typhlosole, papillae, rugae, etc).

Histology. Wall of alimentary canal of vertebrates is made of 4 distinct concentric layers or coats. (i) The outermost *serosa* or *serous coat* is *visceral peritoneum*, made by mesothelial cells and a thin layer of connective tissue. (ii) Beneath serosa, the *muscular coat* is composed of smooth muscle fibres arranged in outer *longitudinal* and inner *circular muscle fibres*, with a network of autonomic ganglionated myenteric plexus of Auerbeach between them. (iii) Beneath muscular coat lies *submucosa*, a connective tissue layer containing elastic fibres, nerves, blood and lymphatic vessels, and glands. (iv) The innermost coat or *mucosa* is further differentiated into : (a) innermost layer of *columnar epithelium*, often glandular and ciliated, supported by a thin basement membrane, (b) middle thin connective tissue, called *lamina propria* or *corium*, having blood capillaries, lacteals and nerves, and (c) outer narrow band of inner circular and outer longitudinal muscle fibres, called *muscularis mucosa*, which separates mucosa from submucosa.

[I] Mouth

Mouth is the anterior opening leading into oral cavity and is subject to a great deal of variations. In amphioxus, true mouth (enterostome) is located at the end of vestibule, perforating the membranous velum. In cyclostomes (lamprey), it is a circular opening (*cyklos* = circular + *stoma* = mouth) at the vortex of the buccal funnel, and permanently open in the absence of jaws or other mechanisms for closing it. In gnathostomes, mouth is usually terminal, although in elasmobranches and sturgeons it is located ventrally. True fleshy and muscular *lips* occur only in mammals. Muscular lips and cheeks are adaptations for sucking. In fishes, amphibians and most reptiles, mouth is surrounded by unmodified or heavily cornified skin forming immovable lips.

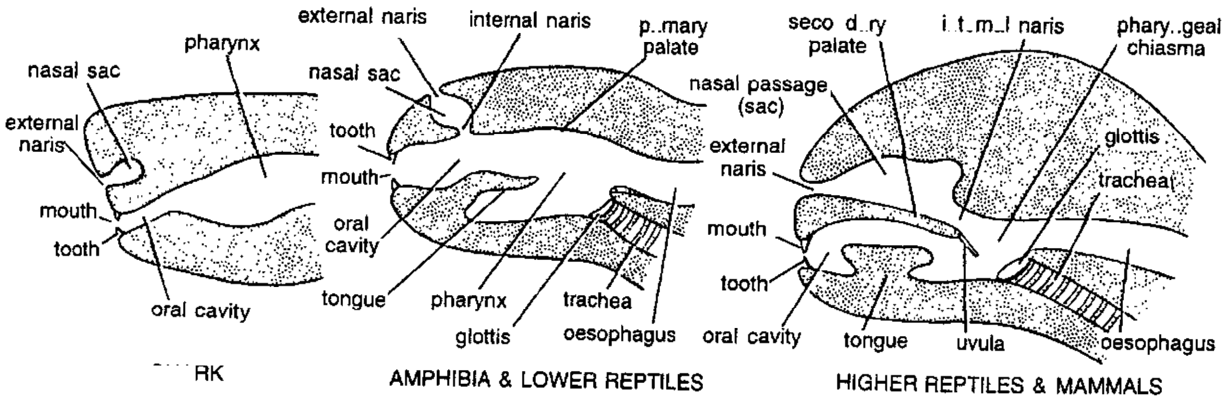

Fig. 2. Diagrams illustrating the relation of nasal passages to oral cavities in different vertebrates.

[II] Oral cavity

In a broader sense, the term "mouth" is used as a synonym for oral cavity. In fact, oral cavity begins at the mouth and merges with pharynx without a definite line of demarcation (Fig. 2). In gnathostome fishes, oral cavity is shallow, loosely organized and roofed with dermal bones usually bearing teeth. In addition to serving as a passageway for food, it is also a passageway for water and serves for aquatic respiration. In amphibians and reptiles, oral cavity is more compact and its muscular floor serves for swallowing food and also used in breathing in the absence of a diaphragm. It reaches culmination in mammals with a space, called *vestibule*, between lips and teeth, and bounded laterally by *muscular cheeks*, thus forming an efficient sucking and chewing organ.

Nasal sacs in vertebrate embryos originate as ectodermal invaginations of head. In most fishes, nasal cavities are quite independent of oral cavity. In Dipnoi, amphibians and most reptiles, having only primitive or *primary palate*, nasal cavities open into oral cavity, rather anteriorly, by a pair of *internal nares* or *choanae*. In amniotes, with formation of a *hard* or *secondary palate*, the respiratory nasal passage becomes effectively separated from oral cavity or food passage, and the internal nares open far posteriorly into pharynx. In birds this palate is cleft so that nasal and oral cavities are in direct communication. In mammals, bony plate is continued posteriorly as a membranous *soft palate*. Sometimes, a fleshy pendulant process, the *uvula*, hangs from soft palate into laryngeal pharynx.

[III] Derivatives or accessory organs of oral cavity

These are mainly teeth, tongue, oral glands and anterior and middle lobes of pituitary (adenohypophysis).

1. Teeth. Teeth are hard and pointed structures attached to jaw bones, that aid in food-getting. Two types of teeth occur in vertebrates : epidermal and true teeth. *Epidermal teeth* are horny projections of stratum corneum and best represented in cyclostomes (lampreys). Other examples are conical projections from lips of tadpoles of some species of frogs, serrations on beaks of some turtles and birds, horny plates in duckbill, sirenians and baleen whales, and egg-tooth for cracking egg-shell before hatching in turtles, *Sphenodon*, crocodiles, birds and monotremes.

True teeth occur in all vertebrates except agnathans, sturgeons, some toads, sirens, turtles, modern birds, etc. Teeth are polyphyodont, acrodont and homodont in fish, amphibians and most reptiles, but they are diphyodont, thecodont and heterodont in mammals. Teeth are similar in structure to the placoid scales of sharks, composed of a core of dentine surmounted by a crown of

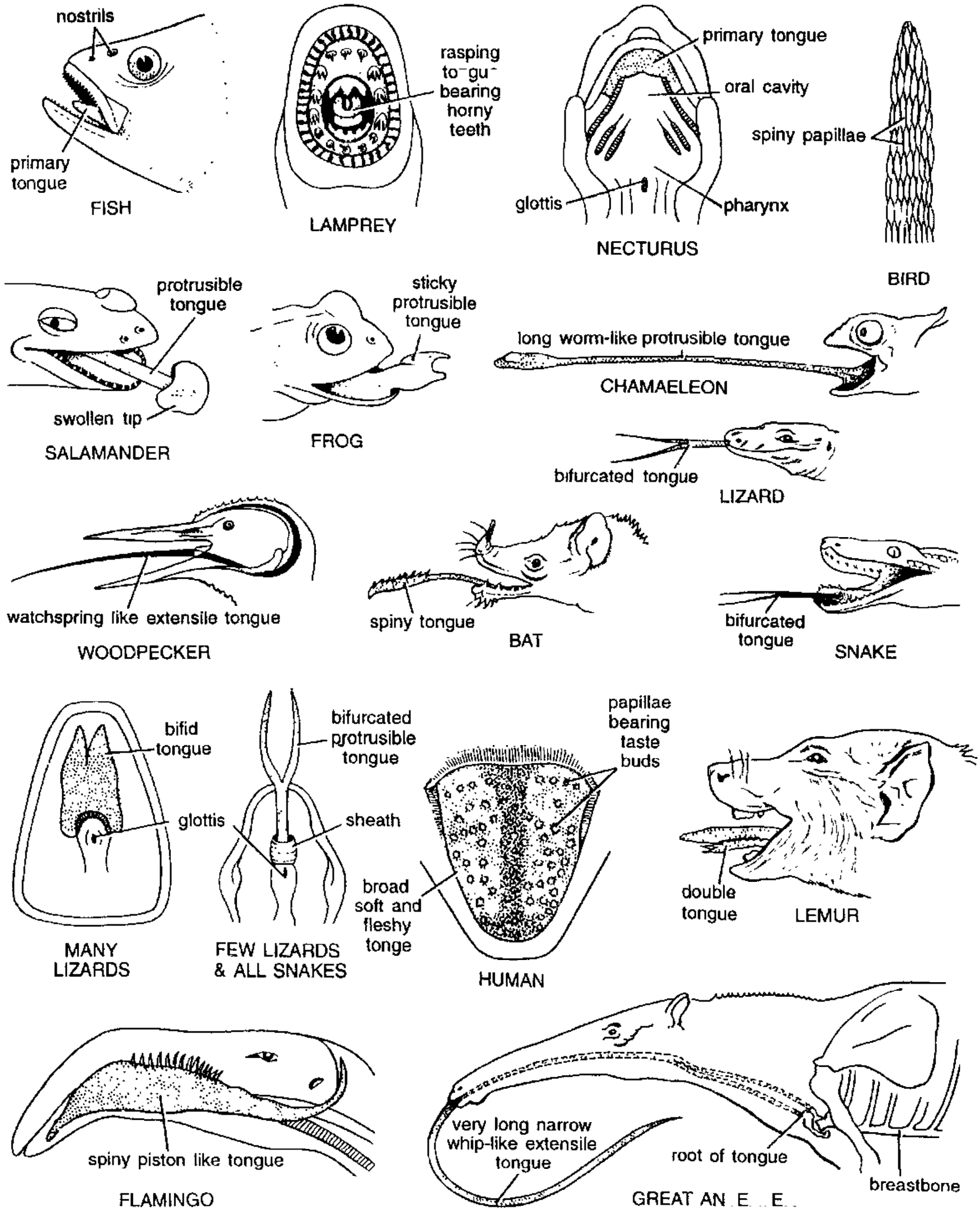

Fig. 3. Types of tongues in some vertebrates.

enamel, and are believed to have evolved from bony scales. Readers may refer to further details under the heading 'Dentition in Mammals' discussed in Chapter 34.

2. Tongue. A structure called tongue is found in the mouths of nearly all vertebrates (Fig. 3). They show much diversity and not all are homologous with the mammalian organ with which we are most familiar. In cyclostomes (lamprey), it is a thick, fleshy, extensile, rasping organ on buccal floor, armed with horny teeth. The *primary tongue* of fishes and *Necturus* is an immobile, non-muscular, sensory elevation on buccal floor, bearing teeth in some teleosts. Tongue of most amphibians (frogs, toads, salamanders) is sticky, attached at the anterior end and free at the posterior end. It can be thrust out of mouth suddenly by rapid injection of lymph, for capturing insect prey called *definite tongue.* In turtles, crocodilians, some birds and whales, tongue is immobile. In snakes, some lizards, some birds and some mammals (anteaters), it is long, highly protractile and often used for food-capture. In some lizards and snakes, it is forked at the free end, and retractile into a basal sheath. In most mammals (man), tongue is attached to buccal floor by a ligament, the frenulum. Principal role of mammalian tongue is to help in manipulation and swallowing of food. It also bears numerous microscopic taste buds. Human tongue is also of great importance in speech. In amniotes tongue is made by fusion of four parts viz., *primary tongue,* a muscular and glandular part called *tuberculum impar* and two *lingual folds.*

3. Oral glands. Vertebrates exhibit a great variety of glands opening into mouth cavity, and often named according to their location, viz palatine, lingual, sublingual, maxillary, labial, parotid, etc. As a rule, oral glands are absent or few in aquatic forms, but gradually increase in number and complexity in terrestrial forms. Fish and aquatic amphibians have only simple *mucous glands.* Poisonous snakes have large *poison glands.* The largest oral glands are enzyme-secreting *salivary glands* of mammals secretes enzyme called *salivary amylase* or *ptyalin.*

4. Adenohypophysis. Pituitary, the most important endocrine gland of vertebrates, consists of three lobes having dual embryonic origin. A ventral evagination of diencephalons, called *infundibulum,* forms the posterior lobe termed *pars nervosa* or *neurohypophysis.* Whereas a dorsal diverticulum of stomodaeum, called *Rathke's pocket,* constricts off to form the anterior and middle lobes of pituitary or *adenohypophysis.*

[IV] Pharynx

Region of foregut between oral cavity and oesophagus is termed *pharynx* which is lined by endoderm. Being concerned with digestion as well as respiration, it shows greater modifications than other parts of digestive tract. In fishes, pharynx is extensive and perforated by gill slits for aquatic respiration. In tetrapods, it is short and a crossroad between respiratory and food passages. From the wall of pharynx in embryo are derived spiracle, gill clefts, lungs, air bladder, tonsils and endocrine glands such as thymus, thyroid and parathyroids.

[V] Oesophagus

Oesophagus is a simple, muscular, distensible tube connecting pharynx with stomach. Its length is related to the length of neck. It is very short in neckless vertebrates (fishes and amphibians) but longer in amniotes, reaching extreme in birds, giraffe, etc. It may be lined internally with finger-like fleshy papillae (elasmobranchs), horny papillae (marine turtles) or longitudinal folds. In grain feeding birds (pigeon), oesophagus forms a paired or unpaired membranous sac, or *crop,* modified for storage of food. In pigeons of both sexes, epithelial lining of crop undergoes fatty degeneration controlled by a pituitary hormone, *prolactin,* forming 'pigeon's milk' which is fed to nestlings. Oesophagus has no serous coat as it lies outside coelom. In mammals when it passes diaphragm it has serous lining. Food bolus passes down oesophagus into stomach by a muscular wave of contraction and relaxation called *peristalsis.* Oesophagus exhibit difference from rest part of the alimentary canal. The important differences are — it has no visceral peritoneum

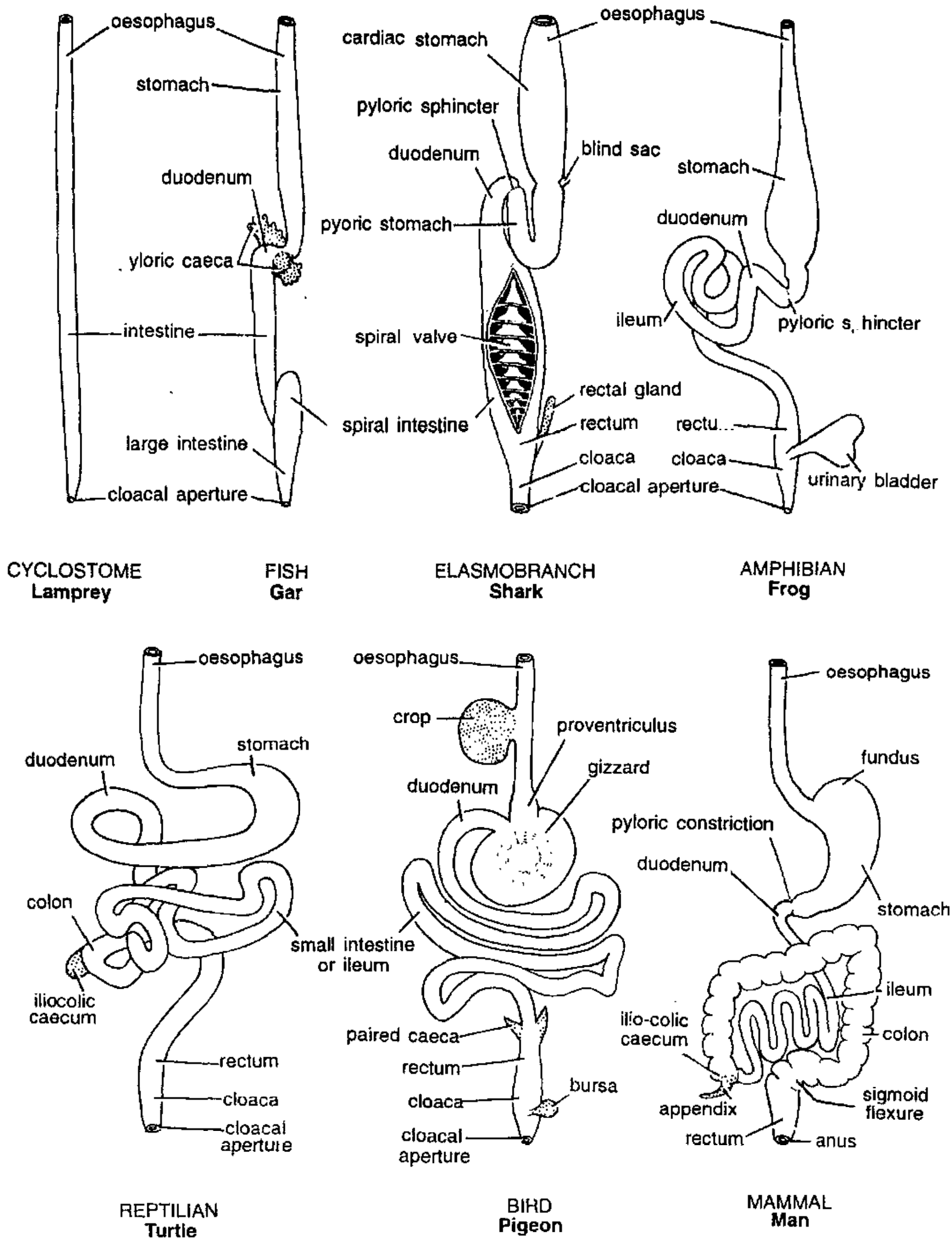

Fig. 4. Digestive tracts of some vertebrates.

lining but outer covering is *tunica adventitia.* Muscle fibers of the anterior part of the oesophagus are striped, middle part is both striped and non striped and posterior part is only unstriped muscles. But ruminants all along their oesophagus have striped and voluntary muscles. Internal mucosal lining is of stratified squamous epithelial cells.

[VI] Stomach

The sac-like muscular enlargement of digestive tract between oesophagus and intestine is called *stomach* (Fig. 5). It is held in place by *mesogaster,* a part of dorsal mesentery. It serves for temporary storage and maceration of solid food and for preliminary stages of digestion.

A *true stomach* is not present in protochordates, cyclostomes, chimaeras, lung fishes and some primitive teleosts. Only when its epithelial lining contains gastric glands, is it properly called a true stomach. Absence of stomach is considered to be an ancestral trait. A well-developed stomach occurs in elasmobranchs and tetrapods. The anterior end of stomach connecting to oesophagus is nearer heart and therefore called *cardiac end.* Main sac-like portion is termed *body.* The caudal end connected to intestine is called *pyloric end.* It terminates at a pyloric valve or sphincter called *pylorus.* In many vertebrates, especially fishes, one to several hundred finger-like *pyloric caeca* may be present at the junction of pylorus with duodenum.

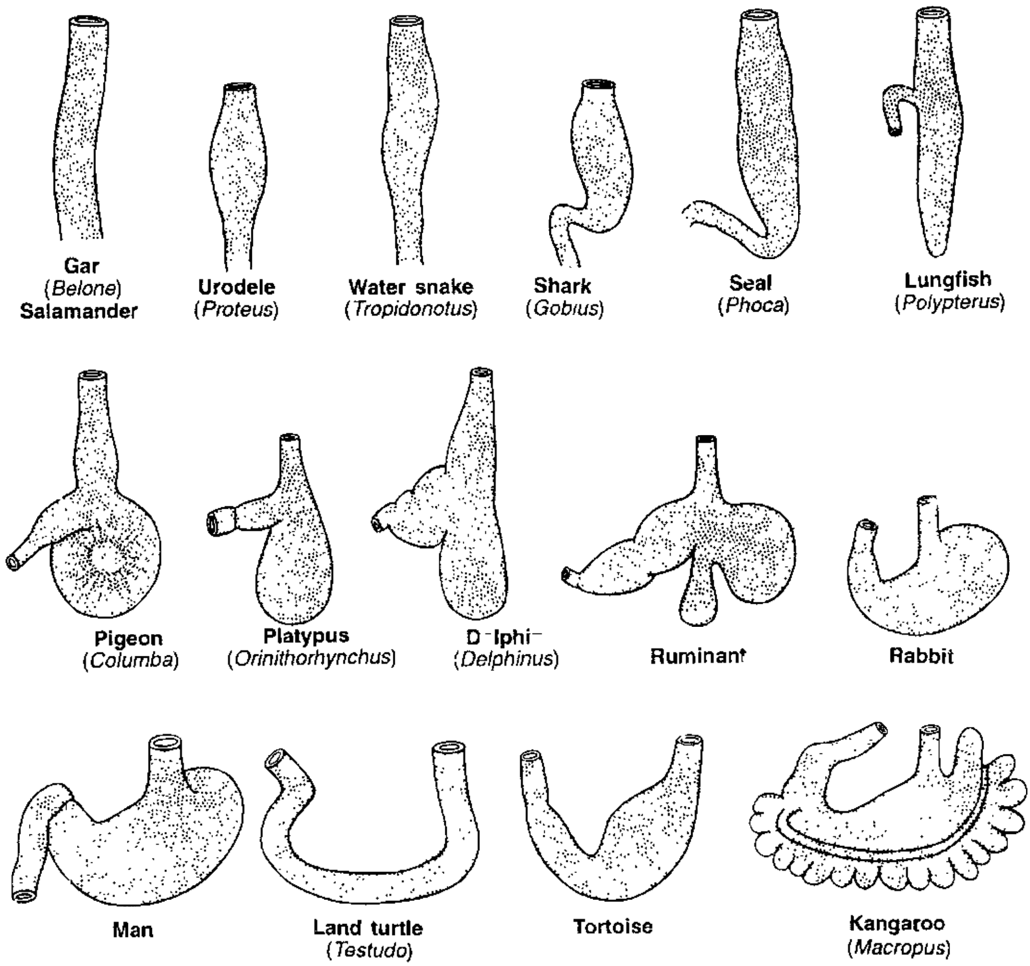

Fig 5. Different shapes of vertebrate stomachs including human.

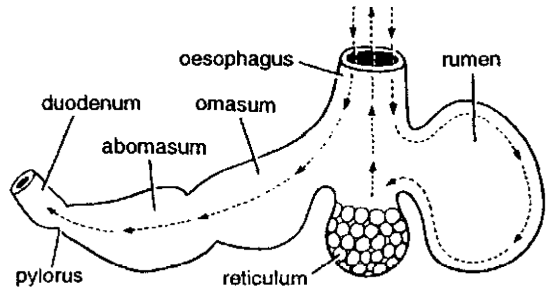

Fig. 6. Stomach of a ruminant or cud-chewing mammal. Arrows indicate course of food.

Stomach is *straight* in vertebrate embryos and may remain so throughout life in lower vertebrates (cyclostomes, gar, *Belone*, salamander, etc.). It is long and *spindle-shaped* in *Proteus*, *Necturus*, snakes and many lizards with elongated and narrow bodies. It forms a wide *curved* tube in turtles and tortoises. More often, flexures develop producing a *J-shaped* or *U-shaped* stomach (elasmobranchs, *Gobius*, seal, man etc.). As a result, stomach exhibits a short concave border, called *lesser curvature*, and a large convex border, called *greater curvature*. Expansion of greater curvature forms the so-called *fundus* region. In *Polypterus*, stomach appears like a *blind pouch* due to fusion of cardiac and pyloric limbs along lesser curvature. In crocodiles and seed-eating birds, stomach is divisible into an anterior, thin-walled *proventriculus* with gastric glands, followed by a thick-walled highly muscular *gizzard* or *ventriculus*. The latter has a tough, horny lining and contains small stone pieces or pebbles called *gastrolith* which help in maceration of food.

Stomach of mammals shows greatest modifications. It may be a simple sac or divided into *cardiac*, *fundic* and *pyloric* regions, each region with its characteristic gastric glands. In cud-chewing mammals or ruminants (cow), stomach has 4 well-defined chambers or compartments (Fig. 6). Of these, the first three chambers (*rumen*, *reticulum*, *omasum*) are claimed to be the modifications of oesophagus and serve as reservoirs of food. Only the last chamber (*abomasum* or *rennet*) represents true stomach containing gastric glands, comprising of the usual parts— cardiac, funduc and pyloric. In camel, omasum is absent and the pouch-like *water cells* projecting from rumen and reticulum probably help in digestion but do not serve for storage of water as generally believed. A pyloric --l-r--m--t i- bl--d sucki-- b-ts s-rv-s t- st-r- bl--d. A tru- stomach is wanting in monotremes, it is represented by a wide sac devoid of glands internally a-d is li-ed throughout by stratified epithelium.

Histological stomach shows two peculiarities. The *muscularis mucosa* consists of an outer longitudinal layer and inner circular muscle layer. Epithelial lining of stomach is thick and provided with several types of glandular cells forming *gastric glands*. Gastric glands are of three types *Cardiac, fundic* and *pyloric glands.* Cardiac and fundic glands secrete mucus only but fundic glands have three types of cells— *mucus neck cells* producing mucous, *oxyntic cells* producing HCl and *Zymogen cells* producing pepsin.

[VII] Small intestine

The part of digestive tract following stomach is *intestine*, in which digestion and absorption of food take place. Hence it is the most important part of digestive tract and undergoes several modifications in vertebrates. In cyclostomes (lamprey), elasmobranchs (dogfish), some primitive bony fishes (sturgeon, *Polyodon*) and an occasional teleost, intestine is a short, straight and wide tube. Its lumen cantains a *typhlosole* or *spiral valve* which compensates for the short absorptive area. This *valvular* or *spiral intestine* is equivalent to the small intestine of higher vertebrates. Teleost and tetrapod intestine is without a spiral valve, greatly elongated, coiled and further differentiated into an anterior *small intestine* and a posterior *large intestine*. Small intestine is the chief site of digestion and absorption. Its internal surface bears numerous, small finger-like projection or *villi* which increase the absorptive area. Many bony fishes have one to several pyloric caeca, arising from small intestine. A large number of digestive glands are also present in small intestine, they are tubular called *crypts of Lieberkuhn* found all along the length of intestine and secrete mucus and group of enzymes called *saccus entericus.*

First part of small intestine is known as *duodenum.* It is short, starts at the pyloric valve and terminates beyond the entrance of ducts from pancreas and liver into it. It has characteristic *Brunner's glands* in submucosa and also secretes hormones (*secretin, cholecystokinin*) for stimulating pancreas and gall bladder to release their juices.

Duodenum is followed by remaining small intestine, called *ileum,* which is narrow, greatly elongated, and much coiled. Only in mammals, small intestine beyond duodenum is divided into an anterior two-fifth *jejunum* and a posterior three-fifth *ileum.* Nodules of lymphoid tissues called *Peyer's patches* are found in ileum. However, the division is somewhat arbitrary and based on differences in shape of their villi and in nature of their glands and walls.

[VIII] Large intestine

Large intestine of most fishes and amphibians (*colon* or *rectum*) is wider than small intestine. It is straight, short and leads into a posterior terminal chamber, the *cloaca.* Cloaca also receives the urinary and genital ducts and opens to outside through a *cloacal aperture.* In reptiles, birds and mammals, large intestine is longer and divided into a proximal *colon* and a distal *rectum,* the latter ending into cloaca. All mammals except the monotremes and many bony fishes, lack a cloaca. Their rectum opens directly to outside through *anus,* while the urinary and genital ducts also open independently. Rectum of mammals is derived by partitioning of embryonic cloaca and, therefore, it is not homologous with the rectum of other vertebrates.

In tetrapods, and *ileocaecal valve* or *ileocolic sphincter* is present at the junction of small and large intestines, but absent in fishes. It prevents bacteria in colon from entering ileum. In amniotes, at the ileocolic junction is found an *ileocolic caecum,* usually two in birds. This contains cellulose-digesting bacteria and is very long, even coiled, in such herbivorous mammals as rabbit or horse feeding heavily on cellulose. Man, monkeys and apes have a small caecum, bearing a vestigial *vermiform appendix.* The *rectal gland* of elasmobranchs is a caecum that secretes sodium chloride. *Bursa fabricii* is a blind pouch of lymphatic tissue arising from dorsal wall of proctodaeum in young birds, but atrophies in the adults.

Digestive Glands

1. Liver. Liver occurs in all vertebrates and is the largest gland of the body. It arises as a single or double ventral diverticulum from the floor of embryonic duodenum. This liver bud or rudiment, soon divides into anterior and posterior parts. Anterior part branches repeatedly to become the *liver proper* of the adult animal (Fig. 7). Posterior part forms the *gall bladder, cystic duct* and *common bile duct* receiving numerous *hepatic ducts* from the liver proper and emptying into duodenum. Shape and division into lobes of adult liver varies in different vertebrates. Colour is also variable, especially in teleosts, where it may be green, yellow, orange, brown or red.

A true liver is absent in protochordates. *Hepatic caecum* of amphioxus and *digestive glands* of ascidians have somewhat different characters. In cyclostomes, it is small and single-lobed in lampreys but two-lobed in hagfishes. Liver is elongated, narrow and cylindrical in fishes, urodeles and snakes, but short, broad and flattened in birds and mammals. It is bilobed in elasmobranchs, two or three-lobed in teleosts, amphibians, reptiles and birds, and many-lobed in mammals. Liver is relatively large in carnivores than herbivores.

Liver cells manufacture alkaline *bile* which is stored in gall bladder before getting released into duodenum. Bile contains no digestive enzymes, nevertheless it neutralizes acidity of liquid food or chyme entering intestine and aids in fat digestion and absorption. Detailed functions of liver are given in Chapter 50. No other gland of vertebrate body has more varied functions than that of liver. But, curiously enough, it has never acquired any endocrine function.

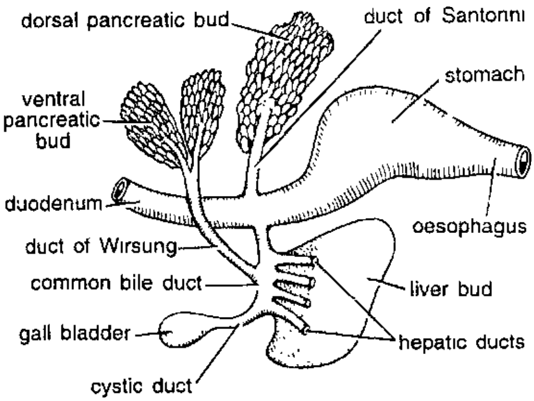

Fig. 7. Embryonic development of liver, gall bladder and pancreas.

A *gall bladder* is present in hagfishes and all higher vertebrates. However, it is absent in lampreys, many birds (pigeon) and many mammals (rats, hyrax, whales some Artiodactyla and all Perissodactyla). Gall bladder is not essential and can be removed surgically without any harm.

2. Pancreas. Pancreas is also a constant structure of all vertebrates and second largest digestive gland after liver. Typically, pancreas arises as one or two ventral diverticula from liver bud, and one dorsal diverticulum from embryonic duodenum. It is endodermal in origin from embryonic archenteron. Distal portions of diverticula divide to form acinous type glands, one *dorsal pancreas* and one *ventral pancreas*. Both may persist, as in fishes, but more generally the two unite to form a single gland as in tetrapods. Proximal portions of diverticula form *pancreatic ducts* all of which may persist. But usually the ducts undergo reduction or fusion, so that only one or two pancreatic ducts remain as in mammals. The ducts open into duodenum separately or jointly or one of them may unite with the common bile duct (Fig. 7).

Pancreas plays a dual role. It is partly *exocrine* secreting digestive enzymes through pancreatic ducts into duodenum, and partly *endocrine* secreting hormones such as *insulin*. A somewhat detailed treatment of pancreas can be seen in Chapter 50.

No pancreas is present in lancelet. In lampreys, some teleosts, lungfishes and lower tetrapods, it is distributed diffusely in liver, mesenteries and intestinal wall and probably only exocrine in function. In elasmobranchs and higher tetrapods, pancreas is well-defined and compact.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give a comparative account of digestive system of *Uromastix* and *Columba*.
2. Compare the digestive system of pigeon with rabbit and give reasons for their differences.
3. Give a comparative account of stomach in different vertebrates you have studied.
4. Give a general account of teeh.

» ***Short Answer Type Questions***

1. Write notes on— (i) Colon, (ii) Gizzard, (iii) Liver, (iv) Pancreas, (v) Ruminant stomach, (vi) glands of digestive system.

» *Multiple Choice Questions*

1. The part of archenteron connected to yolk sac :
   (a) Primitive gut (b) Fore gut
   (c) Mid gut (d) Hind gut
2. Oesophagus in adult vertebrates is derived from :
   (a) Primitive gut (b) Fore gut
   (c) Mid gut (d) Hind gut
3. True muscular lips are found in :
   (a) Cyclostomes (b) Fishes
   (c) Amphibians (d) Mammals
4. In frogs tongue is :
   (a) Primary tongue (b) Definite tongue
   (c) Horny tongue (d) Immobile tongue
5. The largest oral glands are found in :
   (a) Mammals (b) Birds
   (c) Reptiles (d) Amphibians
6. Largest oesophagus is found in :
   (a) Dog fish (b) Frog
   (c) Giraffe (d) Sparrow
7. Epithelial lining in a true stomach contains :
   (a) Salivary glands (b) Mucous glands
   (c) Goblet cells (d) Gastric glands
8. In ruminants true stomach is represented by :
   (a) Abomasum (b) Reticulum
   (c) Rumen (d) Omasum

ANSWERS

1. (c) 2. (b) 3. (d) 4. (b) 5. (a) 6. (c) 7. (d) 8. (a)

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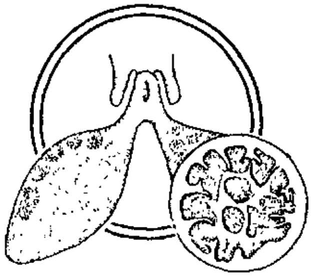

Respiratory System in Vertebrates

Every cell in a living organism consumes oxygen (O_2) during oxidation of substances resulting in the release of heat and energy and production of carbon dioxide (CO_2). This CO_2 acts as a poison for protoplasm unless removed from the body. The term *respiration* is used in several senses. According to a simple definition, it means intake of O_2 and getting rid of CO_2 by a living organism. The system designed for exchange of gases (O_2 and CO_2) between the organism and its environment is termed the *respiratory system.*

Respiratory Organs

Exchange of O_2 and CO_2 in an organism takes place in two locations. During *internal respiration,* also termed *cellular* or *tissue* respiration, gaseous exchange occurs between blood and tissues or cells of the body. During *external respiration,* gaseous exchange takes place between blood and the external environment. Blood serves as a transportation medium for carrying O_2 and CO_2 away from the body cells. The body structures which are needed for gaseous exchange between the blood and the surrounding medium are known as *respiratory organs.* Depending on the type of medium, vertebrates have two principal types of respiratory organs : *gills* for aquatic respiration (in water) and *lungs* for terrestrial respiration (in air). The same animal may have both gills as well as lungs. *Accessory respiratory organs* are also present in some vertebrates. All respiratory structures consist of a moist, semipermeable and highly vascularized membrane, exposed to the external medium, so that exchange of gases takes place by diffusion between the body blood and the environment. Gills and lungs are derivatives of the embryonic pharynx.

Gills

Gills or *branchiae* are the aquatic respiratory organs of fishes and amphibians. Amniotes do not utilize gills at any time in their embryonic or adult life. In addition to gas exchange, gills may serve for loss or gain of water, and elimination of salts in marine teleosts. On the basis of their location, gills are of two general types : *internal gills* and *external gills.* In some animals, both internal and external gills are present.

[I] Internal or true gills

Internal or true gills are characteristic of fishes. They are located in the gill slits and attached to the visceral arches. In amniotes, embryonic pharyngeal pouches do not open by gill slits to outside in the adults, so that no gills are present in them.

1. Gill slits. Gill slits are one of the most fundamental traits of the Chordata. In the embryo, the pharyngeal cavity is connected to the outside by a series of lateral openings, known as *pharyngeal clefts* or simply *gill slits.* These persist in the adult state of protochordates, cyclostomes, fishes and certain amphibians, but become reduced, abolished or modified in higher vertebrates. The number of gill slits varies in different chordates— 140 in amphioxus, 6-14 pairs in cyclostomes, 5 pairs in most elasmobranchs, 6 pairs in *Hexanchus*, 7 pairs in *Heptanchus*, 4 pairs in chimaeras, 5 pairs in most bony fishes, and 4 pairs in some teleosts. The gill slits are separated from one another by partitions called *visceral* or *gill arches.* The arches are supported by skeletal structures of splanchnocranium, together forming the *visceral skeleton.*

2. Structure or a true gill. True gills are developed on the walls of some gill clefts or gill arches (Fig. 1). Typically, a gill is composed of two rows of numerous *gill filaments* or *lamellae.* These are derived from epithelium on either side of an *interbranchial septum* containing arteries and supported by the branchial cartilage or bone of a gill arch. A single row of lamellae on one side of branchial *septum* forms only half the gill, called a *demibranch* or *hemibranch.* A septum with two attached demibranchs comprise a complete gill or *holobranch.* Gill filaments are richly supplied with blood capillaries and it is here that exchange of gases with water takes place.

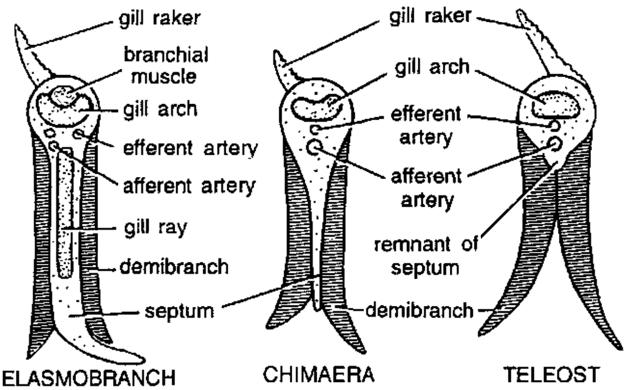

Fig. 1. Types of gills in fishes in section.

Gills of elasmobranchs (e.g. dogfish) are generalized in structure and relationships. Gills of bony fishes are also basically similar but show the following differences :

(a) Operculum. In a bony fish, a bony flap, called *operculum* or *gill cover,* arises from the hyoid arch and covers the gills in a common *opercular cavity* which opens by a single slit-like crescentic *external gill opening* behind.

(b) Interbranchial septum. The median septum is best developed in elasmobranchs. It is reduced in some intermediate fishes like chimaeras. It is greatly reduced or virtually absent in teleosts.

(c) Spiracles. In elasmobranchs and ganoids, the first gill slit, between mandibular and hyoid arches, bears a reduced *pseudobranch* and opens to outside through a small opening, the *spiracle.* In chimaeras, lung fishes and teleosts, spiracles become either closed or lost in the adult.

(d) Reduction in number of demibranchs. Number of gills greatly varies among fishes. There are 7 pairs in *Heptanchus*, 6 pairs in *Hexanchus* and 5 pairs in most elasmobranchs in addition to spiracle. However, the demibranch found on hyoid arch in elasmobranchs is lost in modern ganoids and teleosts which have only 4 holobranchs. Additional demibranchs are lost in some lungfishes. The extreme case of reduction is found in the eel *Amphipnous* in which first and fourth branchial arches are without gills, while the second arch retains only a demibranch.

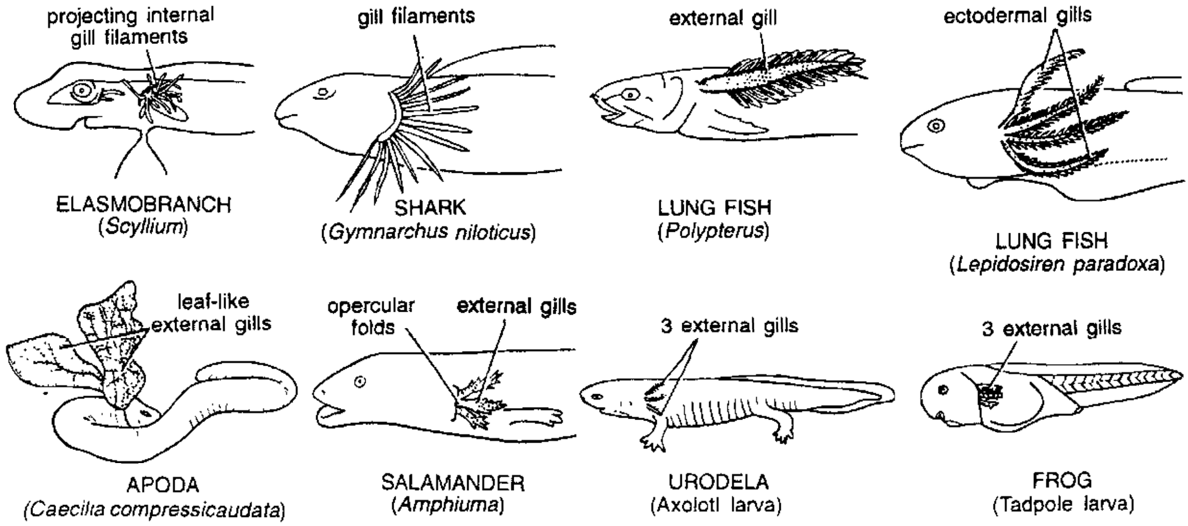

Fig. 2 Larval external gills of fishes and amphibians.

[II] External or larval gills

As against true gills, the external gills are formed as branching outgrowths from the exposed outer epithelium of gill arches and not from that of the pharyngeal pouches (Fig. 2). They are ectodermal in origin, and usually temporary organs found only in larval stages, hence also termed *larval gills.* They occur in the larvae of lampreys, a few bony fishes including *Polypterus* (bichir), lungfishes (e.g. *Lepidosiren*), and all amphibians including caecilians. In amphibians, larval external gills are absorbed at the time of metamorphosis, but in water-living perennibranchiate urodeles, both external gills and gill slits persist during adult life. In *Amphiuma*, gills are absorbed but gill slits remain. Gills assume various shapes being pectinate, bipinnate, dendritic, leaf-like, etc. Each gill consists of a narrow main central axis bearing a double row of filaments. Thoroughly vascularized by aortic arches, external gills are simply waved in water, and no respiratory water current passes through gill slits as in the case of true gills.

Lungs and Ducts

Lungs are the essential respiratory organs of land vertebrates or tetrapods and lung fishes. They are very elastic and distensible. Phylogenetic history of the development of lung is still obscure. Most accepted theory regarding the origin of lung was forwarded by Goethe. He believes that they are derived from the last pair of gill pouches which do not open to exterior through gill slits. Lungs receive blood supply from 6th aortic arch also strongly supports this view. In tetrapod embryos, lungs arise as a single midventral diverticulum (*lung primordium*) from the floor of pharynx (Fig. 3). It soon bifurcates into right and left *lung buds*. The undivided common portion develops into *windpipe* or *trachea* and *larynx* and opens into pharynx through *glottis*. Each lung bud branches repeatedly and grows posteriorly into coelom, invested by mesoderm. Thus, each lung has an inner endodermal lining derived form embryonic gut, an outer visceral peritoneum and in between the two a mesodermal mesenchyme containing lymph and blood vessels, nerve and smooth muscle fibres and connective tissue.

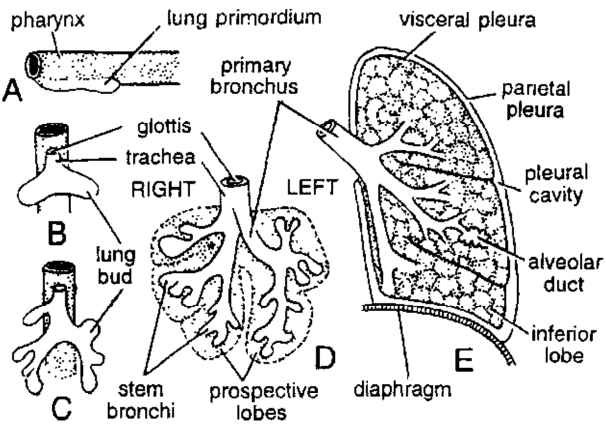

Fig. 3. Stages in development of a vertebrate lung in embryo. A—Lung primordium. B & C—Lung buds. D—Embryonic lung. E—Lung at birth.

Larynx. Beginnings of larynx are seen in Amphibia. In its simplest condition (*Necturus*), it is supported by a pair of *lateral cartilages*, bounding the slit-like glottis. In other amphibians, each lateral cartilage is divided into a dorsal *arytenoid* and a ventral *cricoid*. Sometimes both the *cricoids* fuse to form a cartilaginous ring (frog). It is suggested that these skeletal parts have evolved from the modification of vestiges of *branchial arch* (probably VI). It is further supported that this region is innervated by a branch of vagus (the X cranial nerve). In Anura, inner lining of laryngotracheal chamber forms two muscular bands, or *vocal cords*, which vibrate to produce various calls. Larynx is scarcely more developed in reptiles. *Cricoid* in case of reptiles is more differentiated than amphibians and in many cases gives off process with which *arytenoids* are movably articulated. It is small and rudimentary in birds in which another organ, the *syrinx*, located at the lower end of trachea, is responsible for sound production. In most common type of syrinx (*Bronchotracheal type*), there is tympanum formed of last tracheal cartilage. Besides this, into this box like structure certain membranes project from the walls of bronchi viz., *membrana tympaniformis interna* and *membrana tympaniformis externa*. However, in singing birds there is also another paired vibratory membrane called *membrana semilunaris* which extend dorsoventrally near the junction of bronchi and trachea. A bony ridge *pessulus* support these membranes. Larynx reaches its greatest point of evolution in mammals. Besides paired arytenoid and single cricoid, a single *thyroid cartilage* is added on ventral surface of larynx. Although, thyroid cartilage was paired initially as in monotremes it is made of two plates rather than one. Moreover, in all mammals it develops from remains of paired branchial arch embryologically. The vocal cords reach maximum differentiation in mammals. They are two pairs band like folds on the inner walls of larynx, extending between arytenoids and thyroid cartilages, one above the other. The upper is called *false* and lower one is called *true* vocal cord. Elephants do not have false vocal cord and hippopotamus has no vocal cords. A flap-like muscular *epiglottis* is present in front of glottis and is characteristic of mammals.

Trachea. Part of air duct between larynx and lungs is termed *trachea*. Its wall is prevented from collapsing due to a series of usually incomplete *cartilaginous rings* arranged in various ways. Lower end of trachea bifurcates forming two *bronchi*, lined with cilia, and each entering a lung. In Anura, trachea is extremely short or absent, merging with larynx to form a laryngo-tracheal chamber. A definite trachea is differentiated in *Siren, Amphiuma* and *Gymnophiona* only. It reaches to a length of 4-5 cm. The walls are further strengthened by a series of small, irregular cartilages, which are usually united to form bands. Length of trachea varies in reptiles depending upon that of the neck. The cartilage rings of trachea gradually become more solid and complete but are generally incomplete dorsally. In lizards and snakes the anterior cartilage round the trachea forms complete rings. In birds, trachea is unusually elongated, and tracheal rings are complete and ossified. In mammals, trachea is variable.

Lungs proper. Swimming bladders of lung fishes *(Protopterus)* are better lungs than those of most amphibians. Two lungs of modern Amphibia

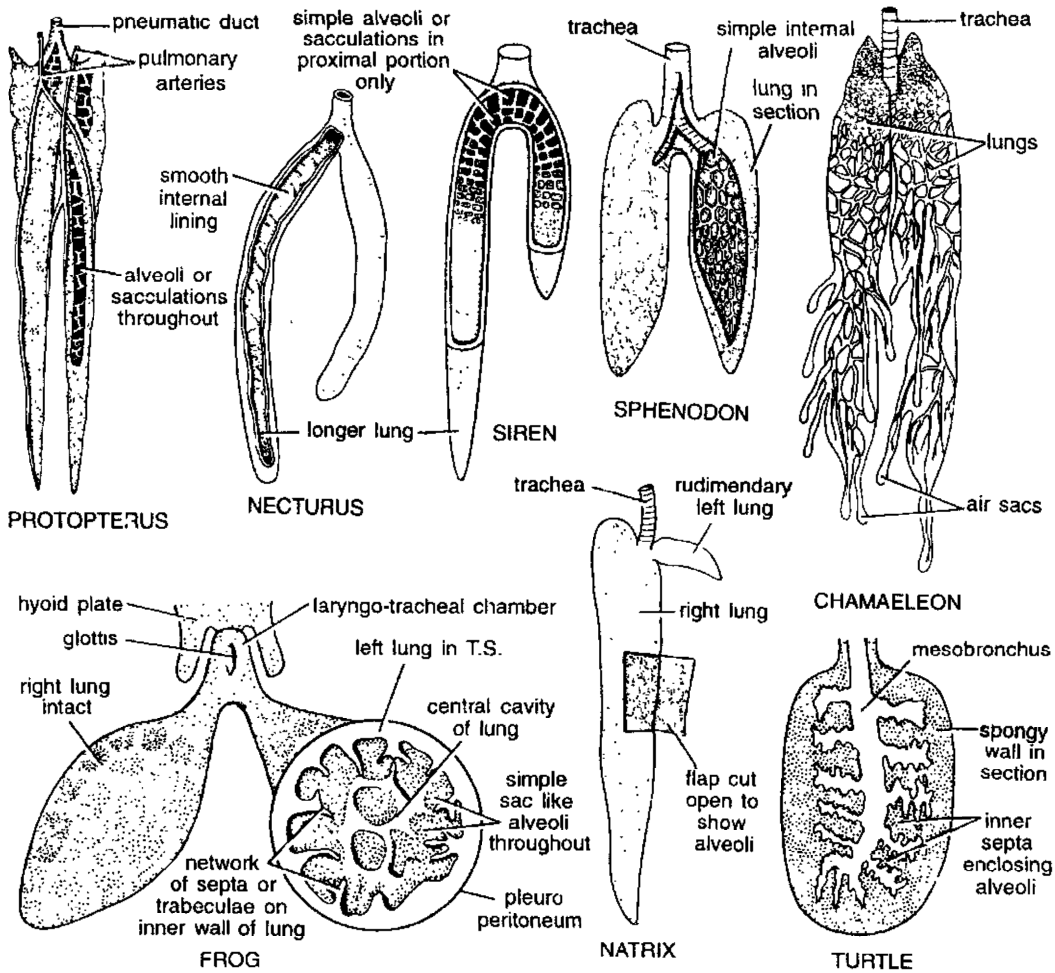

Fig. 4. Different types of vertebrate lungs.

are simple, hollow sacs with a wide central cavity, and suspended freely into peritoneal body cavity (Fig. 4). They are elongate in urodeles but bulbous in anurans. Left lung is usually longer in urodeles but rudimentary in caecilians. Internal lining of lungs may be smooth *(Necturus)*, or may have simple sacculations proximally *(Siren, Amphiuma)*. In frogs and toads (anurans), lung wall may be divided peripherally by a network of folds or *trabeculae* into *air sacs* or *alveoli*. They are richly vascular, lined with mucous epithelium and their inner edges bearing tall ciliated columnar cells.

Lungs of reptiles are more complicated and also abdominal in location. In *Sphenodon* and snakes, lungs remain simple thin-walled sacs. In legless lizards and snakes, left lung may be rudimentary or absent. In Boa and Python both the lungs are functional but left one is slightly smaller. In lizards and turtles, wall of lung is considerably thickened due to inclusion of greater amount of highly vascularized connective tissue in partitions, so that the whole lung becomes spongy. The crocodilian lung most nearly approaches the condition found in mammals. Reptilian lungs also hang freely in the body cavity. In chamaeleons, several long, thin-walled, sac-like diverticula or *air sacs* arise from distal portion of lungs. With the help of these they use to swell to some extent which frightens the predator and helps it to escape.

Structure and function of lungs in birds are not wholly understood (Fig. 5). Avian lungs are unique in architecture and greatly modified due to

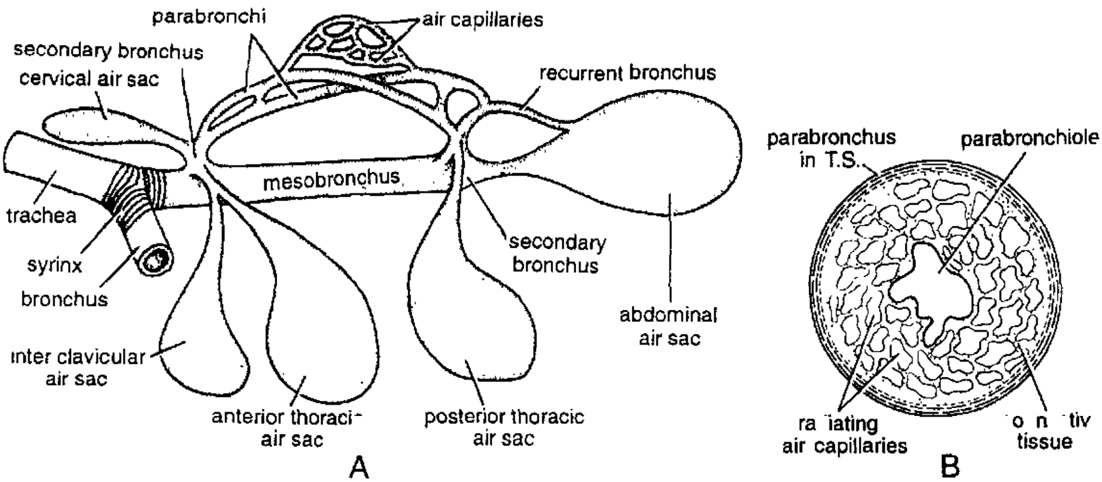

Fig 5. Avian lung. A—Scheme of architecture of a lung and air sacs in a bird. B—Section of a parabronchus showing radiating infundibular or air capillaries.

their aerial mode of life. They show many eculiarities not found in other groups. Lungs are small, compact, spongy and only slightly capable of contr ction nd exp nsion. They are placed outside coelom in p eura cavities. The ower or ventral surface of each lung is closely invested by thin fibrous membrane called *pulmonary*. Several muscle bands called, *costo-pulmonary* muscles which arise from the vertebral ribs are inserted into pleura which are supplied ith *inter-costal nerves*. They give ou several in-walled membranous *air sacs* (= *Cellulae aereae*) that inv d most p rts of the body. The bronchus after entering the lung, divides repeatedly forming a network of anastomosing *air capillaries* which do not terminate blindly. As a result of these novelties, avian lungs become highly efficient organs.

Mammalian lungs are also highly developed, spongy and very elastic (Fig. 6). They lie protected in special chambers, called *pleural cavities*, which are separated from rest of perivisceral body cavity by a muscular *diaphragm*. The pericardium containing heart lies between the pleural cavities. In most mammals, lungs are subdivided externally into lobes, usually more on the right. Thus while there are only 2 left lobes, the right lung has 3 lobes in man and 4 lobes in rabbit. In certain mammals such as whales,

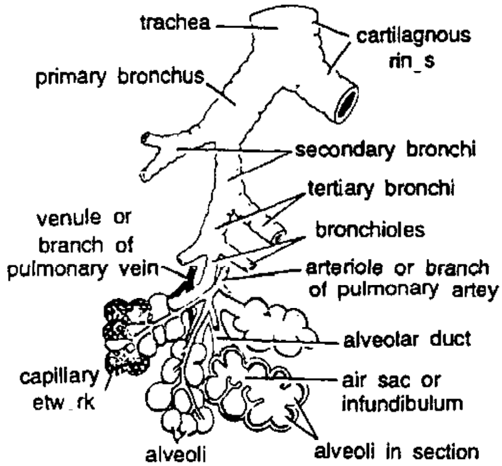

Fig. 6. Mammalian lung. Branching of a bronchus into terminal alveoli.

sirenians, elephants, hyrax, and many perissodactyles, lungs are simple and without lobes. In monotremes and rats, only the right lung is lobulated. The mammalian lung consists like an elaborate branched respiratory tree. The bronchus divides repeatedly inside the lung ultimately resulting into a large number of terminal grape-like clusters of *air-sacs* or *alveoli*. Being terminal and blind, they always retain a certain amount of residual air after every expiration. In mammals, intercostal muscles, ribs, diaphragm, sternum and abdominal muscles, all aid in breathing.

Accessory Respiratory Organs

Although gills serve as chief respiratory organs of aquatic vertebrates, and lungs serve terrestrial vertebrates in a similar way, other structures present may also provide accessory respiratory mechanism, for taking O_2 directly from water or air.

1. Yolk sac and allantois. Practically all embryonic vertebrates use yolk sac with its vitelline circulation for gaseous exchange in addition to absorbing yolk which is used as food. Yolk sac of dogfish embryo and yolk sac placenta of the marsupials, in contact with uterine wall, serve as respiratory devices. In reptiles, birds and mammals, allantois and allantoic (umbilical) vessels also become temporary respiratory organs during embryonic life.

2. Skin. In amphibians, respiration is common via moist and naked skin which is highly vascular. Lungless salamanders or plethodonts rely entirely on skin for respiration, since larval gills disappear at metamorphosis and adults fail to develop lungs. Vascular hairy cutaneous projections in the male of so-called African hairy frog, *Astylosternus* serve a respiratory function. The vascular caudal fin of mud-skipper *Periophthalmus*, which remains submerged, also functions as a breathing organ.

3. Lining epithelium. In some fishes and aquatic amphibians, the lining of cloaca, rectum, gut or bucco-pharyngeal epithelium is highly vascular and aids in respiration.

4. Cloacal bladders. Reptilian skin is cornified and useless in respiration. But, in some aquatic turtles, a pair of thin-walled, lateral and greatly vascular cloacal bladders are continually being filled and emptied of water through vent. These accessory bladders serve as important respiratory organs, especially during submergence for longer durations.

5. Pelvic gills. In American lung fish *Lepidosiren*, the bushy, filamentous vascular gills attached to the pelvic fins of male provide fresh oxygen to the guarded eggs.

6. Opercular gills. In some fishes with an operculum such as *Acipenser*, *Lepidosteus*, *Polyodon*, *Polypterus* and many teleosts, a series of vascular lamellae with a respiratory function develop on the inner surface of operculum.

7. Pseudobranchs. Pseudobranchs in spiracles of elasmobranchs and also in some teleosts are homologous with true gills and regarded as demibranchs of the mandibular arch. However, they are not respiratory as they receive already arterial blood.

8. Pharyngeal diverticula. The vascular posterior extensions of pharynx in *Periophthalmus*, *Amphipnous* and *Channa* (= *Ophiocephalus*) serve to breathe atmospheric air during aestivation and emergence out of water for short periods.

9. Branchial diverticula. The vascular outgrowths of branchial chamber in *Heteropneustes* (= *Saccobranchus*), *Clarias* and *Anabas* form more complicated aerial accessory respiratory organs.

10. Swim bladders. Another important structure serving as a lung in some lower fishes is the swim bladder or air bladder discussed in detail in Chapter 18.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give a comparative account of respiratory organs in the vertebrates studied by you.
2. Write an essay on accessory respiratory organs of vertebrates.

» ***Short Answer Type Questions***

1. Write short note on — (i) Air bladder, (ii) Larval gill, (iii) Pseudobranchs, (iv) Swim bladders.

» *Multiple Choice Questions*

1. Gills and lungs of vertebrates are the derivative of embryonic :
   (a) Pharynx (b) Archenteron
   (c) Heart (d) Kidney
2. A complete gill is called :
   (a) Demibranch (b) Holobranch
   (c) Hemibranch (d) Pseudobranch
3. In bony fishes operculum arises from :
   (a) Hyomandibular (b) Mandible
   (c) Sphenethmoid (d) Hyoid arch
4. Lungs of reptiles are located in :
   (a) Neck (b) Thorax
   (c) Abdomen (d) Tail
5. Respiratory organ of embryonic vertebrates :
   (a) Yolk sac (b) Amnion
   (c) Chorion (d) Egg membrane
6. During submergence in aquatic turtles the accessory respiratory organ is :
   (a) Skin (b) Gill
   (c) Cloacal bladder (d) Air sacs

ANSWERS

1. (a) 2. (b) 3. (d) 4. (c) 5. (a) 6. (c).

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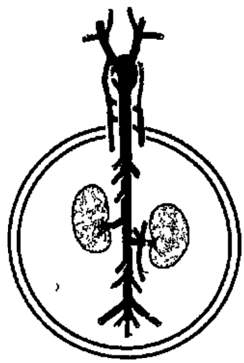

Circulatory System in Vertebrates

In order to carry on vital life processes, all animals, from the simplest protozoans to the most complex vertebrates, required that —

(1) *Food* absorbed through digestive tract and oxygen collected in respiratory organs, must be transported to all parts of the body, continually, for metabolism.

(2) *Waste products* of metabolism (CO_2, nitrogenous wastes, etc.) must be transported from the sites of their productions to excretory organs for their quick elimination from body.

(3) *Hormones* from endocrine tissues, substances for maintaining *homeostasis* or constancy of internal environment, and providing immunity from diseases, must be conveyed to suitable sites for utilization.

For these and other reasons, an adequate internal system for circulating nutrients and other materials throughout the body becomes necessary, called *circulatory system*. In one-celled body of protozoans, distribution occurs through *cyclosis* or streaming movements of cytoplasm. In simple and less active multicellular animals (Porifera, Coelenterata, Helminthes, etc.) exchanges occur by simple diffusion between various adjacent parts of their bodies. But most higher invertebrates and vertebrates are large and active, with most body organs and tissues well removed from exterior or gut. For them, diffusion alone cannot suffice. Thus, they possess a well-developed *circulatory system* for rapid internal transport of gases, nutrients, wastes, etc.

Parts of Circulatory System

Chordates have a completely closed circulatory system (Fig. 1), further distinguished into two systems, *blood vascular* and *lymphatic*, having parts as follows :

1. Blood vascular system. It consists of heart, arteries, veins, capillaries and blood. (i) *Blood* consists of fluid plasma and free cells or blood

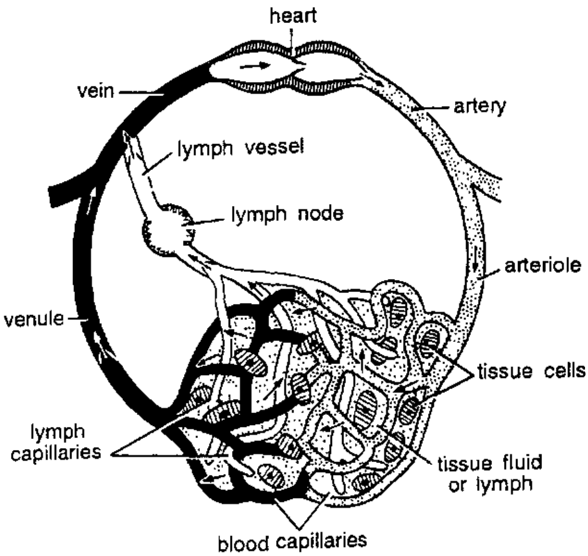

Fig. 1. Fundamental structure and parts of a typical mammalian circulatory system.

corpuscles. (ii) *Heart* is a modified blood vessel with muscular walls. It contracts periodically to pump blood through body. (iii) *Arteries* are blood vessels that carry blood away from the heart. (iv) *Capillaries* are minute tubes with thin walls in tissues, that connect the smallest arteries (arterioles) with the smallest veins (venules). (v) *Veins* carry blood towards heart from capillary networks.

When blood flows through capillaries connected by arteries and veins, the blood vascular system is said to be 'closed', as in annelids and vertebrates. On the other hand, mollusc's and arthropods lack capillaries and have an 'open' or 'lacunar' system. The blood pumped by their heart through blood vessels to various organs, passes through body spaces or sinuses comprising the haemocoel.

2. Lymphatic system. It occurs exclusively in chordates, except cyclostomes and cartilaginous fishes, and consists of lymph and lymph channels. (i) *Lymph* is the *tissue fluid*, lying between and bathing body cells. It is similar to blood plasma but lacks the red blood corpuscles and some proteins. (ii) *Lymph capillaries* forming a network of minute, blind-ending channels, collect lymph. (iii) *Lymph vessels* — l_ger thin-w_ll_d v_ss_ls formed by the union of lymph capillaries, and finally emptying into veins. (iv) *Lymph nodes*, found only in mammals on lymph vessels, produce lymphocytes of blood and form an important link in body's defense mechanism.

In cyclostomes and chondrichthyes no lymphatics are present but little sinusoids are found, representing the first stage of development. Bony fishes and all tetrapodes are provides with lymphatic system. But as far as circulation is concerned, it is active in amphibian due to development of *lymph heart. Lymphatic glands* first appeared in reptiles and found in birds and mammals as well.

Bloo' vascular sys em has un'ergone some striking changes during the evolution of vertebrates. These are mostly correlated with shift from gills to lungs as the site for external respiration during transition from water to land, and with the development of an efficient, high pressure circulatory system necessary for an active terrestrial life.

Evolution of Heart in Vertebrates

In the embryo, two longitudinal endothelial tubes, formed by mesenchyme in ventral mesentery below archenteron, fuse together to give rise to the heart. The vertebrate heart is built in accordance with a basic architectural plan (Fig. 2). It is a sac-like muscular organ comprising a series of chambers, that receives blood from veins and pumps it through arteries.

[I] Single-chambered heart

Cephalochordata. In a primitive chordate, such as *Branchiostoma*, a true heart is lacking. Instead a part of ventral, aorta below pharynx becomes muscular and contractile. Some zoologists consider it as a *single-chambered heart.*

Progressive modifications of heart from primitive to higher chordates occurs on the following lines :

(1) Cardiac tube forms chambers due to constrictions.

(2) Each chamber tends to divide into two separate chambers due to formations of partitions.

(3) Heart gradually shifts from just behind head (fishes, amphibians) near gills into thoracic cavity (amniotes) with elongation of neck and development of lungs.

[II] 2-Chambered, single circuit venous hearts

Cyclostomes. Simplest conditions of vertebrate heart is seen in cyclostomes (ammocoete larva, lamprey, hagfish). It shows a linear series of 4 chambers : *sinus venosus, atrium, ventricle* and a small *conus arteriosus*, through which blood flows in that sequence. It is present in the common body cavity along with other visceral organs.

Elasmobranchs. Heart of a cartilaginous dogfish is typical and generalized for most fishes. It is a muscular and dorso-ventrally bent, S-shaped tube consisting of 4 chambers arranged in a linear sequence. Of these, sinus venosus and conus arteriosus are *accessory chambers*. Only auricle and ventricle are *true chambers* so that heart is considered *two-chambered* in fishes. Thin-walled *sinus venosus* receives venous blood of body through larger veins (common cardinal and hepatic), serves chiefly as a reservoir and opens anteriorly into atrium through the *sino-atrial aperture* guarded by a pair of valves. *Atrium* is large, thin-walled, elastic and muscular chamber lying dorsal to ventricle. It opens ventrally into ventricle through an *atrio-ventricular aperture* guarded by a pair of valves. *Ventricle* has very thick and muscular walls. It opens into a muscular tube of narrow diameter, the *conus arteriosus*, having a series of semilunar valves. All the valves of heart prevent backflow or regurgitation of blood.

Heart of fishes is enclosed in a small *pericardial cavity* separated from general coelom by a transverse septum. In front of *pericardial cavity*, conus becomes continuous with the ventral aorta. In elasmobranchs, transverse septum is perforated by a pair of openings through which pericardial cavity communicates with coelom.

Teleosts. Heart of bony fishes resembles in all respects that of elasmobranchs. In some Chondrostei *(Polypterus)* and Holostei *(Lepidosteus)*, conus is fairly long with numerous valves. In *Amia*, conus and number of its valves are reduced. While in Teleostei, conus is much reduced, or even absent, as it fuses with ventricle, and retains a single pair of semilunar valves. Instead, the part of ventral aorta in contact with conus becomes greatly enlarged with thick muscular walls, and called *bulbus arteriosus*. It is elastic and inflates like a balloon when the ventricle contracts.

In fishes, heart is small, 2-chambered and with a single circuit of blood circulation. All blood passing only once through heart is non-oxygenated. It is pumped into gills for aeration before distribution to body. Such a heart is termed a *branchial* or *venous heart*.

[III] 3-Chambered transitional hearts

Dipnoi. Correlated with the shift from aquatic (gills) to terrestrial respiration (lungs), heart and aortic arches also become modified. Parallel with the *systemic circulation*, a new shorter *pulmonary circulation* develops so that aerated blood from lungs (or swim bladder), returns directly to the heart without making a detour of the whole body. *Atrium* of lung fishes (and most urodele amphibians) is divided by an incomplete *inter-auricular septum*, perforated by the *foramen ovale*, into right and left chambers or *auricles*. This results in a mixing of oxygenated blood received from lungs into left auricle, and deoxygenated blood from rest of body into right auricle. A partial partition also divides the *ventricle*, while a horizontal septum divides the *conus* of lungfishes into a dorsal and a ventral part.

Amphibians. Amphibians heart (anurans) shows an advance over the piscine heart. A twisting or curving results in dorsal *atrium* shifting anteriorly to ventricle. Similarly, *sinus venosus* opens into the right atrium dorsally instead of posteriorly. The *inter-auricular septum* is complete,

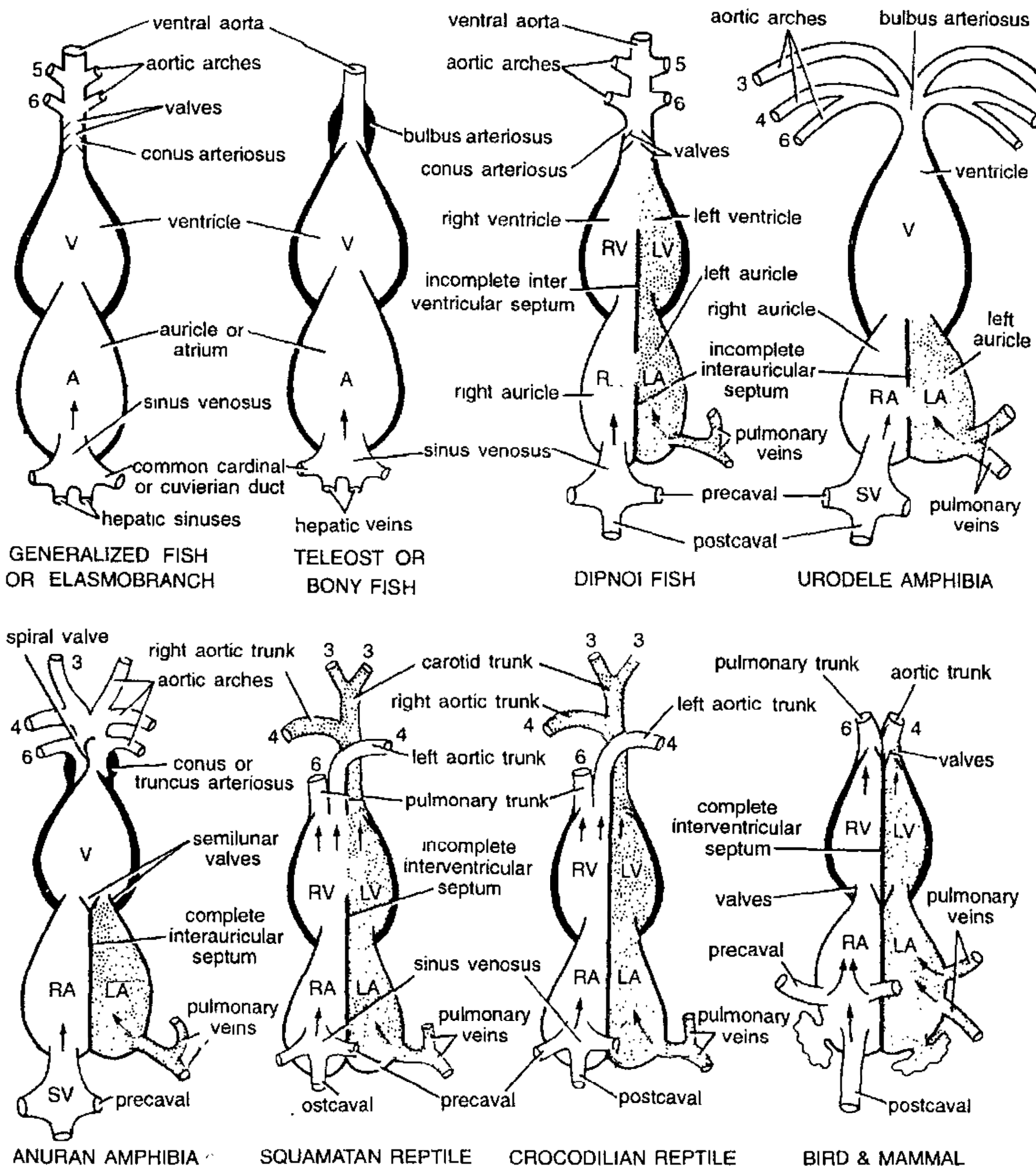

Fig. 2. Successive modifications of heart during evolution in different classes of vertebrates. 1—6 represent aortic arches. Shaded chambers contain mainly oxygenated blood. LA—left auricle, LV—left ventricle. RA—right auricle. RV—right ventricle. SV—sinus venosus.

without foramen ovale. This keeps the oxygenated and deoxygenated bloods separate. *Ventricle* is undivided or single, but its thick muscular wall raised into trabeculae permitting only little mixing of the two bloods. In urodeles, conus is reduced and replaced by a *bulbus arteriosus*. In anurans, from left ventricle, on its anterolateral margins *conus* (or *truncus*) *arteriosus* arises which is prominent and divided by a *spiral valve* which directs deoxygenated blood into pulmonary vessels and oxygenated blood into systemic vessels. The lumen of conus arteriosus is called, pylangium is occupied by spiral valve (= *septum bulbi*). This valve is very complicated in its disposition. It is attached to the walls of conus dorsally and free at other three faces. It divides the lumen of conus arteriosus into two chamber— *cavum pulmocutaneum* and *cavum aorticum.*

Reptiles. Heart of reptiles shows further improvement over that of amphibians. It becomes more strongly muscular. It shows two auricles and two ventricles. In most reptiles, *ventricle* is partially divided by an incomplete *inter-ventricular septum,* which reduces the mixing of oxygenated and deoxygenated blood. In crocodilians, this septum is complete thus making an effective 4-chambered heart, having two auricles and two ventricles. However, complete separation of oxygenated and deoxygenated blood is not achieved. The right and left systemic aortae, carrying arterial and venous bloods, respectively, join to form the dorsal aorta in which the two bloods get mixed before distribution. Besides, a small opening, called *foramen* of *panizza,* connecting the two aortae at their base, brings about some mixing of blood. In crocodiles foramen panizza becomes obliterated. A *sinus venosus* is present in all reptiles, large in turtles, small in snakes and lizards, and distinct internally in crocodiles. Conus and ventral aorta of embryo become split in the adult into three distinct trunks-pulmonary and right and left systemic.

Amphibian heart with only 3 major chambers (2 auricles, 1 ventricle), and reptilian heart with partially 4 chambers (2 auricles, 2 incomplete ventricles), permit a partial mixing of arterial and venous bloods before distribution. Thus, they represent *transitional hearts* showing a midway condition between 2-chambered heart of fishes with a single circulation and 4-chambered hearts of birds and mammals with double circulation and complete separation of arterial and venous bloods.

[IV] 4-Chambered, double circuit pulmonary hearts

Birds and mammals. Birds and mammals have a completely divided *ventricle*, so that their heart is completely 4-chambered (2-auricles, 2 ventricles). Left auricle receives aerated blood from lungs, pours into left ventricle which pumps it to entire body through *systemic circulation.* Right auricle receives deoxygenated blood returning from body, passes it to right ventricle which pumps it to lungs for reoxygenation. Thus there is *double circulation* in which there is no mixing of oxygenated and non-oxygenated blood at all. Such a heart is known as a *pulmonary heart. Sinus venosus* is absent being completely incorporated into right auricle which directly receives two precavals, postcaval. The union of sinus with right auricle in some cases is marked externally by a groove called *sulcus terminalis* and internally by a muscular ridge, *crista terminalis* which separates right auricular chamber (*sinus venerum*) from smaller ventral chamber (*appendix auricular*). Similarly, the left auricle receives blood directly through pulmonary veins. Primitive conus arteriosus is completely replaced by a pulmonary aorta leaving the right ventricle for lungs, and a single systemic aorta leaving the left ventricle for body. All major vessels have valves basally at the point of exit from or entry into heart. Blood from the walls of the heart is brought to the auricle by means of *coronary sinus* in right atrium. The opening of the sinus is guarded by valves called *coronary valve* (= *Thebsian valve*). The inner surface of right auricle wall is marked by small depressions of *Thebesian foramina* in which fine veins directly pass the blood from atrial walls to right atrium. Although, interauricular septum is complete in adults but a fine depression, *fossa ovalis* is present which marks the site of *foramen ovale.* The fossa ovalis is surrounded by a prominent ridge *annulus ovalis.*

Modifications of Aortic Arches in Vertebrates

Basic embryonic plan. In a typical vertebrates embryo, the major arterial channels include a *ventral aorta*, a *dorsal aorta* and usually 6 pairs of *aortic arches* connecting ventral aorta with the dorsal aorta (Fig. 3). Blood leaves the heart through *ventral aorta* which runs forward,

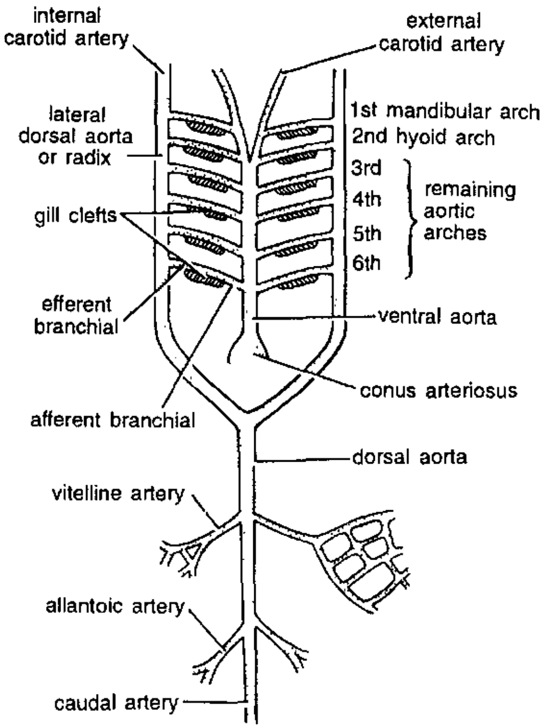

Fig. 3. Basic pattern of chief arterial channels of a typical vertebrate embryo.

midventrally beneath the pharynx and branches anteriorly into a pair of *external carotid arteries* into head. Ventral aorta gives off, at intervals, 6 pairs of *aortic arches* running through the visceral arches. Each *aortic* arch consists of a ventral *afferent branchial artery* carrying venous blood to capillaries in a gill, and a dorsal *efferent branchial artery* taking arterial blood from the gill. All the efferent branchial arteries of the same side dorsally join a *lateral dorsal aorta* or *radix* which is extended into head as the *internal carotid artery*. The two lateral dorsal aortae unite just behind the pharynx to form a single median *dorsal aorta* which continues behind into tail region as *caudal artery*. Branches from these main arterial channels supply all parts of the vertebrate body.

Although arterial system of different adult vertebrates shows major differences, but it is actually built according to the same basic architectural plan as seen in the vertebrate embryo (Fig. 4). The differences are due to increasing complexity of heart on account of a shift from gill respiration to lung respiration. The modifications mainly concern the aortic arches which undergo a progressive reduction in number from lower to higher vertebrates.

Primitive vertebrates. In *Branchiostoma* (amphioxus), nearly 60 pairs of aortic arches are present, connecting the ventral and dorsal aortae. In *Petromyzon*, 7 pairs of aortic arches are found. In other cyclostomes the number varies from 6 *(Myxine)* to 15 pairs *(Eptatretus)*.

Fishes. The primitive elasmobranch *(Heptanchus)* has 7 pairs of aortic arches. Most of the fish embryos present primitive plan with 6 or more pairs of aortic arches, each passing through a gill. But, in adult condition, the number is reduced to 4 or 5. In most sharks (elasmobranchs), only 5 pairs (II, III, IV, V, and VI) are functional. The first gill slit forms the spiracle which is non-functional as a gill. Accordingly the first arch (mandibular) is absent or represented by an efferent pseudobranchial artery. In most teleosts or bony fishes, I and II arches tend to disappear, so that only 4 pairs (III, IV, V and VI) remain functional. In *Polypterus* and lungfishes (Dipnoi), gills are poorly developed, so that a *pulmonary artery* arises from the efferent part of the VI arch on each side and supplies blood to the developing air bladder or lung. In *Protopterus*, the III and IV embryonic arches are uninterrupted by gill capillaries.

In elasmobranchs and lungfishes, each arch forms one afferent and two efferent arteries (by splitting) in each gill. In teleosts or bony fishes, each gill has one afferent and one efferent artery. In tetrapods, true internal gills are absent so that aortic arches do not break up into afferent and efferent arteries. I and II arches totally disappear in all tetrapods.

Amphibians. With the introduction of lungs as main respiratory organs and the diminishing importance of gills, the aortic arches of amphibians show a modification from those of fishes.

Urodeles or the tailed amphibians live in water and retain external gills permanently in

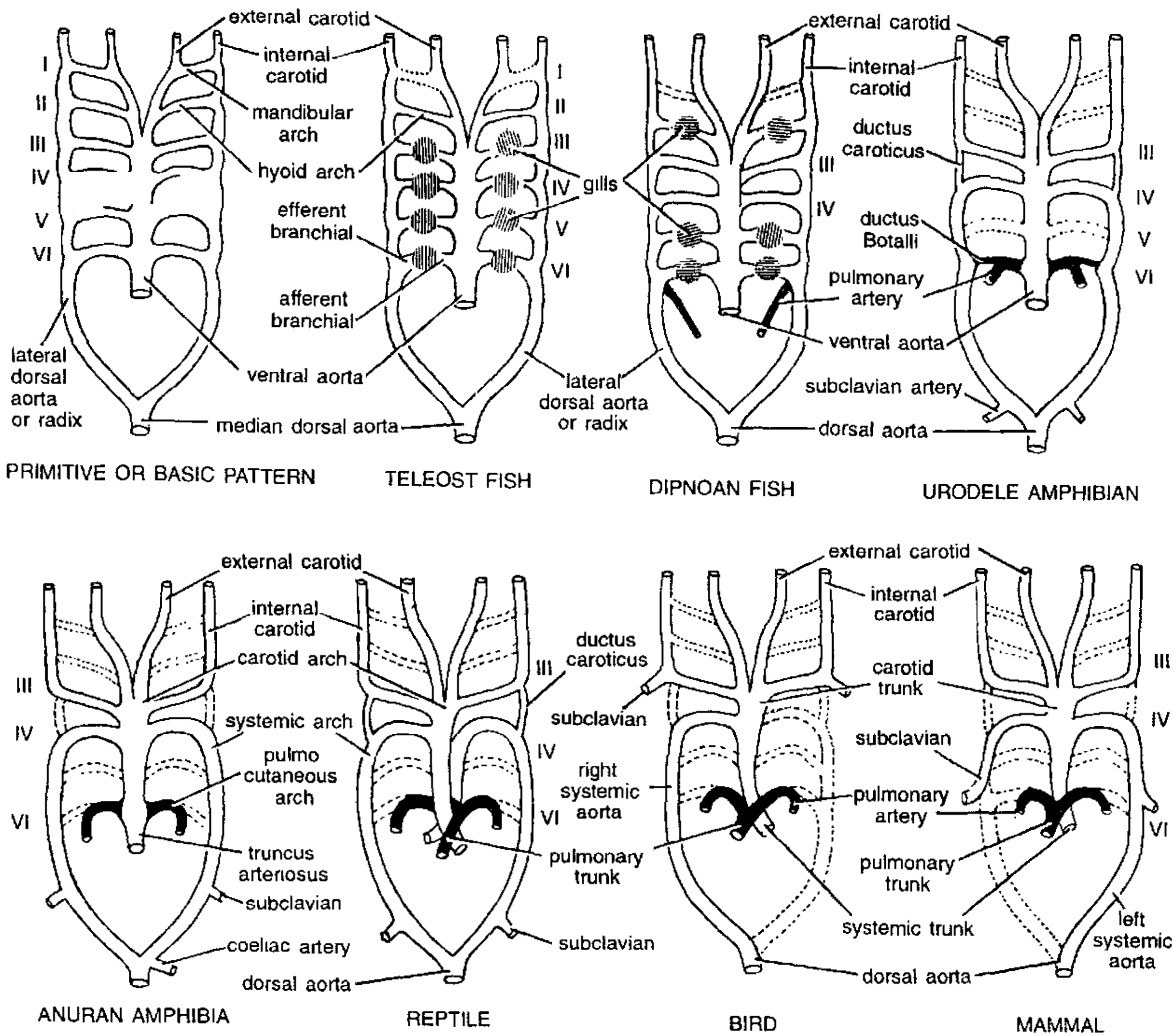

Fig. 4. Modification of aortic arches in respresentative vertebrates.

addition to lungs. Accordingly, their aortic system shows only partial shift from condition in fishes. 4 pairs of arches (III to VI) are usually present, although in some forms (*Necturus*, *Siren*, *Amphiuma*), V arch is incomplete, reduced or absent. Thus tailed amphibians show transition from 4 to 3 pairs of aortic arches. III arch forms the *carotid arches*, IV the *systemic arches*. The radix or lateral aorta between III & IV arches may persist as a vascular connection termed *ductus caroticus*. VI arch on either side becomes the *pulmocutaneous artery* or *arch*, supplying blood to skin and lungs. However, it also retains connection with radix aorta called *ductus Botalli* or *ductus arteriosus*.

In the larval stage of an anuran or tailless amphibian, such as frog tadpole, arrangement of aortic arches is similar to an adult urodele, due to gill respiration. At metamorphosis, with loss of gills, aortic arches I, II and V disappear altogether. Ductus caroticus also disappears so that the III or carotid arch takes oxygenated blood only to head region. IV or systemic arch on each side continues to dorsal aorta to distribute blood elsewhere except head and lungs. Ductus arteriosus also disappears so that VI or pulmocutaneous arch supplies venous blood exclusively to lungs and skin for purification. Thus, adult anurans exhibit only 3 functional arches, (III, IV and VI) which are also retained by the amniotes or higher vertebrates.

Reptiles. Reptiles are fully terrestrial vertebrates in which gills disappear altogether and replaced by lungs. Only 3 functional arches (III, IV and VI) are present. But elongation of neck, posterior shifting of heart and partial division of ventricle brings about certain innovations in the aortic system.

(1) Entire ventral aorta and conus split forming only 3 trunks-two aortic or systemic and one pulmonary.
(2) *Right systemic arch* (IV) arises from left ventricle carrying oxygenated blood to the *carotid arch* (III) to be sent into head.
(3) *Left systemic arch* (IV) leads from right ventricle carrying deoxygenated or mixed blood to the body through dorsal aorta.
(4) *Pulmonary trunk* (VI) also emerges from right ventricle carrying deoxygenated blood to the lungs for purification.
(5) Ductus caroticus and ductus arteriosus are absent. But, ductus caroticus is present in certain snakes and lizards (*Uromasitx*), ductus arteriosus in some turtles, and both in *Sphenodon*. Reptiles also remain cold-blooded, like amphibians and fishes, due to mixing of blood.

Birds and mammals. Birds and mammals are warm-blooded because in both the ventricle is completely divided so that there is no mixing of oxygenated and unoxygenated bloods. As usual, 6 arches develop in the embryo, but only 3 arches (III, IV, VI) persist in the adult. Other features are as follows —

(1) Ventral aorta is replaced by two independent aortae or trunks-systemic and pulmonary.
(2) Arch IV is represented by a single *systemic aorta*, right in birds and left in mammals, emerging from left ventricle and carrying oxygenated blood. Uniting with the radix aorta of its side it forms the dorsal aorta.
(3) The only remaining part of the other lost systemic arch is represented by a *subclavian artery*, on left side in birds and on right side in mammals.
(4) Arch III with remnants of lateral and ventral aortae represents *carotid arteries*, which arise from systemic aorta.
(5) Arch VI forms a single *pulmonary trunk* taking deoxygenated blood from right ventricle to the lungs.
(6) Embryonic *ductus caroticus* and *ductus arteriosus* also disappear. The latter closes but persists until hatching or birth in some cases as a *thin ligament of Botalli* or *ligamentum arteriosum*.

Venous System

Deoxygenated or venous blood from different parts of the body is returned to the heart via veins. Like arteries, the veins of all vertebrates also follow a basic pattern or fundamental plan.

[I] Embryonic veins

The venous system in early embryonic life of all vertebrates is relatively simple, similar and in accordance with the basic pattern. Most of the veins are paired and symmetrically arranged. The major basic embryonic veins include : (i) *Cardinals* (anterior, posterior, and common cardinal or ductus Cuvieri), (ii) *lateral abdominal*, (iii) *vitelline*, (iv) *subintestinal*, and (v) *caudal*.

[II] Modifications of veins in vertebrates

Modifications in adult vertebrates occur by either deletions or additions of some veins to the basic embryonic pattern (Fig. 5). Modifications are few in elasmobranchs but more numerous in tetrapods. In vertebrates, veins can be arranged in three distinct categories– *systemic* or *somatic*, *renal portal* and *hepatic portal*. A fourth category of *pulmonary veins* and *postcaval veins* in added in lungfishes and tetrapods.

1. Systemic veins. Systemic or somatic veins collect blood from all parts of the body and empty into sinus venosus of the heart.

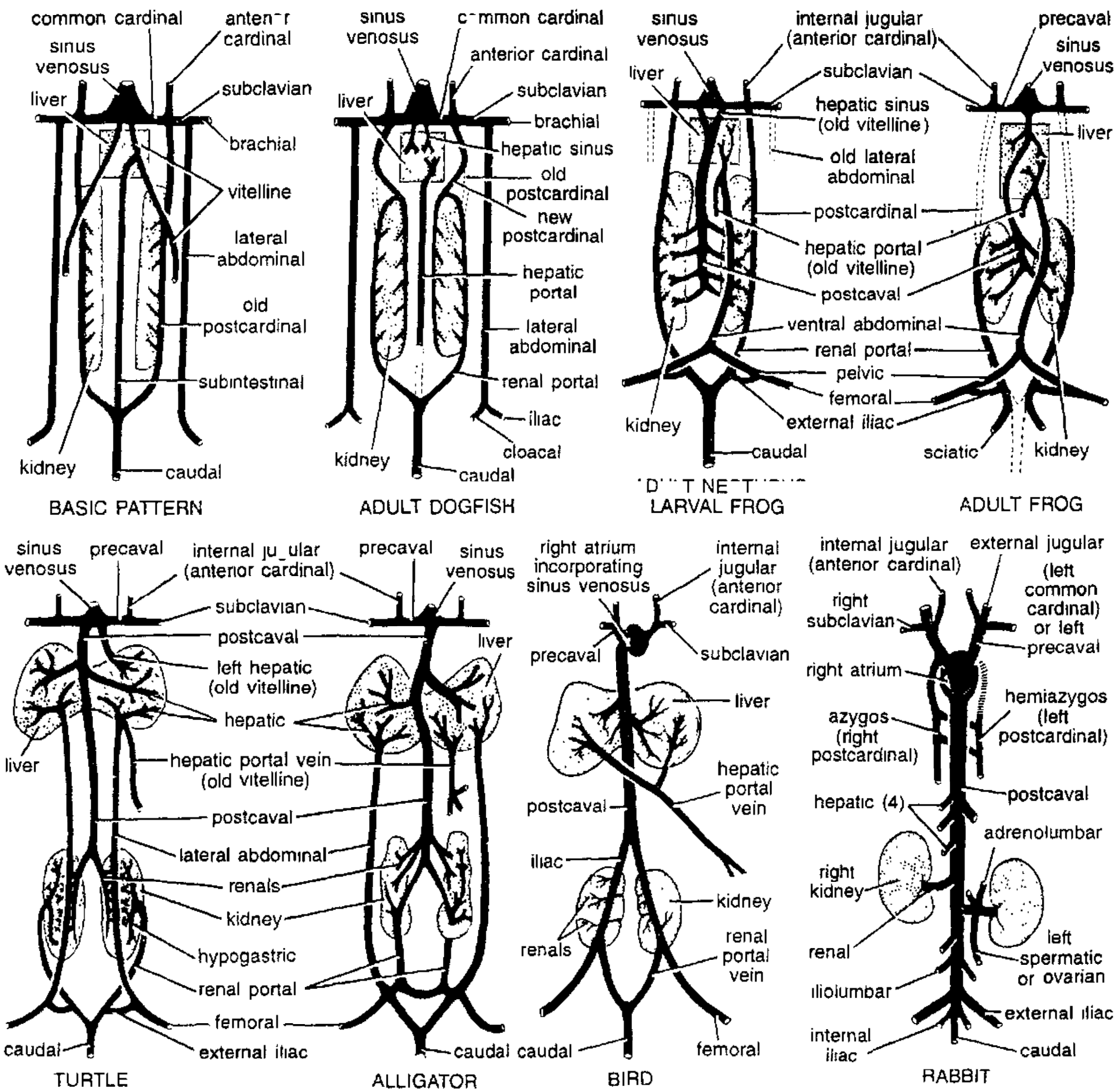

Fig. 5. Modifications of venous system in representative vertebrates. Broken line respresent embryonic vessels that have disappeared in the adult.

(a) ***Elasmobranchs.*** In adult cartilaginous fishes (dogfish), venous system is almost a blueprint of the basic architectural plan of the embryo. A few larger veins expand to form thin-walled *sinuses*. Blood from head and posterior region of body is collected by large, paired *anterior* and *posterior cardinal veins* respectively. On either side they open into the *common cardinal* or *ductus Cuvieri*, that passes inwards through transverse septum to enter the sinus venosus of heart. In fishes and salamanders, an *inferior jugular vein* also collects blood on either side from ventral part of head to join the common cardinal. In embryo, posteriorly, the two posterior cardinal veins remain continuous with a *caudal vein* collecting blood from tail. Each posterior

cardinal, or *postcardinal*, runs anteriorly along the outer margin of kidney, draining it through a series of *renal veins*, before joining the common cardinal. In adult dogfish, the old postcardinals become interrupted near anterior ends of kidneys. Instead new postcardinals (earlier subcardinal channels) develop along the inner margins of kidneys which they drain.

Blood from lateral wall and pelvic fin on either side is returned through a *ventral* or *lateral abdominal vein*. It receives a *branchial vein* from pectoral fin forming a short *subclavian vein* enters the common cardinal of its side. Abdominal veins are absent in bony fishes or teleosts. In some lungfishes (*Neoceratodus*), two abdominals fuse to form a single *ventral abdominal vein* which terminates into sinus venosus. Blood from liver is taken to sinus venosus through a pair of *hepatic veins* or *sinuses*.

(b) Tetrapods. Embryonic tetrapods also exhibit anterior, posterior and cardinal veins. In adult tetrapods, anterior cardinals persist as the *internal jugular veins*. The *inferior jugular veins* are absent. Common cardinals become the anterior venae cavae or *precavals* which join sinus venosus (amphibians, reptiles) or directly enter the right auricle of heart (birds, mammals) when a sinus venosus is lacking. In some mammals, (man, cat) left precaval disappears, so that blood of left side enters right precaval through a *branchiocephalic* vessel.

In adult *Necturus* and larval frog, the *postcardinals* retain primitive condition, joining caudal vein posteriorly and common cardinal (precaval) anteriorly. In tetrapods, anterior part of each postcardinal disappears but partially present in reptiles, birds and mammals under new names, such as *azygos*, *hemizygos* and so forth. Whereas, the posterior part of postcardinal, in continuation with the caudal vein, forms the *renal postal vein*.

With the suppression of postcardinals, a new vessel, called inferior vena cava or *postcaval*, develops in tetrapods. It is a large median vessel between the two kidneys originating in the embryonic subcardinal venous plexus. It conveys blood of hind limbs, tail, kidneys, and liver into sinus venosus (amphibians, reptiles) or into right atrium (birds, mammals).

In amphibians, two embryonic ventral or anterior abdominal veins become fused in the adult to form a single *median ventral abdominal vein*. But it terminates anteriorly into liver and no longer drains the forelimbs. In reptiles, abdominal veins remain paired throughout life and also terminate into liver. They remain connected anteriorly with the hepatic portal system, and posteriorly with the renal portal system (by external iliac). In birds, they are modified into epigastric and coccygeo-mesenteric veins. In mammals, abdominal veins are absent except in spiny anteater *(Tachyglossus)*.

In air-breathing vertebrates, *pulmonary veins* drain the lungs and enter the left auricle. In lungfishes and amphibians, right and left vessels unite to form a common pulmonary vein opening into right auricle.

2. Renal portal system. Blood collected from capillaries in different parts of body is returned directly to the heart through systemic veins and their tributaries. However, in some cases, the returning blood is forced to run through a secondary capillary network in kidneys or liver before being sent to the heart. This is called *portal circulation*. The vein carrying blood from one set of capillaries to another is termed a *portal vein*. All the constituents in a portal circulation together form a *portal system*, named after the organ of body having the secondary capillary network. Two portal systems exist in vertebrates : (i) *renal portal* and (ii) *hepatic portal*.

Renal portal system is not universally present in all vertebrates. Cyclostomes have no renal portal system. In vertebrates embryos, *caudal vein* trifurcates anteriorly into a *subintestinal* and two *postcardinal veins*, (basic pattern). In fishes, connection of caudal vein with subintestinal is lost, while the anterior parts of postcardinals are suppressed. As a result, the persistent posterior parts of postcardinals become *renal portal veins* which pour all blood from tail into kidneys through afferent renal veins. Inside kidneys, they contribute blood to the capillary network surrounding the mesonephric tubules, but never to the glomeruli. Thus renal portal system drains only the tail in fishes.

In amphibians and reptiles, an *external iliac* vein connects the renal portal and abdominal veins, so that the renal portal system drains the tail as well as the hind limbs. In tailless amphibians or anurans (frog), it drains only hind limbs, while in snakes, having no limbs, it drains only the tail. In *Necturus*, renal portal vein is directly continuous with postcardinal, as in the basic pattern.

In crocodilians and birds, renal portal system is degenerate and bypasses the kidneys. Only a very little venous blood enters the capillaries in kidneys while most blood from tail and hind limbs passes nonstop through kidneys and leads directly into the postcaval. In mammals, renal portal system is completely absent, except in monotremes, since blood from tail and hind limbs is drained solely by the postcaval.

Significance. During metabolic activities in the body certain toxic or harmful end products such as urea, uric acid, ammonia, etc., are formed. Renal portal system sends blood from hinder body region directly to the kidneys for the removal of these waste products.

3. Hepatic portal system. Hepatic portal system is of universal occurrence and essentially similar in all vertebrates. In the embryo, the first venous channels to form are a pair of *vitelline veins* (basic pattern) arising from the yolk sac or midgut to enter the sinus venosus of heart. Caudal vein from tail is continued forward beneath the digestive tract as a subintestinal vein, which usually joins the left vitelline vein. As liver develops, vitelline veins unite together forming a single *hepatic portal vein* in lesser omentum. The subintestinal vein also loses connection with caudal vein to become a part of hepatic portal system. It drains different parts of digestive tract (yolk sac, stomach, intestine, etc.), its various derivatives (pancreas, gall bladder, rectal gland, etc.) and spleen, and passes it on to the sinusoids in liver. In adult sharks, vitelline veins remain paired and form *hepatic sinuses.*

Significance. Intestinal capillaries absorb several kinds of dissolved food material, except fats, from alimentary canal. These are carried in blood through hepatic portal vein to liver to be temporarily stored up until required. Carbohydrates and sugars are converted into glycogen to be stored in liver cells. If all the sugar remains in circulation, the concentration of blood sugar may go up leading to diabetes. Stored sugar from liver cells is released whenever sugar content of blood drops below normal, which may otherwise lead to unconsciousness. Liver also converts proteins and amino-acids into urea and renders carbolic acid, cresol, indol, ammonia, etc., harmless.

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Trace the evolution of heart in vertebrate series.
2. Give a comparative account of heart in vertebrate series.
3. Give a comparative account of hearts and aortic arches in reptiles, birds and mammals
4. Describe the embryonic arterial and aortic arches of vertebrates and discuss their modifications in different groups of vertebrates.

» ***Short Answer Type Questions***

1. Write short notes on— (i) Branchial or venous heart, (ii) Ductus Botalli, (iii) Ductus caroticus, (iv) Foramen of Panizza, (v) Hepatic portal system, (vi) Renal portal system, (vii) Truncus arteriosus.

» ***Multiple Choice Questions***

1. Circulatory system does not :
   (a) Transports nutrients
   (b) Transports excretory products
   (c) Transports hormones
   (d) Transfers impulses
2. Smallest arteries are connected to smallest veins by :
   (a) Arterioles (b) Muscles
   (c) Capillaries (d) Venules
3. In urodeles conus is replaced by :
   (a) aorta (b) Vena cava
   (c) Bulbus arteriosus (d) Foramen ovale
4. The union of sinus venosus with right auricle in mammals is marked externally by :
   (a) Sulcus terminalis (b) Crista terminalis
   (c) Sinus venarum (d) Appendix auriculae
5. The opening of coronary sinus is guarded by :
   (a) Besian valve (b) Mitral valve
   (c) Semilunar valve (d) Tricuspid valve

ANSWERS

1. (d) 2. (c) 3. (c) 4. (a) 5. (a).

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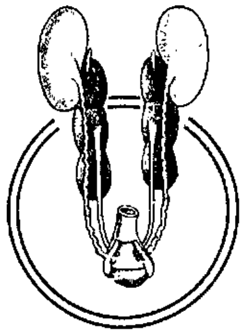

Urinogenital System in Vertebrates

Urinary system of vertebrates includes *kidneys* and their ducts, while reproductive system includes male and female *gonads* and their ducts. Kidneys excrete harmful metabolic nitrogenous wastes and regulate the composition of body fluids, while reproductive organs perpetuate the species. Thus, kidneys and gonads remain functionally unrelated. However, the two systems are intimately related morphologically in vertebrates because the male urinary ducts are also used for discharging gametes. For this reason, it is more convenient to treat and describe the two systems together as the *urogenital* or *urinogenital system*.

Vertebrate Kidneys and Ducts

1. Basic structure and origin. Vertebrate kidneys are a pair of compact organs, lying dorsal to coelom in trunk region, one on either side of dorsal aorta. They are all built in accordance with a basic pattern. Each kidney is composed of a large number of units called *uriniferous tubules* or *nephrons*. Their number, complexity and arrangement differ in different groups of vertebrates.

Kidney tubules arise in the embryo in a linear series from a special part of mesoderm called *mesomere* or *nephrotome* (Figs. 1, 5 & 6). It is the ribbon-like intermediate mesoderm, running between segmental mesoderm (epimere) and lateral plate mesoderm (hypomere) on either side along the entire trunk from heart to cloaca. A uriniferous tubule is differentiated into three parts : *peritoneal funnel, tubule* and *Malpighian body*.

(a) Peritoneal funnel. Near the free end of a uriniferous tubule is a funnel-like ciliated structure called *peritoneal funnel*. It opens into coelom (splanchnocoel) by a wide aperture, the *coelomostome* or *nephrostome*, for draining wastes from coelomic fluid. Nephrostomes are usually confined to embryos and larvae and considered vestiges of a hypothetical primitive kidney.

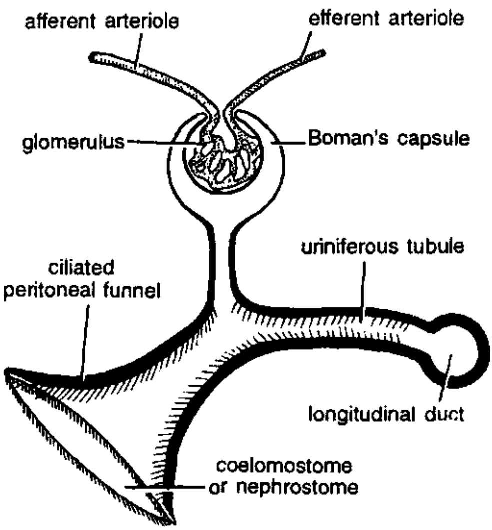

Fig. 1. Structure of an embryonic kidney tubule.

(b) ***Malpighian body.*** A tubule begins as a blind, cup-like, hollow, double-walled *Bowman's capsule*. It encloses a tuft of blood capillaries, called *glomerulus*. It is supplied blood by a branch of renal artery, called *afferent glomercular* [illegible] out of glomerulus to join the capillary network surrounding the tubule.

Bowman's capsule and enclosed glomerulus together form a *renal corpuscle* or *Malpighian body*. Encapsulated glomeruli are termed *internal glomeruli* which are common. Those without a capsule and suspended freely in coelomic cavity are called *external glomeruli* (embryos and larvae). Capsules without glomeruli are termed *aglomerular,* such as found in embryos, larvae and some fishes.

(c) ***Tubule.*** Malpighian bodies filter water, salts and other substances from blood. During passage through tubules more substances are secreted into filtrate, while some are reabsorbed. All the tubules of embryonic kidney are convoluted ductules that conduct the final filtrate to a *longitudinal duct* which opens behind into embryonic cloaca.

2. Archinephros. *Archinephros* is the name given to the hypothetical primitive kidney of ancestral vertebrates (Fig. 2). It may be regarded

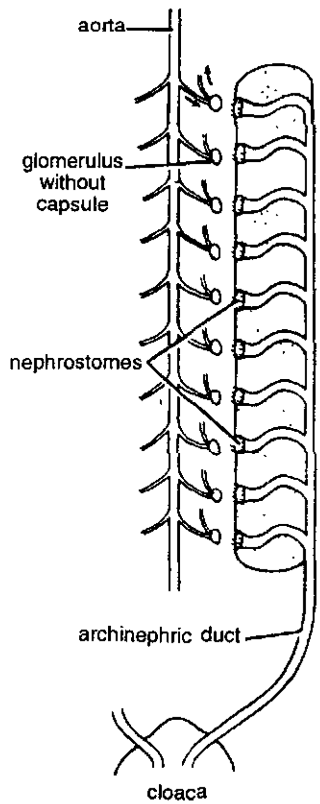

Fig. 2. Hypothetical primitive ancestral vertebrate kidney or archinephros.

as a complete kidney or ***holonephros*** as it extended the entire length of coelom. Its tubules were segmentally arranged, one nephron for each body segment. Each tubule opened by a peritoneal funnel or nephrostome into coelom. Near each nephrostome was suspended in coelom an external glomerulus (without capsule). All the tubules were drained by a common longitudinal *Wolffian* or *archinephric duct* opening behind into cloaca.

Such a hypothetical archinephros is found today in the larvae of certain cyclostomes (*Myxine*), but not in any adult vertebrate. It is supposed to have given rise to all the kidneys of later vertebrates during the course of evolution. Modern vertebrates exhibit three different kinds of adult kidneys : *pronephros, mesonephros* and *metanephros*. It is supposed that these represent the sequence or three successive stages of

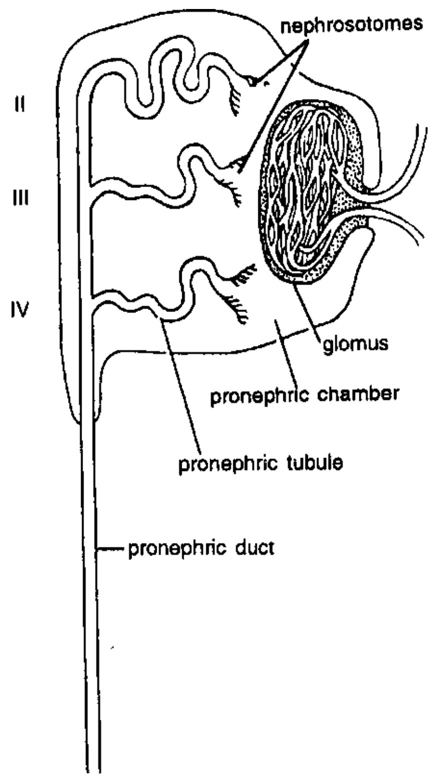

Fig. 3. Encapsulated pronephric kidney of 15 mm. frog larva.

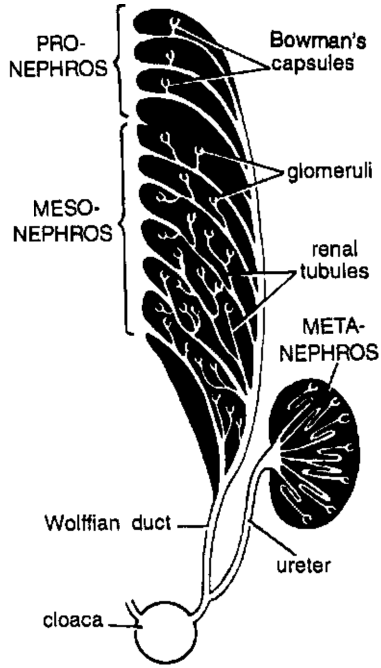

Fig. 4. Diagrammatic plan of pronephros, mesonephros and metanephros in vertebrates.

development of the ancestral archinephros, and all the three are never functional at the same time.

3. Pronephros. In the embryos of all vertebrates, the first kidney tubules appear dorsal to the anterior end of coelom, on either side. These are called *pronephros* as they are first to appear (Fig. 3). Pronephros is also termed *head kidney* due to its anterior position immediately behind the head. A pronephros consists of 3 to 15 tubules segmentally arranged, one opposite each of the anterior mesodermal somites. There are only 3 pronephric tubules in frog embryo, 7 in human embryo and about a dozen in chick embryo. Each tubule opens into coelom by a funnel or nephrostome. Also projecting into coelom near each tubule and not connected with it is an external or naked glomerulus without capsule. In some cases, glomeruli unite to form a single compound glomerulus, called *glomus*. Glomus and tubules become surrounded by a large *pronephric chamber* derived from pericardial or pleuroperitoneal cavity. Originally each tubule has its individual external aperture, but secondarily, all tubules of a pronephros open into a common *pronephric duct*, leading posteriorly into the embryonic cloaca.

Pronephros is functional, if at all, only in embryonic or larval stage. It is mostly transitory and soon replaced by the next stage or mesonephros. However, a pronephros is retained throughout life in adult cyclostomes and a few teleost fishes, but it is nonurinary and mostly lymphoidal in function.

4. Mesonephros. In the embryo, a mesonephros develops from the middle part of intermediate mesoderm, posterior to each pronephros soon after its degeneration (Fig. 4). At first, the new mesonephric tubules join the existing pronephric duct and are segmentally disposed. Later on the tubules multiply by budding so that their segmental arrangement is disturbed due to increased number of tubules per segment. Tubules of pronephros and mesonephros develop similarly

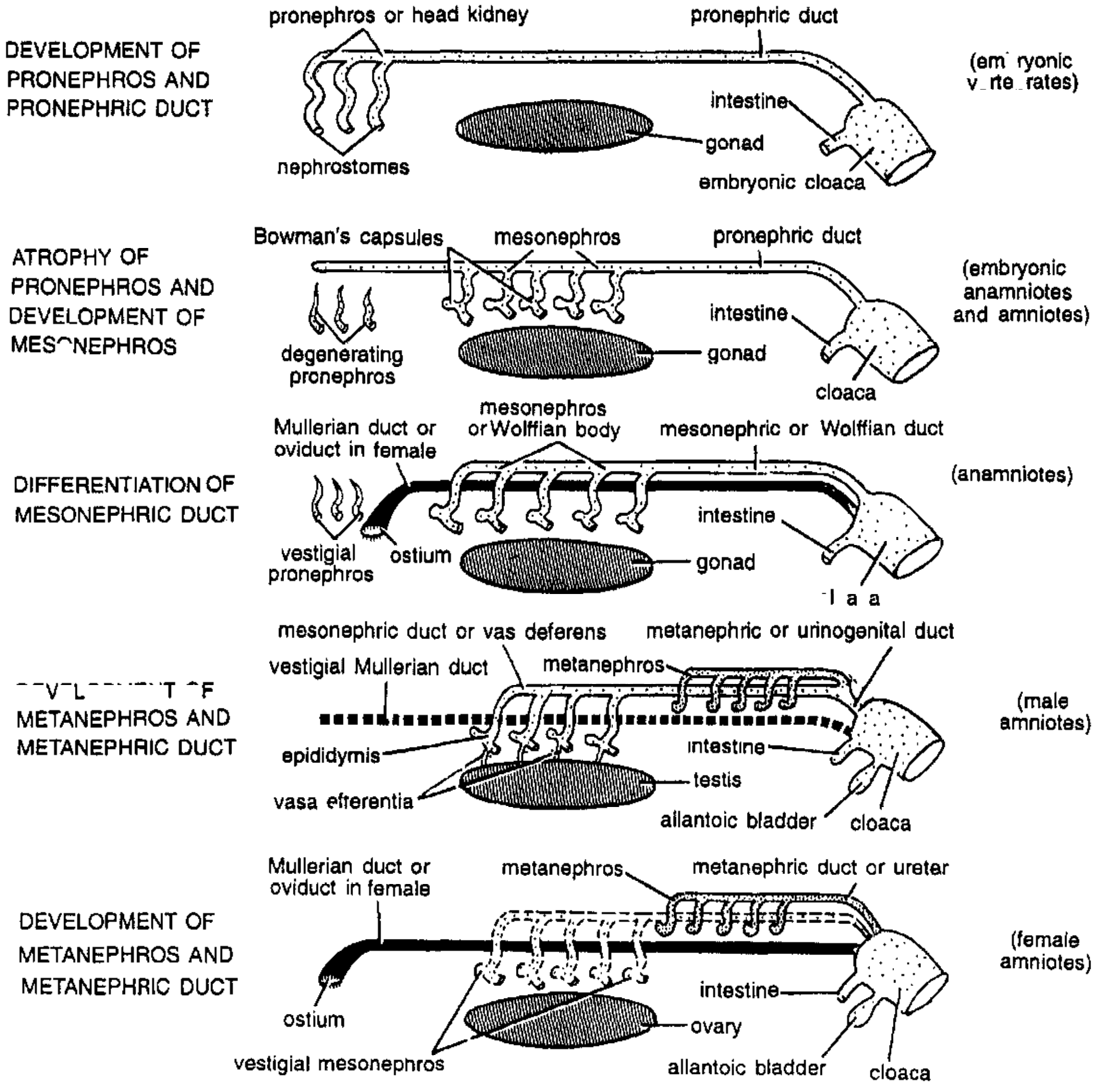

Fig. 5. Evolution of kidney in vertebrate.

and are homologous. However, mesonephros is functionally better than pronephros because mesonephric tubules are more numerous, longer and develop internal glomeruli enclosed in capsules forming Malpighian bodies. Thus, they remove liquid wastes directly from glomerular blood rather than indirectly from coelomic fluid as in case of a pronephros. The mesonephros is also termed *Wolffian body*. With disappearance of pronephros, the old pronephric duct becomes the *Wolffian* or *mesonephric duct*.

In amniotes (reptiles, birds and mammals), mesonephros is functional only in the embryos, replaced by metanephros in the adults. In fishes and amphibians, mesonephros is functional both in embryos as well as adults. In sharks and caecilians, tubules extend posteriorly throughout the length of coelom. Such a kidney is sometimes called a *posterior kidney* or *opisthonephros*. Whereas in adult anurans, urodeles and embryonic amniotes, the mesonephros does not extend posteriorly. Mesonephric kidney is not metameric, but in myxinoids it is segmental and sometimes called a *holonephros*. Nephrostomes are generally lacking in mesonephros of embryonic amniotes.

5. Metanephros. The functional kidney of higher vertebrates or amniotes is a *metanephros*. It is formed from the posterior end of the nephrogenic mesoderm which is displaced somewhat anteriorly and laterally. When metanephric tubules develop, all the mesonephric tubules disappear except those associated with the testis in male and forming vasa efferentia. The adult kidney (metanephros) of amniotes differs from that of anamniotes (mesonephros or opisthonephros) chiefly in :

(1) Its origin from only caudal end of nephrogenic mesoderm.

(2) In greater multiplication and posterior concentration of nephrons or tubules. They are particularly very large in number and highly convoluted in birds and mammals, hence the large size of kidney. It is estimated that each kidney of man is composed of about 1 million nephrons. The high rate of metabolism yields a large amount of wastes to be excreted.

(3) In developing a new urinary duct, called *metanephric duct* or *ureter*. It is budded off from the base of the Wolffian duct (mesonephric duct). It grows anteriorly and dorsally, and eventually the metanephric tubules open into it. Its dilated distal tip forms *pelvis* which forks several times to become the *collecting tubules*. Its proximal portion becomes the *metanephric duct* or *ureter* that empties into cloaca or urinary bladder in mammals.

(4) The mammalian metanephros shows greatest organization of all, with several additional features. A thin, U-shaped *loop* of *Henle* forms between proximal and distal convolutions of a metanephric tubule. Such loops are absent in reptiles and rudimentary in birds. Kidney shows an outer *cortex* with concentration of renal corpuscles, and an inner *medulla* having collecting tubules and loops of Henle, which are aggregated into one or several *pyramids* tapering into pelvis. Mammalian kidneys do not receive afferent venous blood supply as there is no renal portal system.

Urinary Bladders

Most vertebrates have a urinary bladder to store urine before it is discharged. However, it is lacking in cyclostomes, elasmobranchs, some lizards, snakes, crocodilians and most birds. In most fishes it is simply a terminal enlargement of mesonephric ducts and called a *tubal bladder*. In Dipnoi, it evaginates from dorsal wall of cloaca and is probably homologous to the rectal gland of elasmobranchs. In tetrapods, it evaginates from the ventral wall of cloaca. In amphibians, it is termed a *cloacal bladder*. In amniotes, the adult bladder is derived from the proximal part of embryonic allantois, hence called an *allantoic bladder*.

Kidney ducts or ureters generally open dorsally into cloaca. But in mammals, except monotremes, the ureters lead directly into the urinary bladder which opens to outside through a short tube, the *urethra*. Mammals lack a cloaca as the dorsal part of embryonic cloaca forms the rectum and the ventral part becomes the urethra.

Gonads and their Ducts

Reproduction is *sexual* in vertebrates, and the sexes are *separate* (dioecious) with the exception of hagfishes and a few bony fishes having a *hermaphrodite* gonad. Reproductive glands or gonads of males are called *testes* which produce the male gametes called *sperm*. Female gonads are called *ovaries* which produce *ova*. In the embryo, gonads originate as a pair of thick elevated folds or *genital ridges* of coelomic epithelium from the roof of coelom, one on either side of the dorsal mesentery. Genital ridges are much longer than the functional adult gonads, suggesting that in the ancestral vertebrates the gonads extended the whole length of the pleuroperitoneal cavity. The functional adult gonad is derived from the middle or *gonal* part of genital ridge, while its anterior *progonal* and posterior *epigonal* parts remain

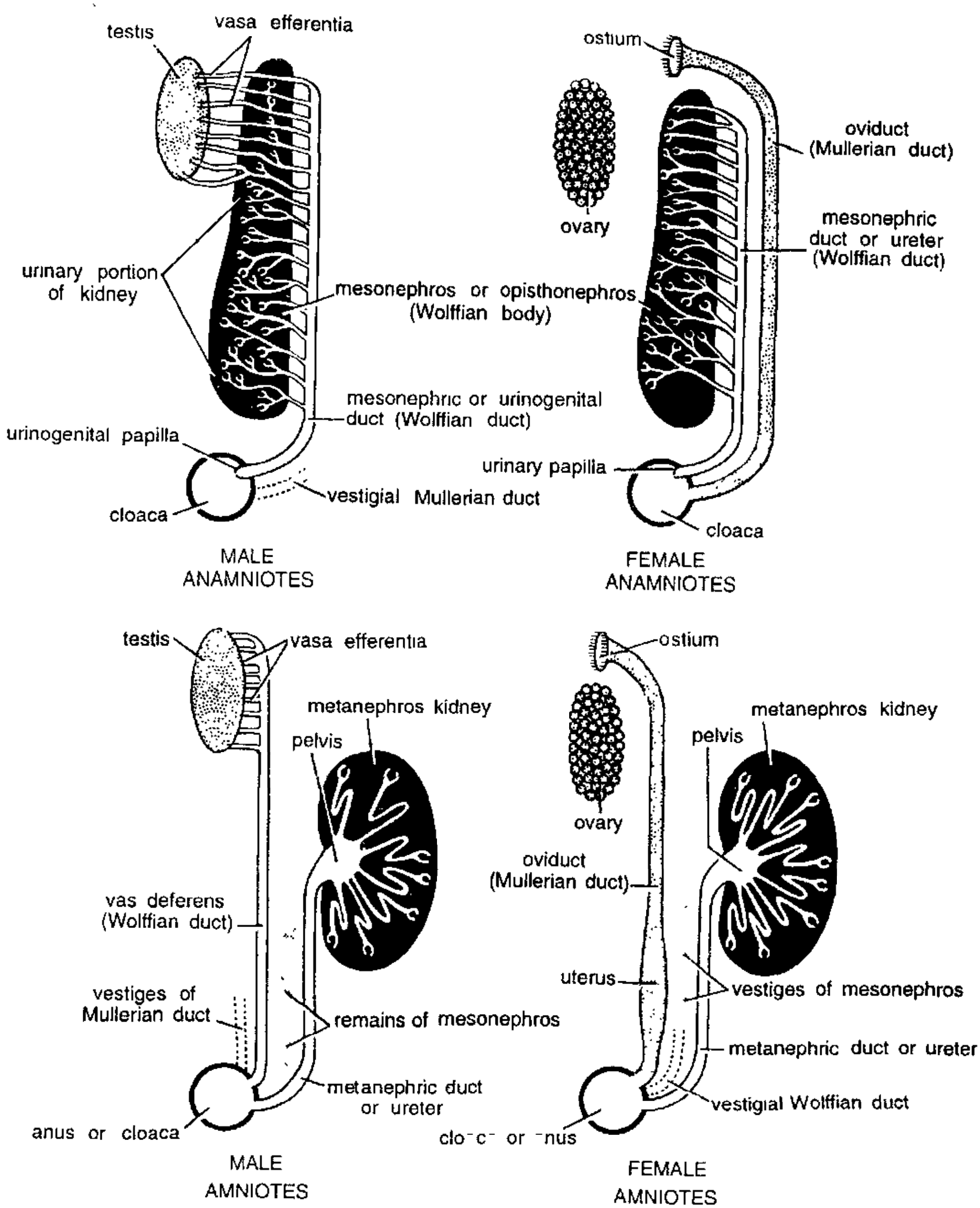

Fig 6. Schematic representation of evolution of urinogenital organs and their ducts in vertebrates

sterile. Gonads remain suspended in coelom from dorsal bodywall by a fold of dorsal mesentery, called *mesorchium* in males and *mesovarium* in females. Generally, one pair of gonads is present. But, some vertebrates have a single gonad only because of either fusion of both embryonic genital ridges (most cyclostomes, perch and some other fishes), or degeneration of one juvenile gonad (hagfishes, some elasmobranchs and lizards, alligators and most birds). Associated with the gonads are special gonoducts or genital ducts, *vasa deferentia* in males and *oviducts* in females, to transport gametes to cloaca or to outside body. However, cyclostomes and a few elasmobranchs lack genital ducts. Their eggs and sperm escape body cavity via abdominal pores.

1. Testes and male genital ducts. Testes of vertebrates are paired organs of moderate size, usually found attached to kidneys. Each testis is a compact gland, covered by coelomic epithelium and composed of numerous highly coiled *seminiferous tubules* embedded in connective tissue. Tubules are lined by germinal epithelium which gives rise to billions of sperm. On maturity the sperm are set free in the lumen of tubules and move towards the genital ducts.

Some *Cyclostomes* have a single median testis without a genital duct. Sperms are released in the coelom from where they pass through *abdominal pore,* located at posterior part of coelom. In dogfish, the two testes are elongated bodies. In most *anamniotes,* the opisthonephros (or mesonephros) is differentiated into anterior genital and posterior renal portions. In the anterior genital portion in males, some uriniferous tubules lose excretory function, form slender *vasa efferentia,* and become continuous with seminiferous tubules of the adjacent testis. They serve to convey sperm of testis to the mesonephric duct of kidney. Thus, in male anamniotes, mesonephric or wolffian duct forms a *urinogenital duct*, serving both as a vas deferens for sperm as well as a ureter for urine. However, in many elasmobranchs (e.g. dogfish), accessory urinary ducts drain urine from kidney to cloaca so that the mesonephric duct serves entirely or mainly as a vas deferens. The anterior genital part of kidney along with the part of mesonephric duct forms an *epididymis.*

In the embryos of *Anura*, each testis is made of two portions. In male frog, the anterior portion disappear and the posterior portion becomes the adult functional testis. In adult male toad, the anterior portion also persists as the *Bidder's organ,* containing large cells similar to immature ova.

In male *amniotes*, a metanephros develops as the adult functional kidney with its own urinary duct or *ureter* to transport urine. Thus, mesonephric or Wolffian duct becomes solely a genital duct or *vas deferens*. The remnants of embryonic mesonephros and a coiled portion of mesonephric duct become the *epididymis* of the adult kidney. From each testis sperms pass first through epididymis, then through vas deferens to reach urethra.

In most mammals testes descend permanently into extra-abdominal skin bags called *scrotal sacs.* In rabbits, bats and rodents, they are lowered into sacs and retracted at will. Passage between abdominal cavity and scrotal sac, through which testis descends, is called *inguinal canal.* However some mammals such as monotremes, insectivores, elephants, whales, etc., lack scrotal sacs so that their testes remain permanently intra-abdominal like ovaries.

2. Copulatory organs. Copulatory organs are absent in anamniotes, since they have usually external fertilization. But, in amniotes, fertilization is internal, and preceded by copulation or mating. Male amniotes usually develop *intromittant* or *copulatory organs* for transferring sperm into the genital tract of females, during copulation. They are particularly characteristic of reptiles and mammals.

In elasmobranchs (e.g. dogfish), bases of pelvic fins are modified as intromittant organs called *claspers*. These are grooved, cylindrical structures that are inserted into the female cloaca to inject sperm. In dog fishes and some allied forms there is blind muscular sac called *siphon,* located at the base of claspers. This sac gets filled with sea water which is used to force the spermatic fluid into the cloacae of female. In several teleosts, the anal fin is modified as a *gonopodium* for sperm transport. It is modification of anal fin. Snakes and lizards have a pair of retractile, grooved and sac-like *hemipenes* which can be everted through cloaca. Their retraction is controlled by modified body wall musculature. Turtles, crocodilians, some birds (drakes, ganders, ostriches) and prototherian mammals have an unpaired, grooved and erectile *penis* formed as a thickening of cloacal floor. Only higher mammals have a true external, erectile penis with a tubular groove continuous with a spongy urethra. A series of *accessory sex glands* associated with penis secrete a fluid in which sperm are carried.

3. Ovaries and female genital ducts. In female anamniotes, ovaries are large, occupying much of the body cavity and produce thousands of eggs as fertilization is external. In amniotes, ovaries produce fewer eggs because fertilization is internal. Ovaries of reptiles and birds are still large and the eggs produced contain much yolk. However, mammalian eggs contain very little yolk so that their ovaries also remain quite small.

Ovaries are generally paired structures, but only a single median ovary occurs in cyclostomes, as also in some teleosts (e.g. perch). They are not attached to kidneys like testes in the males. Only the right ovary is functional in many elasmobranchs, whereas only the left ovary becomes mature in birds and some primitive mammals (e.g. *Ornithorhynchus*).

Histologically, an ovary is a mass of connective tissue with an outer layer of germinal epithelium showing ova in various stages of development. Ovaries are hollow and saccular in fishes and amphibians but compact in amniotes, especially in mammals, in which each ovum is surrounded by a follicle. Mature eggs are released either internally into the central ovarian cavity (teleosts) which is continuous with the lumen of the oviduct, or extruded externally into the surrounding coelom or bodycavity (Tetrapoda). This process is termed *ovulation.*

In all vertebrate embryos, except cyclostomes, the coelomic epithelium on the outside of mesonephric duct develops a groove which becomes closed to form a tube called *Mullerian duct.* In adult males, Mullerian duct becomes vestigial and functionless. In adult females, it grows larger and becomes the female genital duct or *oviduct.* It opens anteriorly into coelom, in the region of degenerating pronephros, by a *coelomic funnel* or *ostium,* and terminates posteriorly into cloaca. In female elasmobranchs, the Mullerian duct is formed differently by the longitudinal splitting of the pronephric duct. Thus, in adult female anamniotes, both the Mullerian duct (oviduct) and the Wolffian duct (mesonephric or urinary duct) are present. But, in adult female amniotes, with the development of adult metanephros and its metanephric duct or ureter, mesonephros and its duct (Wolffian duct) degenerate leaving only vestiges known as *provarium.*

In viviparous mammals, posterior ends of both the Mullerian ducts become fused and are modified into a *uterus* in which the embryos develop, and a *vagina* which receives the male intromittant organ during copulation. The remaining anterior parts or oviducts are relatively short, narrow and convoluted and called the *fallopian tubes.* Condition of uteri varies in different mammals. When uteri remain double without fusion, it is called *duplex uterus* (marsupials). When uteri partially fuse so as to form two horns and two separate lumens inside, it is called *bipartite uterus* (hamster, rabbit). When there are two horns but a single internal cavity it is termed *bicornuate uterus* (ungulates). When uterine horns are absent and both uteri fuse completely with a single internal cavity, it is termed *simplex uterus* (Primates, some bats, armadillos).

IMPORTANT QUESTIONS

» ***Long Answer Type Questions***

1. Give general account of evolution of kidney in vertebrate series.
2. Trace the fate of pro-, meso-, and metanephros in vertebrates.
3. Describe the evolution of genital ducts in different vertebrates

» *Short Answer Type Questions*

1. Write short notes on — (i) Archinephros, (ii) Mesonephros, (iii) Metanephros, (iv) Mullerian duct, (v) Nephron, (vi) Opisthonephros, (vii) Pronephros, (viii) renal corpuscle.

» *Multiple Choice Questions*

1. Functional unit of kidney :
   (a) Nephron (b) Neuron
   (c) Renal corpuscle (d) Glomeruli
2. Hypothetical primitive kidney :
   (a) Archinephros (b) Pronephros
   (c) Nephron (d) Mesonephron
3. Archinephros is found in :
   (a) Fishes (b) Reptiles
   (c) Larval cyclostomes (d) Amphibians
4. Wolffian body :
   (a) Archinephros (b) Pronephros
   (c) Mesonephros (d) Metanephros
5. Urinary bladder opens to exterior through :
   (a) Ureter (b) Urethera
   (c) Pelvis (d) Tubule
6. The functional adult gonad is derived from which part of genital ridge :
   (a) Gonal (b) Pregonal
   (c) Epigonal (d) Endogonal
7. In mammals testes are found in :
   (a) Peyer's patches (b) Bidder's organ
   (c) Inguinal canal (d) Scrotal canal
8. Oviduct in vertebrates is modified :
   (a) Wolffian duct (b) Mullerian duct
   (c) Inguinal canal (d) Urinary duct

ANSWERS

1. (a) 2. (a) 3. (c) 4. (c) 5. (b) 6. (a) 7. (d) 8. (b).

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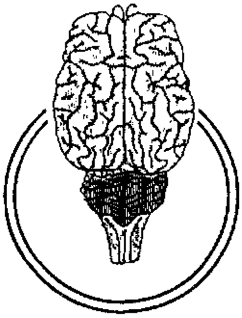

Nervous System in Vertebrates

Nervous System and its Functions

In all the multicellular animals above the level of sponges, the system meant to perceive stimuli detected by the receptors, to transmit these to various body parts, and to effect responses through effectors, is called *nervous system*. In vertebrates, it is highly specialized and plays at least three vital roles :

1. Response to stimuli. By responding to all sorts of stimuli, it acquaints the organism with them so that the organism may react and orient itself favourably in the surrounding environment.

2. Coordination. Along with endocrine system, the nervous system also serves to coordinate and integrate the activities of various parts of the body so that they act harmoniously as a unit. This makes possible the integrated control of the internal body environment *(homeostasis)*. However, the nervous system brings about rapid coordination by means of nerves, whereas the endocrine system does so gradually and slowly by secreting hormones into blood.

3. Learning. By accumulating memories from past experiences, in higher vertebrates at least, the nervous system serves as a centre for learning.

The branch of medical science dealing with the structure (anatomy), functions (physiology) and diseases (pathology) of nervous system is called *neurology*.

Division of Nervous System

For convenience of study, the nervous system is divided into three parts :

1. Central nervous system or CNS. It consists of the *brain* and *spinal cord*. It coordinates the impulses received from receptors and transmitted to the effectors for response.

2. Peripheral nervous system. It is composed of 10 or 12 pairs of *cranial nerves* coming from brain and several pairs of *spinal nerves* from the spinal cord. It provides the connecting link or living lines of communication between the receptors, the central nervous system, and the effectors.

3. Autonomic nervous system. It innervates smooth and cardiac muscles and glands. It is concerned with the involuntary or aut_matic b_dy activities, such as the peristalsis of the alimentary canal and the beating of the heart. Autonomic sys... is .s... y ...s...... a pa.. .. .... peripheral system as the two are connected together.

Anatomy of Nervous System : The Neuron

The nervous system is composed of nerve cells or *neurons*, surrounded by a delicate web of connective tissue called *neuroglia* (Fig. 1). Neuron or neurone is the structural as well as functional unit of nervous system. According to the 'neuron theory', each neuron is a distinct anatomical unit, having no protoplasmic continuity with other neurons. It is also physiologically distinct, so that damage or destruction of a neuron may not affect adjacent neurons. The neuron, rather than the nerve, transmits the nerve impulse.

[I] Structure of a neuron

Neurons are of different shapes, but each consists of an irregular cytoplasmic cell body called *cyton*, with a number of branching cell *processes* or *fibres*.

1. Cyton. Cyton contains a nucleus and several small baso_hilic *Nissel granules* or *tigroid bodies* that readily stain with methylene blue. These granules are made of ribonucleic acid (RNA) and take part in protein synthesis. Cytoplasm of c-t-n als- c-ntains a netw-rk -f fine, thread-like *neurofibrillae*. A group or mass of cell bodies within the gray matter of ra n or spinal cord is called a *nucleus*, while outside the central nervous system it is called a *ganglion*.

2. Nerve fibres. Two types of fibres are differentiated on the basis of the direction of nerve i...pulse con_ucted by them.

(a) Dendrites. These are shorter, usually several, much branched, with Nissl granules, and carry impulses towards or into the cell body.

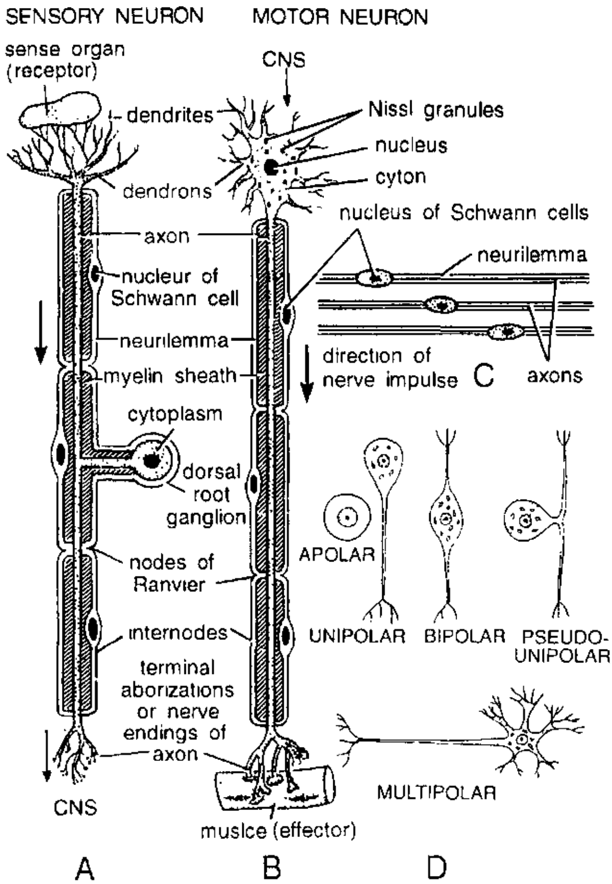

Fig. 1 Structure of neurons and nerve fibres. A—Sensory neuron. B—Motor neuron C—Non-medullated nerve fibres. D—Kinds of neurons.

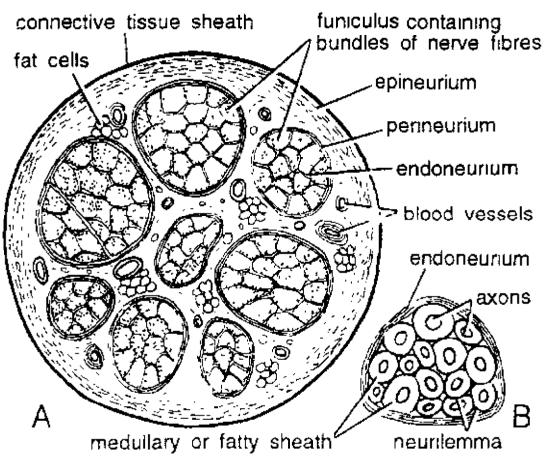

Fig 2 Structure of a nerve A—Nerve in T S B—A bundle of nerve fibres in T.S

(b) Axon. It is longer, usually single, without branches and Nissel granules, and normally conducts impulses away from the cell body.

A nerve fibre (Fig. 2) consists of a central thin cytoplasmic strand, called *axis cylinder*, which is continuous with the cell body. All nerve fibres outside brain and spinal cord, are covered by a thin delicate membrane, the *Schwan sheath* or *neurilemma*. In most long nerve fibres, there is a layer of lipoid or fatty material, called *myelin* or *medullary sheath*, between axis cylinder and neurilemma. Such fibres are termed *myelinated* or *medullated* and appear white. Myelin substance is not continuous uniformly but becomes interrupted at intervals by circular constrictions termed *nodes of Ranvier*. Part of nerve fibres between two adjacent nodes is called an *internode*. Nerve fibres which lack the fatty sheath are called *non-myelinated* or *non-medullated* and are gray in appearance.

Just below neurilemma is a thin cytoplasmic layer with scattered flat nuclei, forming *sheath cells* or *Schwann cells*. They secrete the myelin sheath and neurilemma. Each internode is covered usually by a single Schwann cell. *Collateral branches* may arise at right angles from long fibres or axons.

3. Synapses. Neurons form pathways for conduction of nerve impulses, but cytoplasm of one neuron is not continuous with that of another. Electron microscope has shown that branches of an axon end in *terminal buttons* full of mitochondria. These lie in close proximity but without actual organic connection with terminal branches of a dendrite of another neuron. The small gap thus left between the juxtaposed processes is called a *synapse* or *synapsis*. Only the branches of an axon form a synapse with the dendrites of another neuron. The whole nervous system in fact represents chains of neurons linked together by synapses in a complicated web.

[II] Kinds of neurons and fibres

Nerve fibres and neurons are comparable to a 'one-way-traffic' system, conducting nerve impulses in one direction only. Functionally, the following main types of nerve fibres and neurons are found :

1. Afferent or sensory. These transmit and carry impulses from a receptor to the central nervous system.

2. Efferent or motor. These transmit and carry impulses from the central nervous system to the various effector organs.

3. Association or adjustor neurons. These lie within the brain or spinal cord and link together through synapses the afferent and efferent neurons. Neurones are commonly classfied according to the number of processes.

(i) Apolar neurones. They have no processes.

(ii) Unipolar neurones. All developing neuroblasts pass through a stage when they have only one process the axon. In the adult such unipolar neurons are not commonly seen.

(iii) Bipolar neurones. These neurones are spindle shaped possessing an axon at one pole and a dendron at the other end. In the adult they are found in retina.

[III] Nerve

A nerve consists of numerous nerve fibres (axons or dendrites), outside the central nervous system, bound together in smaller bundles, like wires in a cable, by white connective tissue layers called *perineurium*. Surrounding tissue includes blood vessels to supply nutrients and oxygen. The external coat of fibrous connective tissue of nerve is termed *epineurium*.

Nature of Nerve Impulse

The nature of nerve impulses passing along a nerve fibre is partly physical and partly chemical (Fig. 3). A wave of electric change or disturbance accompanies the nerve impulse. This electric charge, known as the *action current*, can be recorded with a galvanometer. While transmitting an impulse, the nerve consumes more O_2, produces more CO_2 and generates a minute but measurable amount of heat, than a resting nerve. These factors clearly indicate the physico-chemical nature of the nerve impulse.

The synapse has a *polarity*, that is, like a 'physiological valve', it allows an impulse to travel in one direction only, from axon of one neuron to the dendrite of other. In fact, an impulse does not travel through a synapse, but a fresh impulse is induced on its other side. On reaching the terminal buttons of an axon, the impulse induces them to produce a small amount of a chemical terminations neurotransmitter, therefore, all synapses are called cholinergic. Acetyl choline is highly unstable as it is readily neutralized by an enzyme acetyl cholinesterase out one process *h* splits into processes. One these processes is to the phery and the *r* goes to the tral nervous item. Such cells are found in all final ganglia. Utipolar

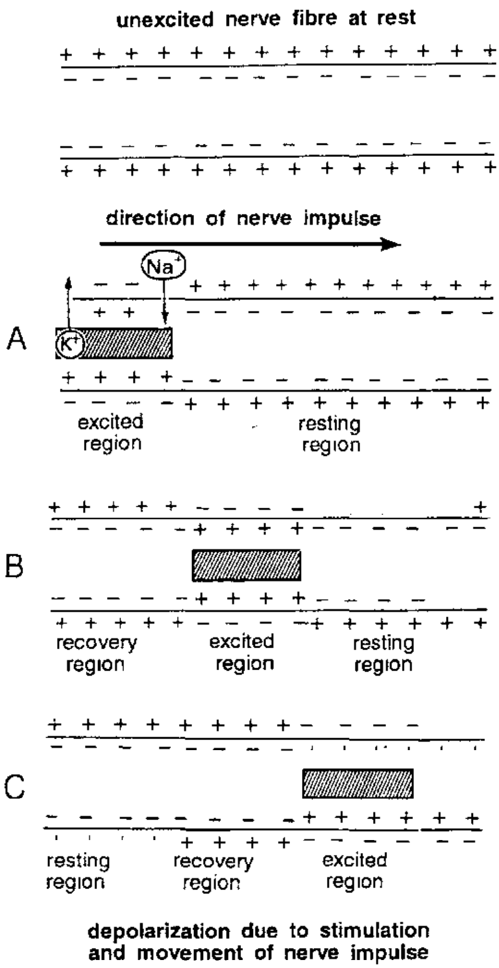

Fig 3. Diagrammatic representation of electrical conduction of impulses along a nerve fibre

neurones. These cells have a number of dendrones and an axon. They have various shapes depending mainly on the number and position of the endrones, usually *acetylcholine*, which sets up a fresh impulse in the next neuron. On the other hand, terminations of sympathetic fibres release *sympathin*, a substance like adrenalin, and which is antagonistic to acetylcholine. These neuro-hormones may continue to stimulate the other neuron, but they are quickly inactivated by an enzyme, *cholinesterase*.

A neuron is able to transmit an electric impulse very rapidly, at a speed of 100 metres per second in man. Medullated fibres conduct impulses much faster than the non-medullated fibres. It travels at a uniform speed with the same intensity for a long time and does not spread to adjacent tissues due to insulation provided by myelin sheaths. A refractive period usually occurs when the depolarized nerve fibre cannot carry another stimulus. It is believed that the nerves are never tired. Impulses are conducted on the basis of 'all or none' principle.

Development of Central Nervous System

The central nervous system of vertebrates includes the *brain* and the *spinal cord*. These are derived from a longitudinal, mid-dorsal ectodermal

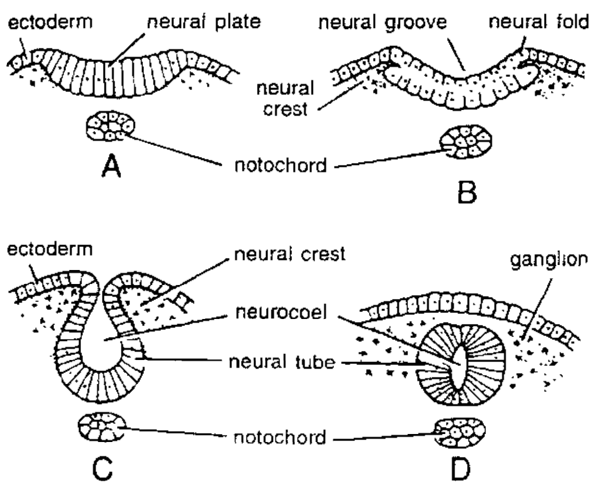

Fig 4 Stages in the embryonic development of central nervous system in T.S.

thickening of the embryo, called the *medullary* or *neural plate* (Fig. 4). This neural plate or neural groove is converted by fusion into a closed mid-dorsal longitudinal *neural tube,* lying above the notochord. The fusion of neural fold is not complete along the entire length of neural groove. A small opening the *neuropore* is left out at the anterior end which communicates to exterior. The neuropore persists for a while and finally closes. Moreover it may not be present in all the cases. Posteriorly, the neural tube may communicate temporarily with the archenteron by the *neurenteric canal.* The neural tube is wide anteriorly because anterior part of neural plate is wider than posterior and this wider part forms the brain. Histologically, the embryonic neural tube exhibits three zones of cells :

1. Germinal layer. These are actively dividing cells, lining the neural canal. They form the connective tissue lining of neural canal, called *ependyma*, and also proliferate into mantle layer cells.

2. Mantle layer. It consists of embryonic neurons or *nematoblasts*, forming the gray matter.

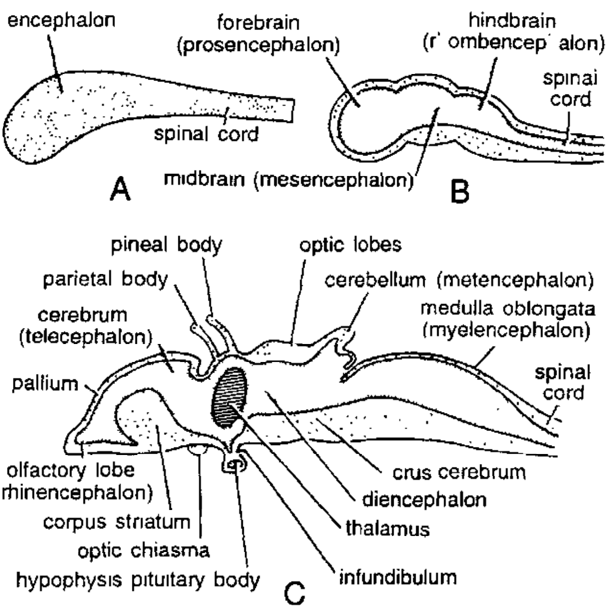

Fig 5 Stages in development of brain. A—Anterior end of neural tube in lateral view. B—M L.S. of embryonic brain to show three primary cerebral vesicles. C—Differentiation of brain from three vesicles.

3. Marginal layer. It consists of nerve fibres, mostly surrounded by fatty myelin sheaths, and forms the *white matter.* Neurons and fibres are supported by a special connective tissue of ectodermal origin, the *neuroglia*, cells of which become increasingly abundant and diversified in higher vertebrates.

Development of brain. The anterior end of embryonic neural tube is already enlarged forming the embryonic brain (Fig. 5), called *encephalon.* By differential growth and two constrictions, it is divided into a linear series of three *primary cerebral vesicles*, termed the *forebrain*, *midbrain* and *hindbrain.* These give rise to the three major divisions of the adult brain— (i) *prosencephalon* (forebrain), (ii) *mesencephalon* (midbrain), and (iii) *rhombencephalon* (hindbrain). These further become subdivided into 5 subdivisions. The various parts of the adult brain in different vertebrates are formed by modifications, that is, by thickenings and foldings of these 5 subdivisions. The adult brain has a series of cavities, called *ventricles*, which are in continuation with the central canal of the spinal cord and filled with a cerebro-spinal fluid.

The various usual parts wit.. prominent associ t d structures of a vertebrate brain have been shown in Fig. 6 and listed in the Table 1.

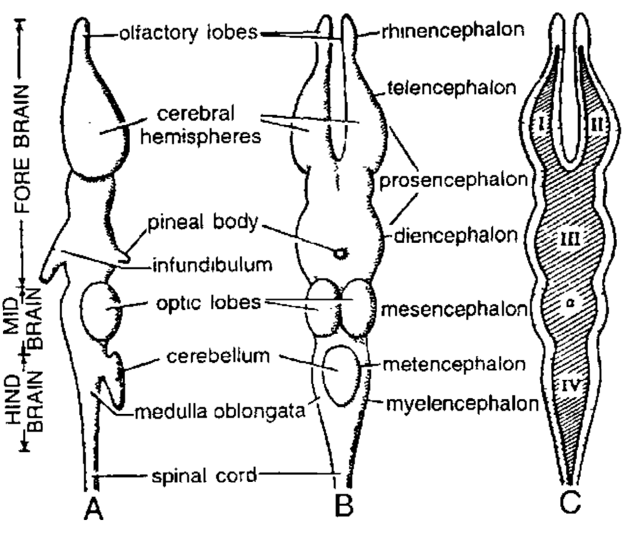

Fig. 6. Pattern of generalized vertebrate brain A—Lateral view B—Dorsal surface C—H L.S. showing ventricles.

***Table 1.* Subdivisions, Parts and Associated Structures of a Vertebrate Brain.**

Divisions	Subdivisions	Parts	Cavity	Associated Structures
I. PROSEN-CEPHALON (Forebrain)	**1. Telencephalon**	Rinencephalon	I Ventricle *(Rhinocoel)*	Olfactory bulbs Olfactory tracts Olfactory lobes Palaeocortex on pallium
		Cerebral hemispheres	II or Lateral Ventricles *(Paracoels)* ↓ Formen of Monro	Corpora striata or basal ganglia Corpus callosum Neocortex on pallium Paraphysis
	2. Diencephalon	Epithalamus (roof)	↓ III Ventricle *(Diacoel)*	Habenulae Pineal apparatus Parapineal or parietal
		Thalamus (sides)		
		Hypothalamus (floor)		Hypothalmic nuclei Optic chiasma Median eminence Infundibular stalk Pituitary Saccus vasculosus Mamillary bodies Anterior choroid plexus
II. MESSEN-CEPHALON (Midbrain)	—	Crura cerebri (floor)	*Iter* or *cerebral aqueduct*	Optic lobes] Tectum Auditory lobes] Cerebral peduncles
III. RHOMBEN-CEPHALON (HINDBRAIN)	**1. Metencephalon**	Cerebellum		Trapezoid body Pons
	2. Myelecephalon	Medulla oblongata	IV Ventricle *(Metacoel)*	Restiform bodies Pyramids

Comparative Account of Brain in Vertebrates

Brain of all vertebrates, from fish to man, is built in accordance with the same basic architectural plan (Figs. 6–8). However, form of brain differs in different vertebrates in accordance with the habits and behaviour of the animals.

1. Cephalochordates. In amphioxus, brain does not consist of forebrain, midbrain and hindbrain. Instead, the so-called brain is made of an anterior *prosencephalon* or *cerebral vesicle* with a single enlarged ventricle. It is lined with cilia and long filamentous processes of ependymal cells as revealed by electron microscope. Anterior extension of notochord may suggest absence of a forebrain.

2. Cyclostomes. Brain is very primitive. Subdivisions are not well marked. Two olfactory lobes are prominent, but cerebral hemispheres are quite small. Cavities of cerebral hemispheres or lateral ventricles are rudimentary. Pineal apparatus and parapineal (=parietal) body are very well developed in *Petromyzon*, though they are vestigial in *Eptatretus (=Bdellostoma)* and absent in *Myxine*. Connected to pineal apparatus is epithalamus made of two *habinulae ganglia*. The two optic lobes are imperfectly differentiated. Medulla oblongata is very well developed while cerebellum is a small transverse dorsal band. A well defined infundibulum from hypothalamus of diencephalon bears a hypophysis or pituitary body.

3. Fishes. Brain of fishes is more advanced than that of cyclostomes. However, subdivisions of brain are seen in their primitive relations.

(a) Elasmobranchs. In elasmobranch fishes (shark or dogfish), olfactory organs are enormous

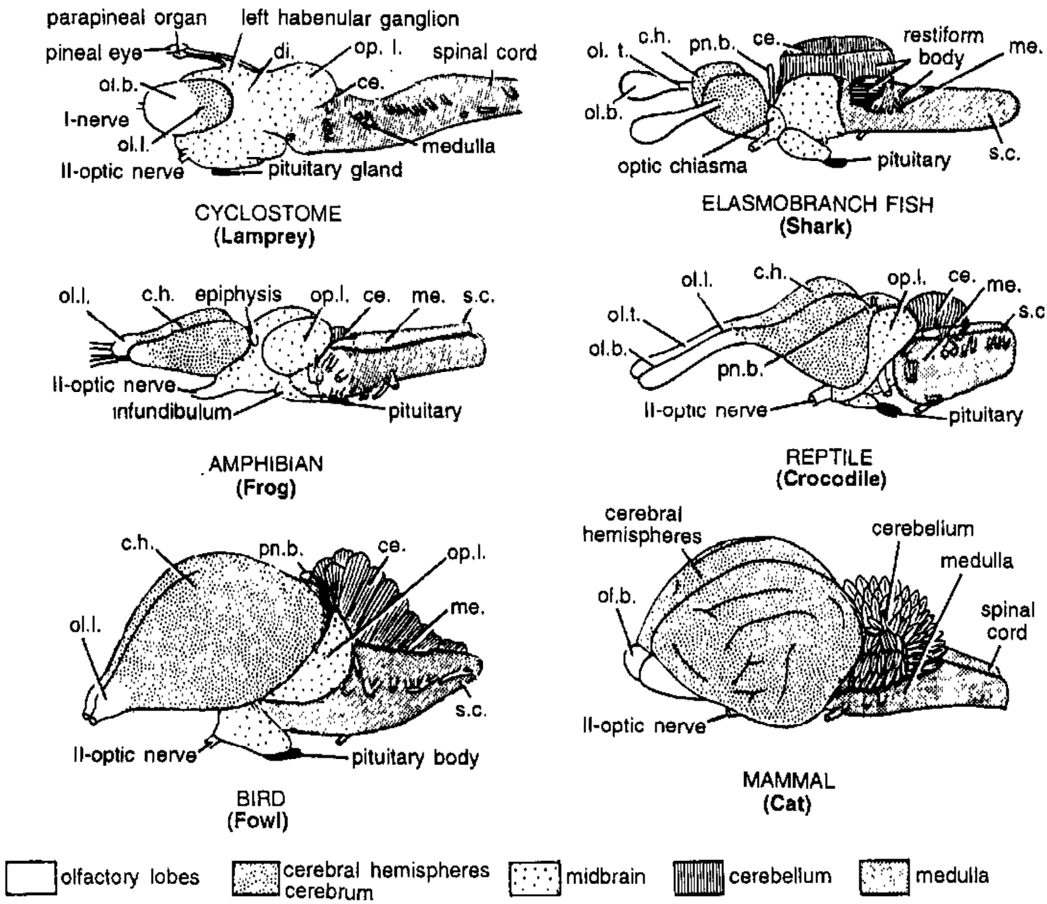

Fig. 7. Brains of representative vertebrates in lateral view. ce.—cerebellum. c.h.—cerebral hemisphere. di.—diencephalon. inf. —infundibulum. m.—medulla oblongata. ol.b.—olfactory bulb. ol.l.—olfactory lobe. ol.t.—olfactory tract. op.l.—optic lobe. pi.—pituitary. pn.b.—pineal body. s.c.—spinal cord.

so that olfactory lobes of brain are correspondingly large, attached to cerebrum by short but stout olfactory tracts or peduncles. Optic lobes and pallium are relatively moderate in size. Midbrain cavity (III ventricle) is quite large and extends into optic lobes. A thin-walled vascular sensory organ, called *saccus vasculosus*, is attached to pituitary and connected by fibre-tracts with cerebellum. Pineal apparatus is well developed. Topographical features of hindbrain are least pronounced. Cerebellum is especially large due to active swimming habit. To assist cerebellum in the maintenance of equilibrium, ruffle-like *restiform bodies* are present at the antero-lateral angles of medulla.

(b) Osteichthyes. In bony fishes, brain is more specialized than in elasmobranchs. In perch, olfactory lobes, cerebral hemispheres and diencephalon are smaller while optic lobes and cerebellum larger than in a shark. Some bony fishes have *restiform bodies*. In bottom-feeders, having scattered taste buds on body surface, the antero-lateral sides of medulla show unusual bulgings or *vagal lobes*. Parapineal body is absent in modern teleosts.

4. Amphibians. Brain of frog shows many contrasts from that of dogfish. Smaller olfactory lobes and larger optic lobes indicate a greater reliance on sight rather than smell. *Corpus striatum* or *paleostriatum* (floor of cerebrum)

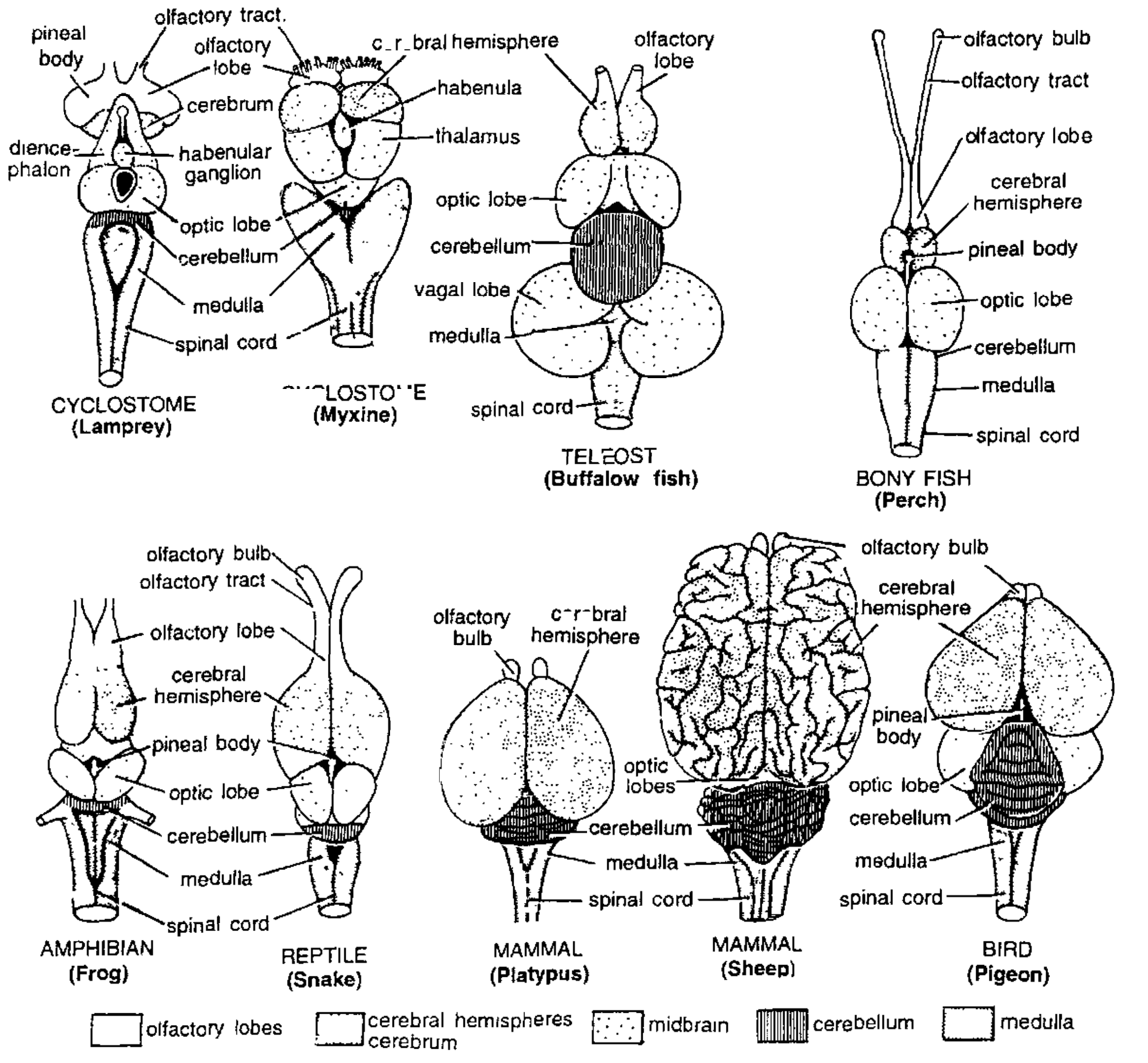

Fig 8 Brains of representative vertebrates in dorsal veiw.

receives greater number of sensory fibres projected forward from thalamus than in fishes. Two cerebral hemispheres show greater development in accordance with more complex activities of locomotion, hibernation, breeding, etc. However, optic lobes are probably the dominant coordinating centres in amphibian brain. The walls of mid brain are thickened and reduce the lumen into a narrow passage called, *aqueduct*. Poor development of cerebellum, a mere transverse band, shows relative decrease in muscular activity. Medulla is also small. A small pineal body is present in all the modern amphibians.

5. Reptilians. Reptilians brain shows advancement in size and proportions over that of amphibians because of complete terrestrial mode of life. Telencephalon increases to become the largest region of brain. Two long olfactory lobes are connected to cerebral hemispheres which are larger than in amphibians because of greater thickness and enlargement of corpora striata. A fine *vomeronasal nerve* from the organ of Jacobson goes to the olfactory bulbs. Parapineal body, more often called the *parietal eye*, is still found in *Sphenodon* and some modern lizards, but is vestigial or absent in other reptiles. A pair of *auditory lobes* are found posterior to optic lobes which are not hollow. The III ventricle is reduced to a narrow *cerebral aqueduct.* Cerebellum is somewhat pear-shaped and larger than in amphibians.

6. Birds. Avian brain is proportionately larger than that of a reptile, and is short and broad. Olfactory lobes are small due to poor sense of smell. Two cerebral hemispheres are larger, smooth and project posteriorly over the diencephalon to meet the cerebellum. Pallium is thin but corpus striatum is greatly enlarged making lateral ventricle small and vertical. Third ventricle is also narrow due to great development of thalami. Optic lobes on mid-brain are conspicuously developed in correlation with keen sight, but they are somewhat laterally displaced. The cerebellum is greatly enlarged with several superficial folds (flocculi) due to many activities involving muscular coordination and equilibrium such as flight and perching.

7. Mammals. Parts of vertebrates brain in linear arrangement become progressively enlarged from fishes onwards until they reach their peak in mammals. Brain is proportionately larger than in other vertebrates. *Cerebral hemispheres* of Prototheria are smaller and smooth, like those of reptiles. They are larger but smooth in Metatheria. In most higher mammals (Eutheria), cerebral hemispheres become greatly enlarged and divided into lobes, with thick cerebral cortex of gray matter. In mammals such as rabbit, the surface of cerebral hemispheres is relatively smooth with few fissures. In others, such as man and sheep, surface is immensely convoluted with a number of elevations *(gyri)* separated by furrows *(sulci).* This folding increases the surface cortex or gray matter containing nerve cells, resulting in greater intelligence without adding to the size of brain. The two hemispheres are joined internally by a transverse band of fibres, the *corpus callosum,* not found in other vertebrates or even in Prototheria and Matatheria.

Olfactory lobes are relatively small but clearly defined and covered by the hemispheres. Diencephalon and midbrain are also completely covered by the cerebral hemispheres. Characteristic of mammals are 4 almost solid optic lobes, called *corpora quadrigemina,* on the roof of midbrain. The III ventricle or *iter* of midbrain is a laterally compressed vertical passage, called *cerebral aqueduct.*

Cerebellum is also large, conspicuously folded and may overlie both midbrain and medulla. Usual folds are a median *vermis,* two lateral *flocculi* and their mushroom - like projections, the *paraflocculi.* The other chief topographical features of mammalian hindbrain include the *pyramids* carrying voluntary motor impulses from higher centres, the *pons varoli* with crossing or decussating fibres connecting opposite sides of cerebrum and cerebellum, and the *trapezoid* body of transverse fibres relaying impulses for sound. Hindbrain contains centres for the regulation of digestion, respiration and circulation.

Cranial Nerves

The peripheral nervous system includes *cranial* and *spinal nerves.* All the nerves arise in pairs. Cranial nerves have both afferent and efferent fibers, arise from brain and emerge through skull foramina. There are 10 pairs of cranial nerves in anamniotes (cyclostomes, fishes, amphibians) and 12 pairs in amniotes (reptiles, birds, mammals). Their sequence and distribution is essentially the same in all vertebrates. Table 2 provides a summary of the serial number, names, origin from brain, distribution, nature and functions of cranial nerves in vertebrates.

Terminal nerves. An additional pair of anterior-most terminal nerves are found in all vertebrates including man. They emerge from rhinencephalon close to olfactory roots through neuropore of cerebrum. They are numbered zero (0) because of their discovery after all other cranial nerves were already numbered.

Autonomic Nervous System

Cranial and spinal nerves (*somatic nerves*) mainly innervate the skeletal or voluntary muscles and direct the adjustment of the vertebrate to its surroundings. On the other hand, *autonomic nerves*

Table 2. **Cranial Nerves (paired) of Vertebrates.**

	Name	Origin	Distribution	Nature	Functions
I.	**Olfactory**	Olfactory lobe or bulb	Olfactory epithelium in nasal cavity	*Sensory*	Smell
II.	**Optic**	Optic lobe on midbrain	Retina of eye	*Sensory*	Sight
III.	**Oculomotor**	Floor of midbrain	Eye, 4 muscles of eyeball	Motor	Movements of eyeball, iris, lens, eyelid
IV.	**Trochlear**	Floor of midbrain	Eye, superior oblique muscles of eyeball	Motor	Rotation of eyeball
V.	**Trigeminal**	Side of medulla	Head, face, jaws, teeth	*Sensory* Motor	Forehead, scalp, upper eyelid, side of nose, teeth Movement of tongue, jaw muscles for chewing
VI.	**Abducens**	Side of medulla	External rectus muscle of eyeball	Motor	Rotation of eyeball
VII.	**Facial**	Side and floor of medulla	Anterior 2/3 tongue. Muscles of face, neck and chewing	*Sensory* Motor	Taste Facial expression, chewing, movement of neck
VIII.	**Auditory (acoustic)**	Side of medulla	Organ of Corti in cochlea Semicircular canals	*Sensory*	Hearing Equilibrium
IX.	**Glossopharyngeal**	Side of medulla	Posterior 1/3 tongue, mucous membrane and muscles of pharynx	*Sensory* Motor	Taste & touch Movements (swallowing) of pharynx
X.	**Vagus (pneumogastric)**	Side and floor of medulla	Muscles of pharynx, vocal cords, lungs, heart, oesophagus, stomach, intestine	*Sensory* Motor	Vocal cords, lungs Respiratory reflexes, peristaltic movements, speech, swallowing, secretion of gastric glands, inhibition of heart beat
XI.	**Spinal accessary**	Floor of medulla	Muscles of palate, larynx, vocal cords, neck, shoulder	Motor	Muscles of pharynx, larynx, neck, shoulder movements
XII.	**Hypoglossal**	Floor of medulla	Muscles of tongue, neck	Motor	Movements of tongue

and ganglia innervate the involuntary or smooth muscles of viscera, heart and glands and control the internal body environment.

Readers may refer to the note on autonomic nervous system described in the end of nervous system of rabbit in Chapter 30.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. Give a comparative account of brain of vertebrates.
2. Describe the brain of a lizard and compare it with that of a mammal.
3. Compare the brains of frog and rabbit.

» *Short Answer Type Questions*

1. Give in tabular form the origin, distribution, nature and function of cranial nerves in vertebrates.
2. How does a nerve impulse travel along a nerve cell across a synapse.
3. Write short notes on — (i) Acetylcholine, (ii) Autonomic nervous system, (iii) Conduction of nerve impulse, (iv) Neuron, (v) Synapses.

» ***Multiple Choice Questions***

1. The branch of medical science dealing with the structure, functions and diseases of nervous system :
   (a) Neurology (b) Nephrology
   (c) Endocrinology (d) Cardiology
2. Connecting link between the receptors, central nervous system and effectors :
   (a) Central nervous system
   (b) Peripheral nervous system
   (c) Sympathetic nervous system
   (d) Parasympathetic nervous system
3. Connective tissue of nervous system :
   (a) Areolar (b) Adipose (c) Cartilage (d) Neuroglia
4. Nissel's granules are made up of :
   (a) DNA (b) RNA
   (c) Nucleoprotein (d) Thymine
5. A mass of cell bodies within the gray matter of brain or spinal cord :
   (a) Cyton (b) Neuroglia
   (c) Ganglion (d) Nucleus
6. Bipolar neurons are found in :
   (a) Cornea (b) Conjuctiva
   (c) Retina (d) Lens
7. The central nervous system in vertebrates is derived from :
   (a) Basal plate (b) Archenteron
   (c) Neural plate (d) Blastopore
8. Function of restiform bodies in elasmobranchs :
   (a) Maintenance of equilibrium
   (b) Swimming
   (c) Sound production
   (d) Steering
9. Cerebral hemispheres in Eutherians are connected internally by :
   (a) Corpus callosum (b) Corpus luteum
   (c) Corpus albicans (d) Cerebral aqueduct
10. Terminal nerves are numbered :
   (a) 11 (b) 12 (c) 13 (d) 0

ANSWERS

1. (a) 2. (b) 3. (d) 4. (b) 5. (d) 6. (c) 7. (c) 8. (a) 9. (a) 10 (d).

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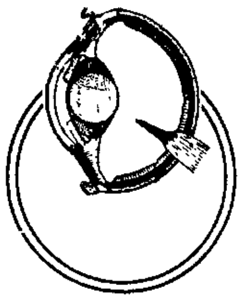

Receptor Organs in Vertebrates

Organisms are subjected to many influences from their surroundings constituting the environment. All changes in the environment, both external anc internal, are known as *stimuli*. Organs of the body that detect these changes or stimuli are called *receptors* or *sense organs*. They receive information from the environment in the form of energy (mechanical, chemical, electrical, thermal or radiant) and change it into nerve impulses which are transmitted to the brain or spinal cord via afferent or sensory nerve fibres to which they are connected. Thus, sense organs have dual functions : (i) they *detect* environmental changes or stimuli and then (ii) *transmit* this information in the form of nerve impulses to the central nervous system. In turn, the central nervous system integrates the incoming information and sends out messages via efferent or motor nerve fibres to effector organs which respond in appropriate manner.

Common Senses

At least the following 5 senses are more common although more senses are recognized by the biologists.

(1) **Touch.** Includes contact, pressure, heat, cold, etc.

(2) **Taste.** For certain substances in solution.

(3) **Smell.** For votatile chemicals and gases in air.

(4) **Hearing.** For vibrations in air, water or solid.

(5) **Sight.** For light waves.

Classification of Sense Organs

Senses organs are classified in many ways.

1. General and special receptors. Various minute sense organs are distributed widely upon or within the body especially the skin. These *cutaneous* sense organs are collectively termed

Table 1. **Types of Receptors or Sense Organs According to Stimuli and Location.**

	Sense Organs or receptors	According to type of stimulus	According to location of stimulus	Stimuli	Functions
1.	**Skin** (cutaneous)	*Mechanoreceptors* *Thermoreceptors*	*Exteroceptors*	Contact temperature	Detecting touch, hot and cold, etc.
2.	**Muscles** (kinesthetic)	*Mechanoreceptors*	*Proprioceptor*	Mechanical stretch	Feeling and gauging pressures
3.	**Tongue** (gustatory)	*Chemoreceptor*	*Exteroceptors*	Dissolved chemicals	Tasting
4.	**Nose** (Olfactory)	*Chemoreceptor*	*Exteroceptor*	Volatile chemicals and gases in air	Smelling
5.	**Eyes** (visual)	*Photoreceptors*	*Exteroceptors*	Light	Seeing
6.	**Ears** (auditory)	*Statoacoustic*	*Exteroceptors*	Sound and gravity	Hearing and balancing

general receptors, for their exact functions are not clear and any one of them can not be related to a single sensation alone.

On the other hand, the tongue, nose, eyes and ears are termed *special receptors*. They are concentrated in small areas particularly on the cephalic end of the body. They respond to particular types of stimuli or special senses and their functions are better understood.

2. Types according to stimuli. Table 1 lists the main receptors or sense organs according to the type of stimuli they receive and their location in the body. In a broad sense, we can recognize the following types on the basis of the stimulus to which they are sensitive :

(a) Mechanoreceptors. These are stimulated by touch and pressure (skin), vibrations or sound and balance (ears).

(b) Chemoreceptors. These are sensitive to smell, that is chemical substances or odours in air (nose), and to taste, that is substances in solution (tongue).

(c) Photoreceptors. These are sensitive to light waves or sight (eyes).

(d) Thermoreceptors. Sensitive to heat and cold (skin).

(e) Nerve endings. Sensitive to pain (skin).

3. Types according to location. Receptors may also be classifies according to the location of stimulus.

(a) Exteroceptors. These receive environmental stimuli from outside the organism and supply information about the surface of the body (touch, pressure, taste, heat, etc.). These include eyes, ears, nose, taste buds and cutaneous sense organs. The exteroceptors inform the organism about food mate or enemy.

(b) Proprioceptors. These are stretch receptors present in the muscles, joints, tendons, connective and skeletal tissues. They supply information about the so-called kinesthetic sense of equilibrium and orientation. They act like pressure gauges and are responsible for maintenance of body posture.

(c) Interoceptors. These lie in various internal organs. They provide information about the internal body environment, such as CO_2 concentration, blood composition, pain, fullness, etc. They are responsible for maintaining an appropriate internal body environment necessary for the continued survival of the organism.

4. Somatic and visceral receptors. Exteroceptors and proprioceptors are also called *somatic receptors*. Similarly, interoceptors are also called *visceral receptors*.

Some sense organs have a dual role. For example, sensory epithelium of nose and taste buds serves both as exteroceptor (somatic) as well as visceral receptor.

The readers have already gone through description of various receptors or sense organs found in different vertebrate types such as dogfish *(Scoliodon)*, frog *(Rana)*, lizard *(Uromastix)*, pigeon *(Columba)* and rabbit *(Oryctolagus)*, treated in earlier chapters in this text. To describe them all ..ere again will be merely a repetition of what ..as already been written elsewhere. Inste~d, the following description shall attempt to point out some of the more important differences among similar receptors in different classes of vertebrates.

Olfactory Organs in Vertebrates

Olfactory organs are special visceral chemoreceptors concerned with the sense of smell. These consist of a pair of cavities, the *olfactory* or *nasal sacs*, on the anterior end of head. Their external openings are called *nares* or *nostrils.* Cyclostomes have a single blind olfactory sac with a single external naris, but there are two olfactory nerves. In fishes, olfactory sacs are blind sacs except in all lobe-finned fishes and Dipnoi having internal nares. In all air-breathing animals or tetrapods, each olfactory sac has an external as well as an internal nostril. Unlike other receptors, processes of olfactory cells lead directly to brain so that they are termed *neuro-sensory cells.*

Olfactory sense is well developed in fishes and mammals. But birds are practically devoid of it except in the kiwi. It has been experimentally demonstrated that salmon fishes with plugged nasal sacs are unable to find their home river tributaries in which to spawn. It has been said that man can distinguish seven primary odours (camphoraceous, musky, floral, pepperminty, ethereal, pungent and putrid). In most vertebrates groups, olfaction provides vital information to search food, predators, mates, and even the way home.

Organs of Jacobson or vomeronasal organs are independent chambers below nasal cavities, found in most tetrapods, although they are sometimes vestigial.

Gustatory Organs in Vertebrates

Sense of taste or gustation is the perception of dissolved substances by small group of receptive cells called *taste buds* (Fig. 1). A taste bud is an

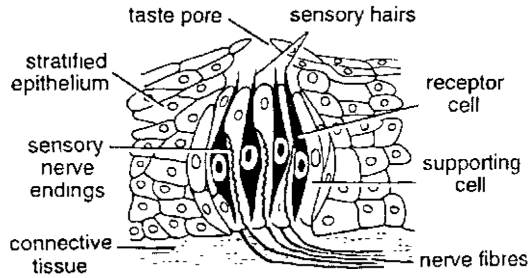

Fig. 1. Diagrammatic representation of a taste bud.

ovoid cluster of columnar epithelial cells. Each of which bears a delicate *bristle* or *hair* at its free end. The ends of several sense cells round a small depression called *taste pore* through which the fluid from oral cavity gets access to sense cells. These cells in turn are connected to nerves. These occur in all vertebrates and are fairly uniform in structure. In *amphioxus* certain cellular entities are present on cirri, resembling with taste buds, but their function is still unknown. In lower vertebrates, such as fishes, taste buds occur in many parts of the mouth and pharynx, even on the skin of head. In catfish they are abundant on the whiskers. In bottom - feeders or scavengers, they are distributed over the entire body surface.

In tetrapods, the taste buds are restricted to the tongue, palate and pharynx. Taste buds are abundant on the papillae of tongue. They are most abundant in mammals but least abundant in birds. Taste buds are supplied by V, VII, IX and X cranial nerves. In man, taste buds on tongue can distinguish 4 types of fundamental tastes : sweet, sour, bitter and salty. The papillae on the mammalian tongue may be *vallate* or *foliate.* Number of taste buds on papillae also varies from animal to animal e.g., in sheep, it is 48, in cow it is 1760, in pig 4760. Thus, for example in cow which has 20 papillae, the number of taste bud is about 35000 in all. In some cases, the sensation of taste is in reality due to sense of smell. For example, many spices have relatively little taste, but affect the sense of smell powerfully. During bad cold, when access to the olfactory organs in the nose becomes difficult, the food appears tasteless.

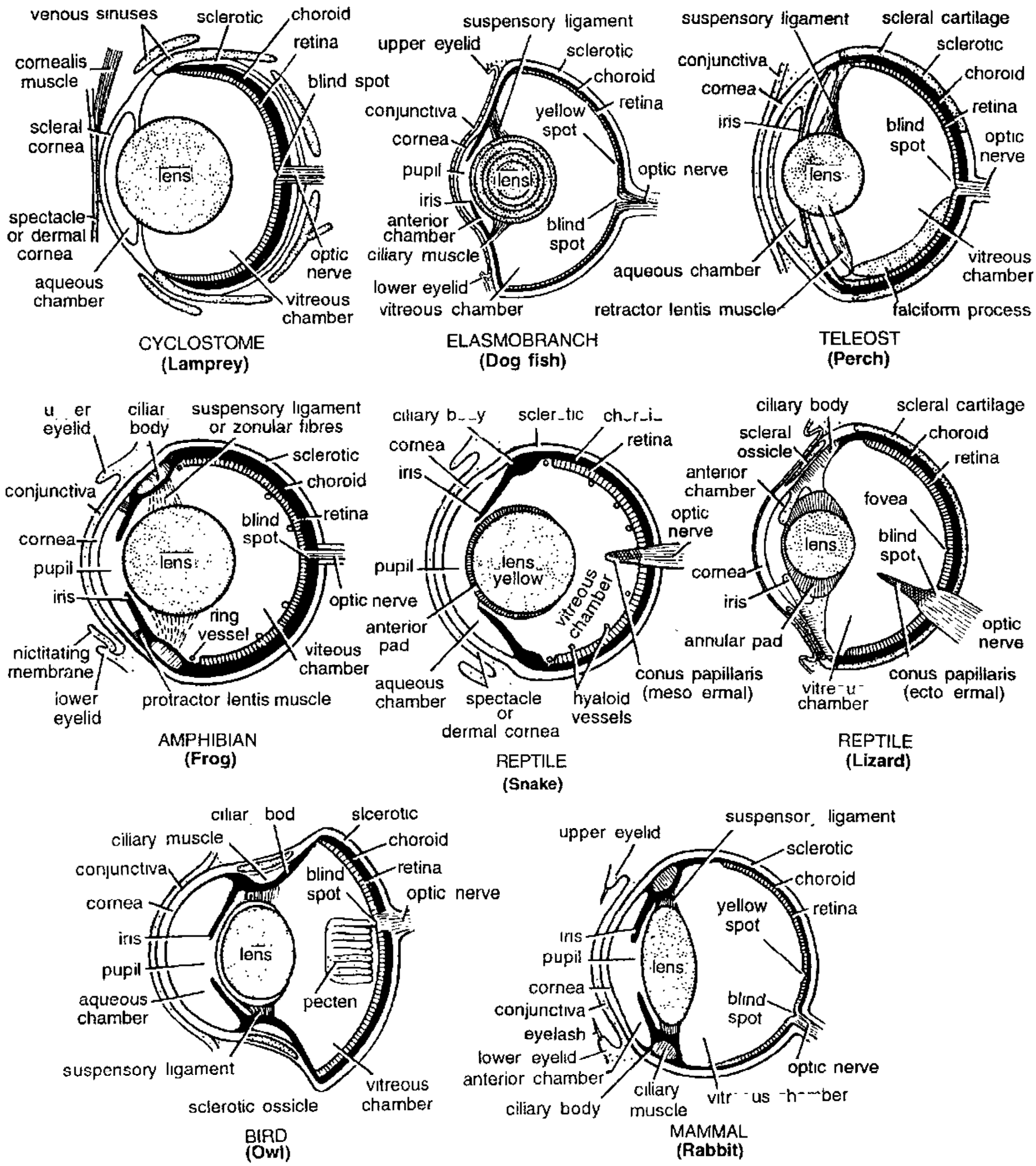

Fig. 2. Eyes of different vertebrates in sagital section.

Photoreceptors or Eyes

The sense of sight is due to stimulation of the eyes. Vertebrates have two types of eyes — (i) Unpaired *median* and (ii) Paired *lateral.*

1. Median eyes. Median eyes were abundant in most ancient fishes, amphibians and reptiles. They are also found in some living vertebrates in the form of *pineal* and *parapineal organs* formed as dorsal evaginations of the diencephalon of forebrain. They are light sensitive in lampreys (cyclostomes). They have a lens and sensory innervation but lack a retina and do not form an image. Pineal and parapineal bodies probably do not serve as light receptors above reptiles. The parapineal of reptiles, when present *(Sphenodon),* is covered by a translucent tissue. It serves as a third eye and is often termed the *parietal eye.*

2. Lateral eyes. The lateral eyes of all vertebrates are essentially similar (Fig. 2). They are of the 'camera type' with a lens which focuses images of external objects on the sensitive retina serving as a photographic film. However, the eyes of lower vertebrates (fish and amphibians), which live in water, differ from the eyes of higher vertebrates (reptiles, birds and mammals), which live out of water, in several important respects. It is because the problems associated with sight under water are different from those in the air.

(a) Eyelids and tear glands. Water itself cleans and moistens the eye, so that fishes lack movable eyelids and tear glands.

(b) Refractive index and cornea. Refractive index of water is nearly the same as that of cornea. Thus, the cornea of a fish's eye does not bend light rays. Thus cornea remains flat in lower vertebrates but bulges out in higher vertebrates.

(c) Shape of lens. Most refraction is achieved through lens which is nearly spherical in shape with greater refractive power in fishes. On the other hand, tetrapods have a flat or oval lens with less refractive power.

(d) Method of accommodation. It also differs in lower and higher vertebrates. Fishes, amphibians and snakes focus by moving the lens back and forth in camera fashion. On the other hand, mammals, birds and reptiles other than snakes have tough sclera and immovable lens. However, their lens has elastic properties so that the shape of the lens is changed so as to alter its magnifying power.

Amphioxus has no eye but numerous *photoreceptor cells* are found in the nerve cord. Cyclostomes have degenerate type of eye, in which eye ball is buried under the thick skin that too is without cornea, iris, lids and ciliary apparatus. *Geotria macrophthalmus*, a freshwater cyclostome of Africa has large eye. Eyes in Elasmobranchs are large, rounded cornea that helps the spherical lens in focusing. The lens can project through the pupil and see to some extent, things on the sides. In a few elasmobranchs at the center of the choroids there is an additional layer (*Tapetum lucidum*), made of reflecting crystals. In the outer part of choroids of a few teleosts, a silvery or greenish golden layer is found called, *argentia*, which acts as reflector. Fishes are mostly colorblind and do not have cones in the retina. Among amphibians, eyes are normally small in aquatic urodeles and sunken into skin. Amphibian eye is simpler than fishes. It lacks tapetum lucidum and argentia. Besides this, retina also does not have fovea. Reptilian eyes are lateral in position and their field of vision is also different. Reptilian eyes are with well developed eyelids and glands. The lens is less convex than amphibians. Avian eyes are relatively large, occupying much space in the head. Eye ball is not spherical and has good power of accommodation. It the lumen of eye, a fan like organ *pectin* is found, which is probably nutritive in function. Features of mammalian eye have already been discussed.

Statoacoustic Organs or Ears

In cyclostomes the ear is said to be most primitive and has a single canal flattened on the bottom and rounded dorsally. It bears ampullae at both the ends. The lamprey (*Petromyzon*) and other cyclostomes have paired canals which are dorso-ventral in position. The tube is lined by epithelial cells equipped with sensory processes

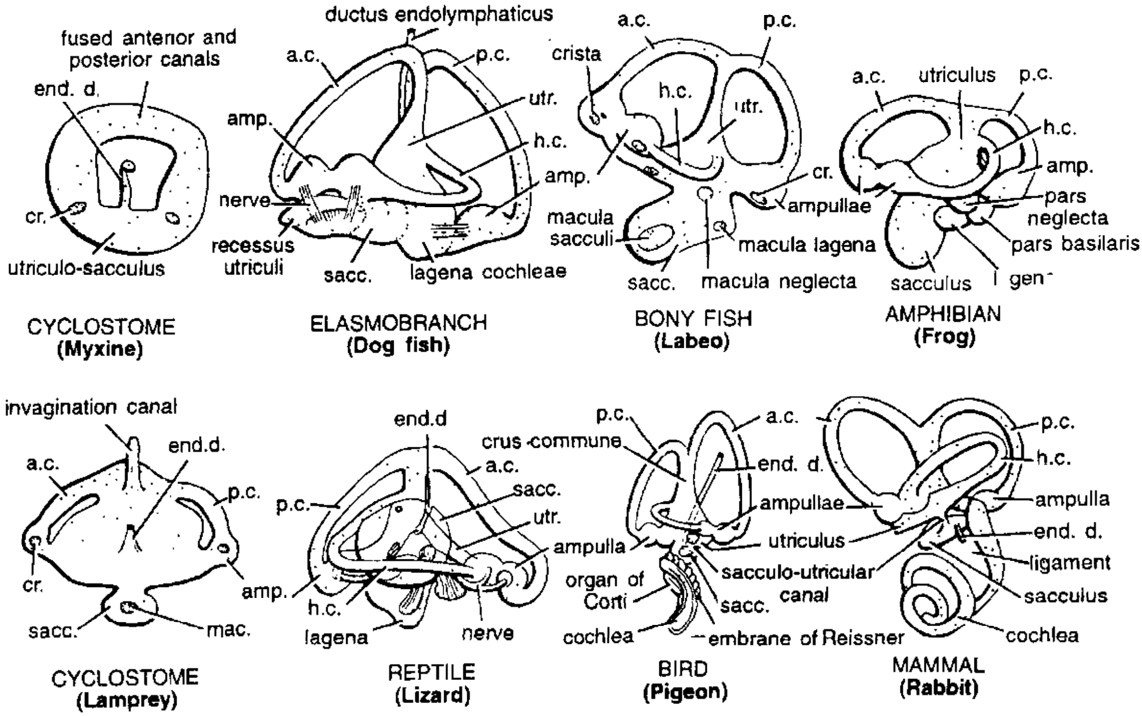

Fig. 3. Internal ears of representiative vertebrates a.c —anterior vertical semicircular canal. amp.—ampulla. cr.—crista. end.d.—endolymphatic duct. h.c.—horizontal canal. mac.—macula. p.c.—posterior vertical canal. sacc.—sacculus. utr.—utriculus.

and indicates the body position. This condition of cyclostomes is degenerate than primitive. It is so because of its semi attached host.

In fishes. The two senses of hearing and equilibrium are associated with the ears (Fig. 3). All the vertebrates possess a pair of inner ears or *membranous labyrinths*, embedded within the otic capsules of the skull lateral to the hindbrain. Each membranous labyrinth consists of 3 *semicircular canals* (only 1 or 2 in cyclostomes), a *utriculus* and a *sacculus*. Sacculus in fishes forms a rudimentary diverticulum, the *lagena*, which is a forerunner of cochlea of higher vertebrates, concerned with audition. Teleost fishes of the order Cypriniformes (catfishes, suckers, carps, etc.) utilize an air-filled swim bladder as a hydrophone. Sound waves in water, create waves of similar frequency in the gas filled bladder. These are transmitted via a chain of small bones, the *weberian ossicles*, to the sacculus. Weberian ossicles are modified transverse processes of the first 4 (occasionally 5) trunk vertebrae.

In tetrapods. In tetrapods, a middle ear cavity is added containing an ear ossicle, the *columella auris* or *stapes*, for transmitting sound vibrations from external tympanic membrane to a fenestra ovalis in the otic capsule (Fig. 3). An outer ear canal or external auditory meatus is also developed in amniotes. The lagena of fishes becomes a papilla called *cochlea* in amphibians. It gradually elongates in higher vertebrates into a *cochlear duct* containing the actual receptive structure, the *organ of Corti*.

The hearing apparatus of mammals is basically similar but much more elaborate. The cochlear duct is spirally coiled. In most mammals, an external flap, called *auricle* or *pinna*, collects and directs sound waves into the external auditory meatus. Instead of a single columella, the middle ear cavity in mammals is crossed by three *ear ossicles* : malleus, incus and stapes.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. What are receptors? How would you classify them?
2. Describe the structure of eye and explain the process of focusing in vertebrates.
3. Describe the structure of ear invertebrates.
4. Explain the mechanism of hearing and equilibrium in vertebrates.

» *Short Answer Type Questions*

1. Write short notes on — (i) Accommodation of eye, (ii) Chemoreceptors, (iii) Cochlear duct, (iv) Eustachian tube, (v) Mechanoreceptors, (vi) Nerve endings, (vii) Organ of Jacobson, (viii) Parietal eye, (ix) Proprioceptors, (x) Taste buds.

» *Multiple Choice Questions*

1. Receptors stimulated by touch and pressure, vibrations and balance :
   (a) Chemoreceptors (b) Mechanoreceptors
   (c) Photoreceptors (d) Thermoreceptors
2. Which of the following is a visceral receptor?
   (a) Interoceptor (b) Propioceptor
   (c) Exteroceptor (d) Thermoreceptor
3. Muscles are :
   (a) Thermoreceptors (b) Mechanoreceptors
   (c) Chemoreceptors (d) Photoreceptors
4. In tetrapods taste buds are present on :
   (a) Tongue (b) Palate
   (c) Pharynx (d) All
5. Organ of Pecten is found in the eye of :
   (a) Fish (b) Frog (c) Snake (d) Bird

ANSWERS

1. (b) 2. (a) 3. (b) 4. (d) 5. (d).

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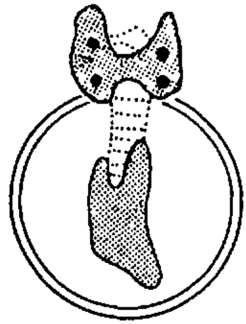

Endocrine System in Vertebrates

Exocrine and Endocrine Glands

Groups of cells specialized in structure and function to produce chemical substances needed in metabolic processes of body are known as *glands.* All animals, invertebrates as well as vertebrates, have two kinds of glands in their body — *exocrine* and *endocrine.*

1. Exocrine glands. Most glands discharge their products through *ducts.* These are called *glands* of *external secretion* or *exocrine glands.* They may discharge their secretions into an internal organ. For example, ducts of salivary glands and liver carry their secretions to parts of alimentary canal. On the other hand, sweat and mammary glands liberate their products to exterior through openings on the external body surface.

2. Endocrine glands. The term *'endocrine'* means internally secreting. Hence the glands, which do not have any duct, are called *glands of internal secretion, ductless glands* or *endocrine glands.* Their secretions are known as *internal secretions, endocrines,* or more commonly the *hormones.* These are released directly into a blood capillary and then transported by the blood stream to other parts of the body, where they coordinate their metabolic activities. Thus, function of endocrine system is chemical coordination.

Some glands, such as pancreas and gonads, are composite in nature, having both exocrine as well as endocrine functions. Pancreas secretes enzymes which are discharged through the pancreatic duct into duodenum, whereas the endocrine part of pancreas (islets of Langerhans) secretes hormones which diffuse directly into blood stream.

The study of endocrine glands and the hormones secreated by them is done under the branch of Zoology called *endocrinology.* The study of hormones is also known as *hormonology.*

Hormones

1. Definition. Secretions of endocrine glands are commonly called hormones. The term 'hormone' (Gr., *hormon,* arouse or excite) was coined by the British physiologist E.H. Starling in 1905. He defined hormone as 'any substance normally produced in the cells in some part of the body and carried by the blood or lymph stream to distant parts, which it affects for the good of the body as a whole'. An endocrine organ produces one or more hormones. Some ductless glands however, produce chemicals which inhibit (control), rather than stimulate the activities are called, *chalones.*

2. Chemical nature and properties. (i) Chemically speaking, hormones do not belong to any single group of organic compounds. They may be proteins, peptides, amino acids, fatty acids or steroids, (ii) Most of them are of *low molecular weight* and diffuse freely to bring about prompt responses, (iii) They are *soluble* in water, (iv) They are non-antigenic, (v) They do not have *cumulative effect.* Soon after their function is over, they become destroyed, inactivated or excreted. Thus, they must be continually replaced by new hormone molecules synthesized in the appropriate endocrine glands. (vi) Like vitamins they act in very low concentrations. (vii) They function like organic catalysts, sometimes as coenzymes of other enzymes, (viii) Their chemical nature is well known and most of them can be synthesized in the laboratory.

3. Functions. Main functions of hormones are :

(a) Internal chemical coordination. There are two major internal coordinating systems in the body : nervous system and chemical or endocrine system. Together they regulate several bodily functions such as growth, development, tissue activities and behaviour. But, unlike nervous control, which is very rapid but short, the endocrine or chemical control is slower but reasonably steady and lasting longer. Hormones serve as *chemical messengers* and bring about chemical coordination of various parts in the body.

(b) Specificity. Interestingly enough, there seems to be something fundamental or basic about chemical coordination in living organisms. The hormones are much the same in all the vertebrates and not specific for the animals in which they are produced. They are also effective in other different animals. For example, adrenalin has similar effect in protozoans, crustaceans and man and other vertebrates. Auxin, the growth hormone of plants also stimulates the protozoan *Euglena viridis.*

(c) Catalysts. Like enzymes and vitamins, hormones contribute no energy to cells. But they are indispensable to normal cellular physiology and well being of the organism. Hormones may act as catalysts or participate directly in chemical or metabolic processes. They are highly effective in very small amounts. They are oxidized or destroyed rapidly so that they do not produce permanent effects unless they are made available continuously.

(d) Target organ. A hormone such as thyroxine or growth hormone affects similarly every cell in the body. Most hormones, however, affect only particular cells or organ in the body. For example, only pancreas responds to the hormone secretin circulating in blood. Such cells or organ are called the 'target organ' of that particular hormone. Similarly, thyroid gland is the target organ of thyrotropin (TSH) secreted by the pituitary. Also ovary or testis is the target organ of the gonadotropins FSH and LH also from pituitary.

(e) Abnormalities. Normal body function requires an optimal amount of hormones. Upsets or hormonal imbalance may cause various functional diseases. Either a *hyposecretion* (deficiency) or *hypersecretion* (excess) of any one hormone may result in a characteristic pathological condition.

4. Classification. Hormones can be arranged in different categories. Depending on the biochemical structure, hormones can be classified as follows :

(a) Phenolic hormones. Ex. *Thyroxine, adrenaline.*

(b) Steroid hormones. Ex. *Estradiol, progesterone, testosterone.*

(c) ***Proteinous hormones.*** Ex. *Parathormone, insulin, prolactin.*

On the basis of their control and influence over physiological processes, hormones can be classified under the following categories :

(i) Concerned with metabolism. Ex. *Thyroxine, parathormone, insulin, adrenocortical hormones.*

(ii) Concerning digestion. Ex. *Gastrin, secretin, cholecystokinin, enterogastrone.*

(iii) Regulating growth and development. Ex. *Somatotropin.*

(iv) Controlling reproduction. Ex. *Testosterone, estrogen, progesterone.*

5. Mechanism of hormone action. Several hypothesis or theories are current regarding the mechanism of hormone action. According to them, a hormone combines with some specific receptor within a cell. If cells do not have this specific receptor they do not recognize that particular hormone. But hypothesis differ regarding the nature and location of the receptor, and what happens after the hormone is bound to its receptor. Experiments with steroid hormones indicate that their receptors are located in the nuclei of cells of their target organs.

According to one hypothesis, the hormone combines with some substance, such as protein, in the cell membrane. This changes the molecular structure of cell membrane in such a way that its permeability increases to specific substrates. An example is the greater uptake of glucose by muscle cells stimulated by the hormone insulin.

Another hypothesis stipulates a remarkable biological amplification inherent in hormonal process. This can be represented by the sequence of enzymatic events after *epinephrine* or *glucagon* combines with a specific *adenyle cyclase* enzyme of liver cells (Fig. 1). It stimulates the production of *cyclic 3′, 5′-adenosine monophosphate* (*cyclic* AMP) from ATP. The cyclic AMP is regarded as a 'second messenger' that activates another enzyme, a *protein kinase.* This in turn phosphorylates, that is, transfers a phosphate group from ATP to a third enzyme, *phosphorylase kinase,* and activates it. The latter in turn phosphorylates and activates an inactive fourth enzyme, *phosphorylase-b,* to active *phosphorylase-a.* This finally catalyzes the production of *glucose-1-phosphate* from *glycogen.* Each of these steps involves an amplification of 10 to 100 fold so that even a very small amount of epinephrine leads to the production of a very large amount of glucose.

A third general hypothesis suggests that the hormone enters the nucleus, and may regulate gene transcription by activating previously repressed specific genes (Fig. 2). It may combine with a histone or other protein (i) bound to DNA,

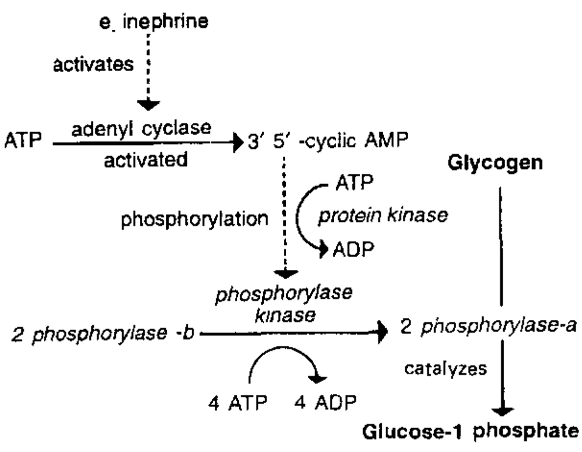

Fig. 1. Mec' anism of ' ormone action represente ' diagrammatically by sequence of enzymatic action during which epinephrine stimulates production or glucose from glycogen in liver cells.

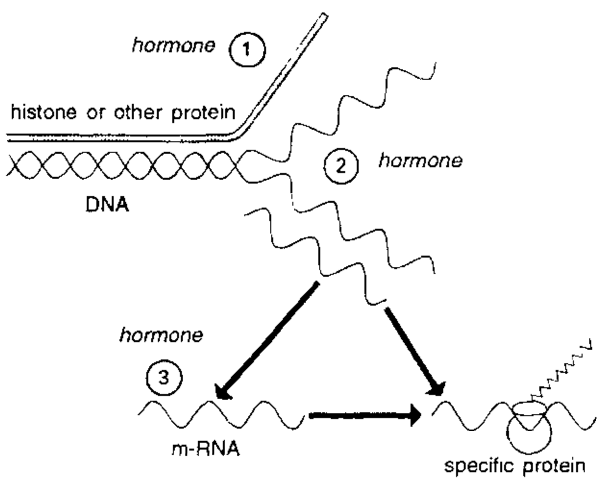

Fig. 2 A diagram showing possible sites (1 to 3) at which a hormone may regulate gene transpriction

may in'erac' wit' 'he DNA i'self (ii) or may combine with a specific messenger RNA (iii) leading to the formation of new kinds of m-RNA which code for the synthesis of new specific proteins. This theory also accounts for great amplification of hormonal effect, because a very small amount of hormone b regulating gene transcription could produce many molecules of m-RNA and of protein.

Endocrine Glands

The accompanying diagram shows the approximate location of some of the more important endocrine glands in the body of a man or woman (Fig. 3). The readers shall find a reasonably good 'escr'pt'on o' en'ocr'ne g'an's an' t'e'r' ormones in chapter 30 on rabbit. The table 3 also provides a summary of vertebrate hormones and their p'y'iologic effect' or function'. While Figure 4 illustr tes few p th l gic l c nditi ns cr a d due to hormonal i balance i ......

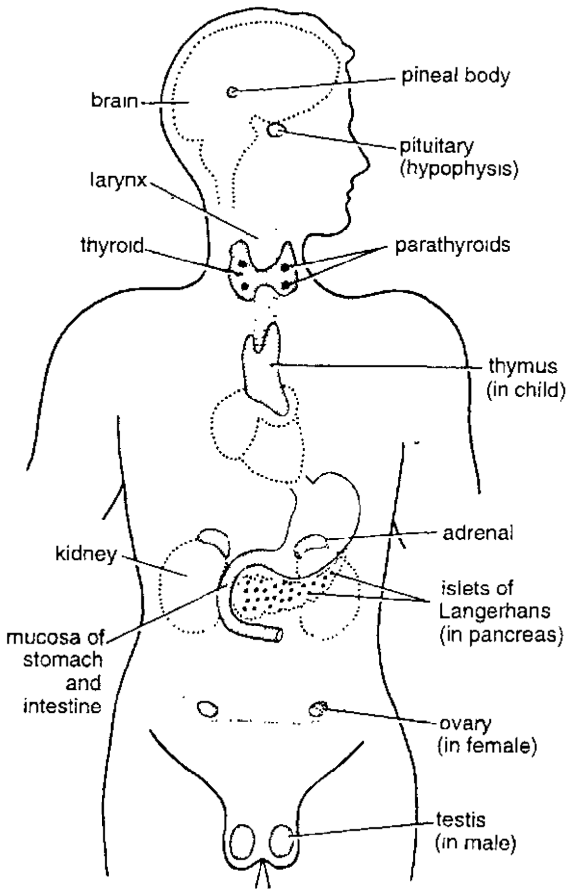

Fig. 3. Diagram to illustrate the approximate location of some of the important endocrine glands in the body of man and women.

Endocrine Glands in Vertebrates

Elasmobranchs. Elasmobranchs have most of the vertebrate endocrine glands *viz., pituitary, thyroid, pancreas, adrenal, mucous membrane of stomach* and *duodenum* and *gonads* but *thymus* and *parathyroid* are absent. As far as function of *pituitary* gland is concerned, its function is not known except it keeps other glands healthy and causes expansion of melanophores. A single *thyroid* gland is found below the ventral aorta. The adrenal gland is found in the form of two separate sets of tissues *viz., suprarenal bodies* and *interrenal bodies.*

Amphibia. Most of the endocrine glands are found in the amphibians. But the relationships of various lobes of pituitary gland differ from that of higher vertebrates. Anterior lobe of pituitary is not formed from *pars anterior* and *pars tuberalis.* Moreover pars anterior lies posterior to other lobes. Thyroid glands is paired and lies deeply, lateral to hyoid. Secretions of thyroid besides controlling growth, also controls periodic ecdysis. One pair of small, red, rounded *parathyroid* glands lie on either side of posterior part of hyoid. Second pair of visceral cleft develops into *thymus.* Components of *adrenal glands* are fused and found on ventral surface of kidney in the form of yellow band. *Corpus luteum* is absent in ovaries.

Reptiles. Most of the endocrine glands are found in reptiles. *Thyroid* is single in snakes and turtles, but paired in lizards. *Parathyroid* two pairs, at considerable distance from *thyroid,* near aortic arches due to development of infundibular stalk, *pituitary* gland lies somewhat posterior. Lizards and snakes (squamata) have no *pars distalis. Adrenals* lie close to gonads. The *pineal gland* is well developed. *Gonads* control the development of secondary sex characters.

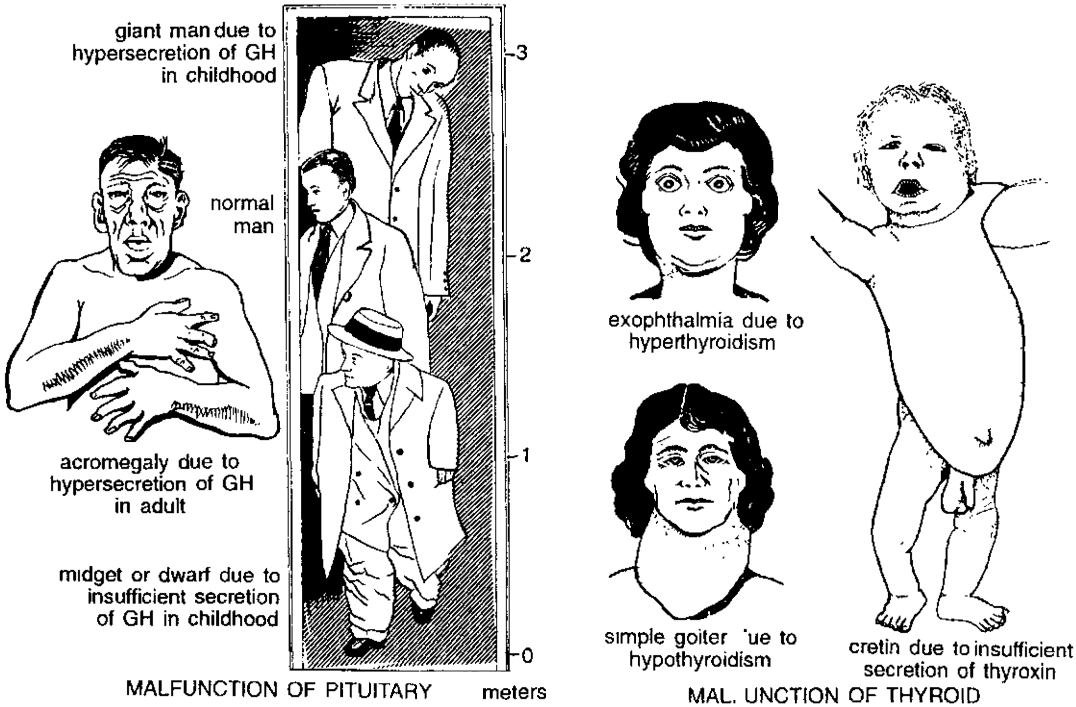

Fig. 4. Some pathological conditions due to hormonal imbalance in man.

Aves. All endocrine glands present. *Thyroid* paird, located on either side of trachea. *Parathyroid* one or two pairs lies slightly posterior to thyroid. No intermediate lobe in *pituitary* but hormone *intermedin* is secreted from anterior lobe of pituitary. *Thymus* is paired, elongated gland, lying on either side of trachea. *Adrenal* glands lie close to gonads, anterior to kidneys. *Testes* have few interstitial cells. *Ovaries* have well developed follicle cells as endocrine component.

Endocrine Glands as a System

Endocrine glands are located at widely separated places in the body. They are of different origin (ectodermal, mesodermal or endodermal) and structure. Their secretions or hormones also differ chemically (proteins, steroids, polypeptides, etc.). But, it is interesting to note that each gland affects the functioning of almost every other gland. For example, if the anterior lobe of pituitary is removed, both the testes and ovaries also secrete little hormones, if any (Fig. 4). Thus all the glands of internal secretion together constitute an interrelated and interdependent *endocrine system* which coordinates various body activities. When the role of pituitary in controlling the activities of thyroid, adrenals, gonads, etc. was first discovered, the pituitary was regarded a 'master controlling gland'. But in view of the interrelationships of all endocrine glands and the reciprocal effects of their hormones, it is probably not correct to regard pituitary as a special master gland.

Neuro-endocrine Interrelationships

All the endocrine glands have nerve fibres to and from the nervous system, so that the roles of the nervous and endocrine systems are complementary and frequently integrated. A remarkable example of cooperation between nervous and endocrine systems occurs in the mammalian hypophysis or pituitary gland. *Neurosecretions* are hormones produced by cell bodies of specialized neurons of central nervous system. The majority of neurosecretory neurons are found in *hypothalamus*

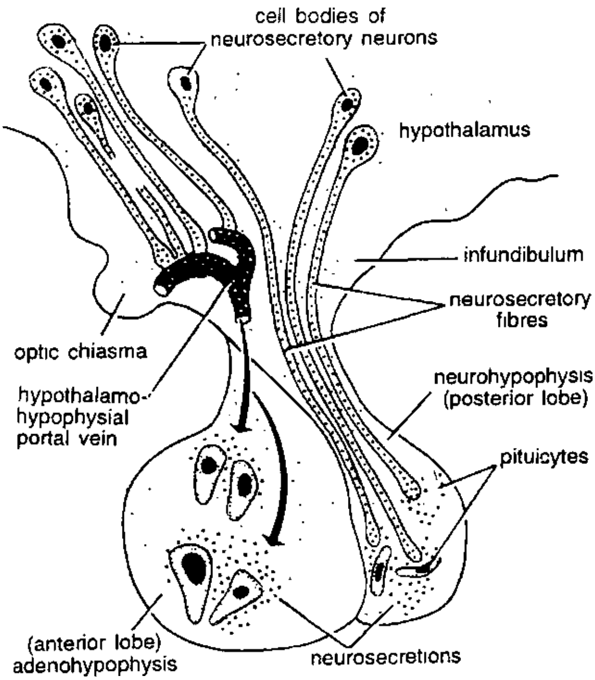

Fig. 5. Neurosecretory neurons of hypothalamus discharging their neurosecretions into hypophyseal vein and into neurohypophysis of pituitary.

which is a part of brain, but extend their axons into the neurohypophysis. Their secretions flow along these axons (neurosecretory fibres) and released into circulatory channels at axon terminals. Some of these secretions are released into hypophyseal portal vein and carried to the anterior lobe or *adenohypophysis* of pituitary. However, most neurosecretions are released into blood sinusoids of pars nervosa or *neurohypophysis* of pituitary and transported to all parts of the body. These neurosecretions regulate the hormonal activity of pituitary cells called *pituicytes.* Remote tissues and glands of the body affected by neurosecretions in blood circulation, exert a kind of hormonal feedback so that production of hormones by hypothalamus and pituitary may be affected (accelerated or decreased). Thus, activities of brain and other endocrine glands become interrelated or integrated via internal secretions as well as via peripheral nerves. Indeed, it is impossible to demarcate any dividing line between nerve cells and endocrine cells as both secrete similar substances with similar physiological effects.

Pheromones

Meaning. *Hormones* are chemicals released into the internal environment by endocrine glands. They regulate and coordinate the activities of other tissues in association with nervous system.

On the other hand, *pheromones* are chemicals secreted by *exocrine glands* and released into the *external environment.* They influence the behaviour and cause specific reactions in other *animals* of the same species. They represent a means of communication, a means of imparting information by smell.

Types and functions. There are generally two major categories of pheromones : (a) quick action pheromones and (b) slow action pheromones.

(a) Quick action pheromones. These act in some way on the recipient's nervous system resulting in immediate effect on its behaviour. These also fall into 3 broad types : (i) *Sex attractants,* (ii) *trail pheromones,* and (iii) *alarm pheromones.*

(i) Sex attractants. These are odorous, volatile substances exuded by the female and are detected by the extremely sensitive chemoreceptors present in the antennae of males of the same species. In response, the males become sexually stimulated and can be drawn towards female from a distance, as great as 4.5 km in some cases. Among the sex attractants isolated and identified are *bombykol* secreted by female silkworms, and *gyplure* secreted by female gypsy moth. A female silkworm contains on an average 0.01 mg of sex attractant sufficient to stimulate more than a billion males.

Sex attractants have been tested as possible specific insecticides in biological control. Synthetic forms of such chemicals are used for attracting insect pests which are killed with potent insecticides. If attractants are spread in large quantities over an insect-infested field, the confused males might never find females and mate with them.

(ii) Trail pheromones. Trail pheromones are secreted by the fire ants returning to their nest

after finding food, so that other ants can also follow the trail to reach food. These are highly volatile and evaporate within two minutes only so that there is no risk of confusion created by the old trails.

Similarly, worker bees on finding food, secrete *geraniole*, to guide other worker bees to the source of food, in addition to their wagging dance.

(iii) Alarm pheromones. These are released by ants when disturbed. Alarm substances have a lower molecular weight and are less specific than sex attractants. This causes several different species of ants responding to the same alarm substance.

(b) Slow action pheromones. These pheromones act more slowly and affect growth and differentiation of the recipients. They play an important role in regulating the composition and activities of colonial insects such as ants, bees and termites. Queen bees secrete *9-ketodeconic acid*. When ingested by worker bees, it retards development of their ovaries and ability to build royal cells rearing new queens. It also serves as a sex attractant for males during nuptial flight.

In termites, special castes such as queens, kings and soldiers secrete inhibitory pheromones. These affect the corpus allatum of the nymphs and prevent their developing into these specialized castes. If a queen dies, there is no longer any 'antiqueen' pheromone released so that one or more nymphs develop into queens. Same happens in case of other specialized castes.

Males of migratory locusts secrete pheromones which accelerate the growth of young locusts. In mice, if several females are put together in a cage their estrous cycles become erratic. However, if one male mouse is also placed with them, his odour synchronizes the estrous cycles of all the females *(Whitten effect)*.

Existence of human pheromones remains doubtful. According to the French biologist J. Le Magnen, only sexually mature women can clearly perceive the odour of *15-hydroxypentadeconic acid*, while males and young girls are relatively insensitive to it. Observation also shows that among room mates and close friends in girls, there is more synchronization of menstrual cycles. Whether it involves any pheromones remains unanswered.

IMPORTANT QUESTIONS

» *Long Answer Type Questions*

1. What are endocrine glands ? Give their names and describe the structure and function of any four of them.
2. Write an essay on endocrine glands in vertebrates.
3. What are hormones ? Describe their chemical nature, properties and functions.
4. Describe the mechanism of hormone action.

» *Short Answer Type Questions*

1. Define endocrine, exocrine, hormone and pheromone with suitable example.
2. Write short notes on — (i) Acromegaly, (ii) Exophthalmia, (iii) Goiter, (iv) Islets of langerhans, (v) Neurosecretion, (vi) Pheromone, (vii) Target organ.

» *Multiple Choice Questions*

1. Function of endocrine system :
   (a) Nervous coordination
   (b) Muscular coordination
   (c) Mechanical coordination
   (d) Chemical coordination
2. Ductless glands producing inhibiting chemicals :
   (a) Exocrine glands (b) Endocrine glands
   (c) Chalone (d) Receptors
3. Thyroxin is a :
   (a) Phenolic hormone (b) Steroid hormone
   (c) Proteinous hormone (d) Fatty acid
4. Endocrine glands absent in elasmobranchs :
   (a) Thyroid (b) Thymus and parathyroid
   (c) Pituitary (d) Islets of langerhans
5. Master of endocrine orchestra :
   (a) Pituitary (b) Thymus
   (c) Hypothalamus (d) Thyroid
6. Hormonal activities of pituicytes are regulated by :
   (a) Thymus (b) Thyroid
   (c) Negative feed back (d) Hypothalamus
7. Pheromones are released into :
   (a) Blood (b) Target tissue
   (c) External environment (d) Coelom
8. Bombycol is secreted by :
   (a) Male silk moth (b) Female silk moth
   (c) Male gypsy moth (d) Female gypsy moth

ANSWERS

1. (d), 2. (c), 3. (a), 4. (b), 5. (a), 6. (d), 7. (c), 8. (b).

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Some Comparative Charts of Vertebrate Animal Types

Chapter 8 of this book was devoted to a comparative study in tabular form of the 3 protochordate types : *Balanoglossus*, *Herdmania* and *Branchiostoma*. Similarly, in the present chapter, the readers will find a comparative survey of the anatomy of the typical vertebrate animal types, such as dogfish (*Scoliodon*), frog (*Rana*), Lizard (*Uromastix*), pigeon (*Columba*) and rabbit (*Oryctolagus*).

Table 1. **Comparative Account of Habitat, Distribution and Habits of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** *(Scoliodon)*	**Frog** *(Rana)*	**Lizard** *(Uromastix)*	**Pigeon** *(Columba)*	**Rabbit** *(Oryctolagus)*
			A. HABITAT		
	Marine, Sometimes occurs in estuaries and rivers.	Amphibious. In fresh water or near about in damp on land.	Dry, soft, sandy tracts with scant vegetation places.	In holes and fissures of rocks and in old buildings.	In fields, grasslands and open woodlands.
			B. DISTRIBUTION		
	Widely in Indian, Pacific and Atlantic Oceans along sea-coasts.	Found all over India.	North-western India, Gujarat.	Common throughout India. Widely distributed in Asia, Europe and North Africa.	Cosmopolitan or common throughout the world.
			C. HABITS		
1. Home	Marine	Amphibious	Terrestrial	Aerial	Terrestrial
2. Locomotion	Swimming in water.	Leaping on land and swimming in water.	Creeping or running on land.	Flying in air and walking on land	Moves by walking, running or leaping
3. Nature	Nonpoisonous, active throughout, predaceous.	Non-poisonous, harmless, nocturnal.	Gentle, sluggish, quiet, diurnal, non-poisonous.	Gentle, harmless, agile, diurnal.	Timid, agile, crepuscular

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
4. Association	Gregarious	Solitary	Solitary	Gregarious	Gregarious
5. Burrow	Non-burrowing	Non-burrowing	Burrowing	Non-burrowing	Burrowing under-ground.
6. Food	Carnivorous and scavenger, feeding on crabs, lobsters, worms, fishes, etc.	Carnivorous mainly insectivorous, feeding on insects, worms, molluscs, etc. Cannibalism occurs.	Chiefly herbivorous feeding on grasses, leaves seeds and fruits. Sometimes on insects.	Mainly herbivorous feeding on grains, pulses, seeds, etc. Sometimes on insects.	Herbivorous, feeding on green vegetation. Also coprophagous.
7. Sound	Silent	Usually silent but croak during mating season.	Silent, rarely squeaking slowly.	Produce a deep gootur-goon sound.	Silent but squeak meakly.
8. Body temperature	Cold-blooded. Poikilothermous	Cold-blooded. Poikilothermous	Cold-blooded. Poikilothermous	Warm-blooded. Homoiothermous	Warm-blooded. Homoiothermous
9. Hibernation	No hibernation.	Hibernates in winter and aestivates in summer.	Hibernates in winter.	Active throughout the year.	Active throughout the year.
10. Breeding Season	Lasts throughout the year.	Breed during rainy season from July to September.	Breed in March and April.	Breeding occurs throughout the year.	Breed all round the year.
11. Courtship	Precedes copulation.	Males croak loudly to attract females.	Precedes copulation.	Much courtship precedes copulation.	No courtship.
12. Copulation	Occurs. Male twines around female and inserts grooved pelvic claspers into female's cloaca to transfer sperm.	During copulation, called *amplexus*, male mounts upon the back of female and clasps with the help of nuptial pads on his hands.	During copulation, male inserts one of his hemipenes into cloaca of female.	During copulation, male rides on the back of female and their cloacae are apposed.	During copulation, male inserts his copulatory organ into vulva of female.
13. Eggs or young ones	Viviparous or ovo-viviparous. Giving birth to 3 to 7 young ones.	Oviparous. Female lays several hundred small shell-less eggs in water in a spawn.	Oviparous. 10 to 15 dirty-white shelled eggs are laid in a burrow.	Oviparous. Two large white and shelled eggs laid at a time in a nest.	Viviparous. 5 to 8 young ones born in a litter and kept inside burrow.
14. Fertilization	Internal, in oviducts.	External, in water,	Internal, in oviducts.	Internal, in oviducts.	Internal, in oviducts
15. Development	Uterine, direct, without metamorphosis	External, in water. Indirect, tadpole larva undergoing metamorphosis to become adult.	External inside egg shell. Direct, without metamorphosis.	External, within shelled eggs. Direct without metamorphosis.	Internal, uterine. Direct, without metamorphosis.
16. Extra-embryonic membranes and placenta	Embryonic membranes absent (*anamniota*). Yolk sac placenta formed.	No membranes (*anamniota*) and no placentation.	Embryonic membranes (chorion, amnion, allantois) developed (*amniota*). Placenta absent.	Embryonic membranes present (*amniota*). Placenta absent.	Embryonic membranes present (*amniota*). Yolk sac and allantoic placenta developed.
17. Family life	No family life	No family life	No family life	*Monogamous*, i.e., one male breeds only with one female.	*Polygamous*, i.e., one male breeds with several females.

(*Contd.*)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
18. Parental care	Not exists	Not found	No parental care. Eggs develop by the heat of sun.	Parental care shown. Both parents incubate eggs and feed young ones on pigeon's milk.	Mother shows parental care by feeding young on milk and by defending them against enemies.
19. Change of colour	Does not occur	Undergoes change of body colour matching with the surroundings	No change of body colour.	No change in body colour.	No change of body colour.

Table 2. **Comparative Account of External Features of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Shape	Body elongated, streamlined for swimming. Spindle-shaped and bilaterally compressed.	Body streamlined for swimming and oval. Flattened dorso-ventrally.	Body elongated and depressed for burrowing.	Body streamlined and boat-shaped, adapted for flight.	Body elongated but squatty.
2. Size	Length about 60 cm.	Length 12 to 18 cm.	Length 20 to 30 cm.	Length 33 cm.	Length 40 cm.
3. Colour	Dorsal surface dark grey, ventral pale white.	Dorsal surface green with black or brown patches. Ventral surface pale white. Colour changes according to the background.	Dorsal surface yellow brown with dark spots. Ventral surface light pale.	Wild pigeon slaty grey with metallic green and purple sheen on breast and neck. Two black bars on wings.	Wild rabbit dusty brown. Domestic variety white or black and white.
4. Exoskeleton	Includes dermal placoid scales embedded in skin which is rough.	Exoskeleton totally absent so that skin surface is smooth.	Includes horny overlapping epidermal scales covering body and horny claws on digits.	Includes horny epidermal feathers, claws, beaks and scales.	Includes soft fur of horny epidermal hairs all over body and claws on digits.
5. Divisions of Body	Body divisible into 3 parts : head, trunk and tail.	Body consists of 2 regions only : head and trunk.	Body has 4 distinct parts : head, neck, trunk and tail.	Body divisible into head, neck, trunk and tail.	Body distinctly divided into head, neck, trunk and tail.
			A. HEAD		
1. Orientation	In line with rest of body.	In line with rest of body.	In line with rest of body	Head makes an angle with rest of body.	Head makes an angle with rest of body.
2. Shape & size	Head large, triangular and depressed. Not distinct from trunk. Produced in front into a pointed snout or rostrum.	Head large, roughly triangular and flat. Slightly demarcated from trunk. With a short, blunt snout.	Head small, slightly triangular and depressed. Distinct from body. Produced in a short, blunt snout.	Head small, rounded and distinct, produced into an elongated hard beak.	Head large, pear-shaped, distinct, with a large blunt snout or muzzle.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
3. Mouth	Mouth small, ventral, crescentic opening bounded by jaws without lips	Mouth large, terminal, semicircular, bounded by hard immovable lips.	Mouth wide, terminal transverse slit, bounded by hard immovable lips covered with scales	Mouth terminal, V–shaped wide gape bounded by horny beaks without lips.	Mouth terminal, ventrally directed, small transverse slit bounded by soft fleshy and movable lips. Upper lip cleft and bears vibrissae.
4. Teeth	Sharp, pointed, backwardly directed and homodont. Present on both jaws.	Small, conical, backwardly pointed, acrodont, homodont and present only on upper jaw.	Small, conical, acrodont, homodont and on both the jaws.	Teeth absent	Teeth thecodont, heterodont and present on both the jaws.
5. Nostrils	External nares ventral, crescentic, and each divided by a flap of skin. Exclusively olfactory.	External nares dorsally on snout, small, circular and serve for respiration.	External nares on snout, small, oval, with a valve. Olfactory as well as respiratory.	External nares narrow slits at the base of upper beak, without valves, covered by a sensitive skin fold or cere.	External nares large oval openings, without valves. Olfactory as well as respiratory.
6. Ear openings	Ear openings and tympanum absent.	No ear openings. Behind each eye present a circular patch of tight skin, the *tympanum*, covering the middle ear cavity.	Tympanum present deeper at the base of a circular external ear opening behind each eye.	External ear openings covered by special feathers. Tympanic membranes sunken into external auditory meatus.	Large circular openings of external auditory meatus covered by movable skin flaps called *pinnae*.
7. Eyes	Eyes small, lateral and circular. Pupil vertical. Eyelids immovable. Nictitating membrane present.	Eyes large, dorsolateral and bulging. Pupil horizontal. Lower eyelid movable. Nictitating membrane present.	Eyes small, dorsolateral and elliptical. Pupil round. Eyelids movable. Nictitating membrane present.	Eyes large, lateral and circular with round pupil, movable eyelids and nictitating membrane.	Eyes large, lateral and oval with bulging cornea. Pupil round. Eyelids movable with eyelashes. Nictitating membrane present.
8. Gill-slits	Behind each eye present 5 vertical oblique gill-slits.	Gill slits found in tadpole larva. Absent in adult.	Absent in adult.	Absent in adult.	Absent in adult.
9. Brow spot	No brow spot	A faint median brow spot present between eyes on head.	Absent	Absent	Absent
10. Vocal sacs	Absent	A pair of oval, wrinkled, bluish vocal sacs found ventrally on throat of male frog only.	Absent	Absent	Absent
			B. NECK		
Shape & size	Absent	Absent	Short & horizontal with loose skin.	Long, , vertical, cylindrical and flexible.	Short, nearly vertical and flexible.

(*Contd.*)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
			C. TRUNK		
1. Shape & size	Large, oval in section and gradually tapers behind.	Small, broad, oval, dorsoventrally flattened. With a characteristic *sacral hump* on back.	Long, broad, arched dorsally, flat ventrally.	Compact,' spindle-like, flat above but arched below.	Large, cylindrical, differentiated into anterior thorax and posterior abdomen.
2. Skin of trunk	Rough, scaly, firmly attached and without wrinkles	Smooth, loosely attached, wrinkled with longitudinal dorso-lateral folds or dermal plicae.	Rough, scaly, dry and wrinkled	Feathery, dry, loose hard and thin.	Hairy, thick, loose and glandular.
3. Copulatory organ	A pair of rod-like *pelvic claspers* in male.	Absent	A pair of *hemipenes* in male, projecting through cloaca.	Absent	A cylindrical erectile penis in male.
4. Scrotal sac	Absent	Absent	Absent	Absent	Testes lie at the base of penis in a scrotal sac.
5. Apertures	A ventral longitudinal *cloacal aperture*. Small paired openings of coelom, called *abdominal pores*, on sides of cloaca.	*Cloacal aperture* small, terminal and circular. Abdominal pores absent.	Small, ventral transverse cloacal aperture. No abdominal pores. *Preanofemoral pores* found in a row ventrally on each thigh.	Large, transversely elongated, subventral cloacal opening. No ab- dominal pores.	Cloaca absent. Separate anus and urinogenital openings present at hind end.
6. Teats	Absent	Absent	Absent	Absent	4 or 5 pairs of ventral teats or nipples in female. Rudimentary in male.
7. Limbs	Trunk bears median fins (2 dorsal, 1 ventral) and paired pectoral and pelvic fins for locomotion.	Paired fore and hind limbs present. Digits clawless. Hand with 4 fingers. Foot with 5 toes having *webs* or thin transparent skin between them which serves for swimming.	Paired fore and hind limbs. Each bearing 5 clawed digits. Adapted for creeping and burrowing.	Paired fore and hind limbs. Forelimbs modified into wings for flying, bearing long feathers and 3 covered clawless fingers. Each foot bears 4 clawed toes used for perching and walking.	Paired fore and hind limbs. Hand with 5 clawed fingers for burrowing. Foot with 4 clawed fingers for leaping
8. Lines	A pair of lateral line organs on head, trunk and tail on either lateral side.	Lateral lines absent in adult. Instead a mid-dorsal line present.	No lines	No lines	No lines
			D . TAIL		
Shape & Size	Long, laterally compressed, gradually tapering and bearing a caudal fin. Heterocercal. Used in swimming.	Tail and caudal fin present in tadpole larva but absent in adult frog.	Tail long, massive, broad, gradually tapering behind, bearing transverse rows of hard, strongly keeled scales. Used in offence and defence.	Short, stumpy, conical. Bears an oil gland and large tail feathers used for steering during flight.	Tail small, furry, curved upwards. Used for balancing in leaping and for giving warning signals in danger.

Table 3. **Comparative Account of Integument and Exoskeleton in Vertebrate Animal Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** *(Scoliodon)*	**Frog** *(Rana)*	**Lizard** *(Uromastix)*	**Pigeon** *(Columba)*	**Rabbit** *(Oryctolagus)*
			A . INTEGUMENT		
1. Skin surface & attachment	Skin hard, rough, rigid, leathery and firmly attached to body.	Skin thin, moist, slimy, smooth, fitting loosely on body enclosing large subcutaneous lymph spaces beneath dermis.	Skin thicker, dry, rough, and loosely folded along the sides of neck and trunk.	Skin thin, dry, hard flexible and loosely attached to achieve maximum freedom of movement for flight.	Skin thickest, dry, elastic and loosely attached. Variously modified.
2. Colouration	Colour of *Scoliodon* is dark, grey dorsally and pale white ventrally. Fishes in general show greatest colour patterns and brilliance amongst chordates.	Colour of *Rana* is green with black and brown patches above and lighter pale-yellow below.	Body of *Uromastix* is yellow-brown with dark spots above, and lighter and paler below. In reptiles in general color patterns elaborate for warning or concealment.	Rock pigeon is slaty-grey with green and purple sheen around neck and breast and 2 black bars on each wing. Birds in general are beautifully coloured.	Colour of rabbit is dusty-brown and protective. Mammals, in general, are dull coloured.
3. Colour change	Body colour does not change. Some fishes have protective colouration.	Frog has protective colouration for camouflage and can change body colour to match with the surroundings.	*Uromastix* has no power to change colour. However, *Calotes* and chamaeleons can change body colours.	No capacity for change of body colouration in birds in general.	Usually, no capacity to change body colouration.
4. Pigmentation	Pigment containing chromatophores and guanin containing iridophores located in dermis.	Chromatophores located in dermis.	Chromatophores located in dermis.	Pigment cells found in feathers, not in dermis. Colours also due to reflection and refraction of light by feathers.	Pigment granules located in hairs and epidermis, pigment cells in dermis.
5. Cutaneous respiration	Skin protective and sensory. Not permeable to water, hence no cutaneous respiration.	Skin protective and permeable to water, hence serves as an organ of respiration.	Skin protective and water-proof, without cutaneous respiration.	Skin protective, insulating and water-proof. No skin respiration.	Skin protective, insulating and water-proof. No cutaneous respiration.
6. Epidermis	Epidermis many-layered or stratified, but simple, thin and without a cornified stratum corneum, No moulting.	Many-layered or stratified epidermis with a thin stratum corneum of flat and dead keratinized cells continuously shed in patches.	Epidermis stratified with a relatively thicker stratum corneum periodically shed in bits or in one piece.	Epidermis stratified, relatively thinner, and seasonally shed and replaced.	Epidermis greatly stratified. Stratum corneum highly specialized with several modifications. No regular moulting.

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
7. Epidermal glands	Epidermis con- tains numerous unicellular mucus- secreting goblet gland cells. Mul- ticellular poison glands and lumi- nescent glands or photophores also occur in some fishes.	Epidermis is rich in multicellular mucous glands. Some amphibians have poison glands like parotid glands of toad.	Lizard has few but no mucous glands. Male lizard has femoral glands on thighs. Some reptiles have scent or musk glands.	No skin glands occur in birds except a single large preen or uropygial gland on tail. No mucous glands present.	Skin richly glandu- lar containing characteristic ma- mmary, sweat and sebaceous glands besides scent glands. No mucous glands present.
8. Dermis	Dermis is typical with connective tissue fibres, blood and lymph vessels and pigment cells. But all connective tissue fibres run parallel to surface.	Dermis is thin and typical. It consists of an outer loose layer or stratum spongiosum, and an inner compact layer of collagen fibres called stra- tum compactum. Connective tissue fibres are vertical as well as horizon- tal.	Dermis is thick and typical, containing connective tissue fibres, muscle and nerves, blood capillaries and lymphatic vessels, and also pigment cells.	Dermis is mostly thin and typically made of muscle fibres, nerves, blood capillaries and connective tis- sue. It has no pig- ment.	Dermis is propor- tionately thickest of all vertebrates, containing intri- cate fibres, tactile organs, nerves, blood vessels and pigment cells.
9. Dermal scales	Dermal scales are present as placoid scales.	Dermal scales are absent in frog, al- though embedded in the skin of some Gymnophiona.	Dermal scales ab- sent in *Uromastix*, but dermal scales, scutes or plates, called osteoderms, occur in some liz- ards, crocodilians and turtles.	Dermal scales are absent in birds.	Dermal scales or plates occur only in armadillos and whales.
			B . EXOSKELETON		
1. Parts of exo- skeleton	Exoskeleton pres- ent and repre- sented by dermal placoid scales.	Exoskeleton com- pletely lacking.	Exoskeleton pres- ent represented by epidermal horny scales and claws.	Exoskeleton pres- ent formed by scales, claws, sheaths of beaks and feathers of 3 types.	Exoskeleton pres- ent and formed by scales, claws and hairs.
2. Epidermal scales	Epidermal scales are absent. Dermal placoid scales, mesodermal in ori- gin, embedded in skin in oblique rows all over the body.	Both epidermal and dermal scales absent.	Epidermal scales thin, small, over lapping and cover- ing whole of the body.	Epidermal scales small, present on lower legs, feet and base of beak only.	Epidermal scales are absent in rab- bit, but present on the feet and tails of rats, beavers, etc.
3. Dermal scales	Exoskelton in bony fishes in- cludes dermal scales of four types · cosmoid, ganoid, ctenoid and cycloid.	No exoskeleton present in other amphibians.	Exoskeleton in other reptiles in- cludes dermal scutes and plates in snakes, cro- codilians and turtles.	Exoskeleton of other birds also includes scales, claws, horny cov- erings of beaks and feathers.	Exoskeleton in other mammals includes hoofs, nails, horns, etc.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
4. Other parts	Hairs, feathers horns and beaks absent	Hairs, feathers, horns and beaks absent.	Hairs and feathers absent. Grotesque horns (horned toad), rattle (rattle snake) and horny beaks (turtles) present in some.	Hairs and horns absent. Feathers of 3 types – contour, down and filoplume – and horny sheaths of beaks found in all birds.	Feathers and beaks absent. Hairs modified into hair horns (rhino), scales (pangolins), spines (echidna), quills (porcu- pine), etc. Claws become nails (primates) or hoofs (ungulates). Horns and antlers present in ungulates.
5. Moulting	Scales do not moult but grow in size with age.	Stratum corneum of frog moulted periodically in small pieces.	Scales shed periodically in small bits.	Feathers shed and replaced seasonally.	Horny covering of pronghorns and skin of antlers moulted seasonally.

***Table 4.* Comparative Account of Skulls of Vertebrate Animal Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Form of skull	Elongated and dorso-ventrally flattened.	Broad triangular and dorso-ventrally flattened.	Elongated and dorso-ventrally flattened.	Elongated and convex dorsally.	Elongated and convex dorsally
2. Weight and pneumacity	Heavier & solid.	Light in weight.	Heavier & solid.	Very light & pneumatic, in adaptation to flight.	Light, some bones spongy.
3. Skull surface	Smooth, without sutures.	Surface rough, sutures distinct.	Surface rough, sutures distinct.	Surface smooth, sutures disappear.	Surface rough, sutures distinct.
4. Ossification	Wholly cartilaginous. Chondrocranium retained throughout life.	Poorly ossified. Much cartilaginous chondrocranium persists.	Extensively ossified except in naso-ethmoidal region.	Well ossified neurocranium.	Completely ossified neurocranium.
5. Occipital condyles	Dicondylic	Dicondylic	Monocondylic	Monocondylic	Dicondylic
6. Beak or snout	3 anterior cartilages – 2 dorso-lateral & 1 ventro-median, form a snout a rostrum.	Beak absent.	Beak absent.	Premaxillae, maxillae & dentaries form an elongated beak.	No beak present.
7. Number of bones	Whole neurocranium made of a single piece of cartilage. Bones absent.	Bones fewer. Basisphenoid, alishpenoid, orbitosphenoid, presphenoid, supraorbital, postorbital, etc.	Large no. of bones. Alisphenoids, orbitosphenoids, presphenoid, etc. absent. Prefrontal, supraorbital, postorbital, epiptery goid present.	Fewer and thin dermal bones. Alisphenoids, orbitosphenoids & presphenoids present.	Prefrontal, postfrontal, parasphenoid, quadratojugal, etc. absent. Alisphenoids, orbitosphenoids present.
8. Cranium	Small & flat.	Small & narrow due to small size of brain.	Cranium small.	Large, rounded dome-like.	Large rounded dome-like.

(*Contd.*)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
9. Roof of cranium	Brain completely covered by cartilaginous roof. No dermal bones. Bears anterior fontanelle or parietal fossa.	Cranial roof made by a pair of fused fronto-parietal bones. No parietal foramen.	Cranial roof formed by two frontals and two fused parietals bearing a median parietal foramen.	Both frontals and parietals become completely merged into one without sutures and parietal foramen.	Cranial roof formed by distinct paired frontals and parietals and an interparietal. No parietal foramen.
10. Floor of cranium	Cranial floor flat, cartilaginous, without bones.	Cranial floor occupied by a dagger-shaped parasphenoid.	Cranial floor consists of a basisphenoid and much reduced parasphenoid.	Cranial floor contains a large basitemporal and a reduced parasphenoid.	Cranial floor made by basisphenoid and presphenoid.
11. Foramen magnum	Posteriorly directed.	Posteriorly directed.	Posteriorly directed.	Ventrally directed.	Ventrally directed.
12. Occipital bones	Occipital region cartilaginous, without bones.	Includes two exoccipitals.	4 bones – supraoccipital, 2 exoccipitals and basioccipital – firmly fused together.	Usual 4 bones firmly fused together.	Usual 4 bones fused together into a single bone. Each exoccipital forms a paroccipital process.
13. Interorbital septum	Septum absent. Cranium extends forwards. Skull platybasic.	Septum absent. Cranium reaches forwards. Skull platybasic.	Septum thin. Cranium does not extend in front. Skull tropibasic.	Septum thin., Cranium does not extend in front. Skull tropibasic.	Septum present. Cranium does not reach forwards. Skull tropibasic.
14. Otic bones	Absent	Single bone, prootic.	3 bones. Epiotic fused with exoccipital, opisthotic with supraoccipi- tal, while prootic is free.	Auditory capsule mainly formed by prootic.	3 otic bones – prootic, epitoic & opisthotic – fused into a periotic bone.
15. Tympanic bone	Absent	Ring-like or annular. No bulla.	Annular. No bulla.	Annular. No bulla.	Flask-shaped, forming tympanic bulla with periotic
16. Secondary palate	Absent	Absent	Absent	Incomplete, formed by palatines and pterygoids.	Complete, formed by palatines, maxillae and premaxillae.
17. Ear ossicles	None. Hyomandibular persists.	Hyomandibular forms a single ear ossicle, columella.	Hyomandibular becomes columella.	Hyomandibular becomes columella.	3 ear ossicles. Malleus from articular, incus from quadrate, and stapes from hyomandibular.
18. Nasals	Absent	2, separate, large, triangular.	2, small, slender, fused.	2 separate, large; Y-shaped.	2, separate, long, narrow.
19. Sphenethmoid	Absent	Present	Absent	Absent	Absent
20. Lacrimal	Absent	Absent	Small, perforated.	Large, perforated	Small, unperforated.
21. Upper jaw bones	Formed by palato-pterygo-quadrate cartilage of mandibular arch	Formed by premaxilla, maxilla and quadratojugal bones and quadrate cartilage.	Upper jaw bones are premaxilla, maxilla, jugal, pterygoid and quadrate.	Include premaxilla, maxilla, jugal, quadrato - jugal palatine, pterygoid and quadrate.	Include premaxilla, maxilla, jugal, pterygoid and palatine
22. Lower jaw bones	Formed by Meckel's cartilage of mandibular arch	Formed by Meckel's cartilage and 3 bones – mentomeckelion, dentary and angulosplenial.	Formed by articular, angular, supraangular, coronoid, splenial and dentary surrounding an axial Meckel's cartilage.	Include articular, angular, supraangular, splenial and dentary surrounding a Meckel's cartilage.	Include a single membrane bone, dentary.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
23. Jaw suspensorium	Hyostylic. Both jaws suspended from cranium through hyomandibular.	Autostylic. Upper jaw fused with cranium. Lower jaw articulates with quadrate.	Autostylic. Upper jaw intimately fused. Articulation between articular of lower jaw and quadrate.	Autostylic. Upper jaw fused with cranium. Articular articulates with quadrate.	Craniostylic. Upper jaw fused. Dentary articulates with squamosal of skull.
24. Quadrate	Absent	Represented by cartilage.	Small, thick, rod-like, fixed.	Stout, Y-shaped, movable.	Modified into incus of middle ear.
25. Teeth	Not attached to jaw cartilages but to skin. Homologous with placoid scales.	Homodont and acrodont. Present on premaxillae, maxillae and vomers.	Homodont and pleurodont. Found on premaxillae, maxillae and dentaries.	Teeth absent.	Heterodont and thecodont. Present on premaxillae, maxillae and dentaries.

Table 5. **Comparative Account of Pectoral Girdle of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Condition	Cartilaginous. Not well developed.	Bony as well as cartilaginous. Well developed.	Bony as well as cartilaginous. Well developed.	Bony. Well developed for flight.	Largely bony. Well adapted for running and burrowing.
2. Position	Embedded in lateral and ventral body wall, posterior to gills. Supports pectoral fins.	Buried in thoracic body wall around heart which it protects. Supports forelimbs.	Buried in ventro-lateral thoracic wall. Supports forelimbs.	Lies at the antero-dorsal sides of trunk. Supports wings.	Lies along the antero-lateral sides of trunk. Supports forelimbs.
3. Shape & division	U-shaped. Consists of right and left halves firmly fused mid-ventrally.	Like an inverted arch. Made of two identical halves united mid-ventrally	Like an inverted arch with two similar halves uniting mid-ventrally	Made of two roughly V-shaped halves widely apart from each other.	Made of two somewhat triangular halves completely separate from one another.
4. Attachments	Not attached dorsally to vertebral column or ventrally to sternum which is absent.	Both halves united mid-ventrally with sternum.	Both halves meeting ventrally with a T-shaped interclavicle and a rhomboidal sternal plate.	Two halves are firmly connected with sternum through a V-shaped furcula made by two clavicles and one interclavicle.	Two halves do not unite with sternum or vertebral column.
5. Parts or bones	Each half is made of scapular and coracoid portions.	Each half consists of scapular and coracoid portions.	Each half includes scapular and coracoid parts.	Each half consists of scapular and coracoid parts.	Each half includes a large scapulo-coracoid bone.
6. Scapula	It is dorsal, rod-like and tapering.	Scapula is lateral, stout, flat and broader at the two ends.	Scapula is lateral, stout, oblong and broader dorsally but narrower ventrally.	Scapula is elongated, sabre-like, dorsal, connected with underlying ribs by muscles and with coracoid by ligaments.	Scapula or scapulo-coracoid is lateral, large, flat and triangular with broad base dorsal and narrow apex ventral.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
7. Scapular processes	None	None	Scapula gives out an anterior ossified process, *mesoscapula*.	Scapula bears near anterior end a *scapular tubercle*. Anterior end also gives out an *acromian process*.	Outer surface of scapula bears a prominent vertical ridge or *spine*. It terminates below into a free *acromian process* posteriorly giving off a *metacromian process*.
8. Supra-scapula	Absent in fishes. In dogfish, a distinct suprascapula marks the dorsal end of scapula.	Suprascapula is broad, rectangu- lar, flat, calcified cartilage, at- tached dorsally with scapula and covering the first 4 vertebrae.	It is a thin, flat, calcified cartilaginous plate attached dorsally with scapula. It does not cover vertebral column.	Suprascapula absent in birds.	Very much reduced like a thin strip of calcified cartilage along the dorsal edge of scapula.
9. Coracoid	Poorly developed, ventral, flat, supports the floor of pericardial cavity	Coracoid bone is broad and dumb-bell shaped. A rod-like *precoracoid cartilage* is separated from it anteriorly by a wide gap, *coracoid foramen*. Two coracoids meet midventrally through an X-shaped cartilage, the *epicoracoid*.	Coracoid is large, flat and fenestrated. Divided by 2 large gaps into *procoracoid*, *mesocoracoid* and *coracoid proper*. An irregular cartilaginous *epicoracoid* covers the gaps or fenestrae anteriorly.	Coracoid is stout, straight and rod-like. Lower end articulates with *coracoid groove* of sternum. Upper end forms a hook like *acrocoracoid process*. Epicoracoid absent.	Coracoid vestigial, represented by a small hook-like *coracoid process* from scapula above glenoid cavity. Epicoracoid absent.
10. Glenoid cavity	Absent in fishes. Pectoral fins attached directly to pectoral girdle.	Formed posteriorly at the junction of scapula and coracoid to receive the head of humerus.	Formed Postero-laterally jointly by scapula and coracoid bones.	Formed postero-laterally jointly by scapula and coracoid bones.	Formed postero-ventrally at the apex of scapula exclusively.
11. Clavicles	Well developed and placed ventrally.	On either side it is a slender rod-like, transverse bone attached in front of precoracoid cartilage.	Small, slender and curved bones separated medially from each other by interclavicle.	Long, slender, rod-like bones, attached dorsally to scapula and coracoid and ventrally fused with interclavicle.	Slender, slightly curved bony rod. Inner end attached to manubrium of sternum while outer end with acromian process of scapula.
12. Interclavicle	Absent in fishes.	Absent in Amphibia.	T-shaped, interclavicle present between clavicles and two halves of pectoral girdle.	Both clavicles fused with a laterally compressed disc or *hypocleidium*, forming a V-shaped composite bone, the *furcula*.	Interclavicle absent in mammals, except in Prototheria.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
13. Foramen triosseum	Absent	Absent	Absent	Present. Formed by the dorsal end of clavicle, acromian process of scapula and acrocoracoid process of coracoid. Through this tendon of pectoralis minor muscle passes to be inserted dor^ lly upon head of humerus.	Absent

Table 6. Comparative Account of Pelvic Girdle of Vertebrate Types.

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Condition	Simple, cartilaginous, transverse, rod-like, called *ischiopubic bar*.	Bony as well as cartilaginous. Well developed.	Bony, solid and strong. Well adapted for tetrapod locomotion.	Bony, large, light, pneumatic. Well adapted for flight and bipedal locomotion.	Bony, large, stout, well adapted for fast running.
2. Position	Embedded in ventral abdominal wall in front of cloaca Supports pelvic fins.	Occupies posterior region of trunk and gives support to pelvic region and hind limbs.	Occupies pelvic region of trunk and supports hind-limbs.	Occupies pelvic region and gives support to legs.	Occupies pelvic region and supports the hind limbs.
3. Shape and halves	Horizontal, transverse, rod-like not divided into halves.	V-shaped, made of two similar halves, called ossa *innominata*, united posteriorly into a median disc.	Made of two similar triradiate structures or *ossa innominata*, meeting mid-ventrally but not uniting with each other.	Made of two identical halves or *ossa innominata*, completely separated as an adaptation for laying large eggs.	Two identical triradiate halves or *ossa innominata* are firmly united mid-ventrally at a *pubic symphysis*.
4. Attachment with vertebral column	Not attached to vertebral column.	Two limbs run parallel with vertebral column while median disc supports last vertebra or urostyle.	Only iliac bones attached with first sacral vertebra.	Firmly fused with synsacrum as an adaptation for bipedal locomotion.	Ilia firmly articulate with sacrum.
5. Bones	Not differentiated into separate bones.	Each half or *os innominatum* made of 3 bones – ilium, ischium and pubis.	Each os innominatum includes 3 bones – ilium, ischium and pubis.	Usual 3 elements – ilium, ischium and pubis – found in each innominate or hip bone.	Besides usual ilium, ischium and pubis, a fourth bone, called *cotyloid*, also found.
6. Joints	Absent	Joints of bones distinct.	Joints of bones distinct.	Joints of bones not distinct.	Joints of bones distinct.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
7. Ilium	Represented by a small blunt iliac process with a foramen.	Forms anterior long arm resting on transverse process of 9th vertebra. Forms a dorsal vertical blade or *iliac crest*. Posteriorly both ilia united with median disc forming *iliac symphysis*.	Ilium rod-like and stout. Its tip articulating with notch of transverse process of first sacral vertebra. Ilia of both sides separated without any iliac symphysis. Forms a small *preacetabular process*.	Ilium large plate like, wholly attached to synsacrum. Differentiated into pre- and post-acetabular parts. No iliac symphysis.	Ilium large, raised into a dorso-anterior *iliac crest*. Distal part broad and articulates with flank of sacrum. No iliac symphysis present.
8. Antitrochanter process	Absent	Absent	Absent	Ilium forms a small antirochanter process on posterior border of acetabulum.	Absent
9. Ischium	Not distinct from pubis.	Ischium small meeting with its fellow at a median vertical *ischiatic symphysis* in postero-dorsal part of disc.	Ischium flat, oblong, meeting its felllow at a midventral *ischiatic symphysis* from which project a small cartilaginous *preischium* in front and a *hypoischium* behind.	Broad, plate-like bone hehind acetabulum. No ischiatic symphysis, no hypoischium, etc.	Ischium is postero-dorsal, small and flat. Posteriormost thickened part called *ischial tuberosity*. Ischial symphysis absent.
10. Ilio-ischiatic foramen	Absent	Absent	Absent	A large oval ilio-ischiatic foramen separates ischium anteriorly from postacetabular ilium.	Absent
11. Pubis	Not distinct from ischium	Both pubes are small, triangular, made of calcified cartilage, and fuse at a mid-ventral *pubic symphysis* in the disc. Epipubis absent.	Long slender bone directed antero-ventrally meeting its fellow at a *pubic symphysis* having a small knob like anterior cartilage, the *epipubis*.	Pubis is a thin, slender bone running backwards and parallel to ventral edge of ischium. No pubic symphysis.	Pubis is small slender, ventro-medial and meets its fellow at a mid-ventral *pubic symphysis*. Epipubis absent.
12. Obturator foramen	Absent	Absent	A small obturator foramen pierces pubis near acetabulum.	Ischium and pubis separated by a *notch* in pigeon and by an oval foramen in fowl.	A large obturator foramen separates pubis from ischium.
13. Prepubis	Absent	Absent	Middle of pubis produced into a small rod-like outwardly directed prepubis.	Prepubis absent in pigeon. In fowl, pubis projects in front of acetabulum as a prepubic process.	Prepubis absent.

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
14. Acetabulum	Absent	Present on either lateral side of disc. Formed by all the 3 bones as a prominent cup-like depression into which fits the head of femur.	Present laterally as a concave depression at the junction of ilium, ischium and pubis and receives the head of femur.	All the 3 bones unite to form a deep lateral acetabular cavity perforated basally and covered by a membrane.	Acetabulum is not perforated basally and formed by ilium, ischium and cotyloid bones. Pubis does not participate.
15. Cotyloid bone	Absent	Absent	Absent	Absent	Present

Appendages or limbs of vertebrates are varied. Cyclostomes do not have lateral appendages. Cartilaginous (sharks) and bony fishes have median and paired fins for locomotion in water. In a *median fin* skeleton consists of a single row of rays called *pterygiophores* or *radialia. Paired fins* include *pectoral* and *pelvic fins*. In majority of Chondrichthyes (e.g. sharks), a pectoral fin has 3 *basalia*, termed the *pro-*, *meso-*and *metapterygium*, respectively, and a number of *radialia* or *somactidia* arranged around them. In Osteichthyes (bony fishes), basalia are absent while radials are reduced to small ossicles which lie within the bodywall.

In tetrapods (amphibians, reptiles, birds and mammals), *pentadactyle limbs* (5-toed) replace the paired fins of fishes. Their bones probably represent greatly modified pterygiophores serially homologus in fore and hind limbs. Their basic pattern remains the same throughout tetrapods. Proximal part of limb includes a single rod-like bone, *humerus* in forelimb and *femur* in hind limb. Middle part includes 2 elongated bones, *radius* and *ulna* in forelimb or *tibia* and *fibula* in hind limb. Distal part of forelimb, called hand or manus, includes *carpals, metacarpals* and *phalanges.* Corresponding part of hind limb, called foot or pes, includes *tarsals*, *metatarsals* and *phalanges.* However, these bones show various structural modifications due to adaptations for different modes of life. These modifications mainly involve reduction in number of bones of the hand or foot.

Table 7. **Comparative Account of Limb Bones of Vertebrate Types.**

	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Bones	**Frog** *(Rana)*	**Lizard** *(Uromastix)*	**Pigeon** *(Columba)*	**Rabbit** *(Oryctolagus)*
1. Bones	Bones included are : 1. Humerus 2. Radio-ulna 3. Carpals 4. Metacarpals 5. Phalanges	Bones included are : 1. Humerus 2. Radius & ulna 3. Carpals 4. Metacarpals 5. Phalanges	Bones included are : 1. Humerus 2. Radius & ulna 3. Carpals 4. Carpometacarpus 5. Phalanges	Bones included are : 1. Humerus 2. Radius & ulna 3. Carpals 4. Metacarpals 5. Phalanges
2. Humerus	Bone of upper arm. Short and cylindrical. *Shaft* slightly curved. Proximal end covered by *cartilage* and swollen into a convex *head* which fits into glenoid cavity of pectoral girdle. Below head shaft bears	Bone of upper arm. *Shaft* elongated, flat with expanded ends. Proximal end bears a small rounded *head*, a *medial process* and a *deltoid ridge*. Distal end pulley- like bearing two *epicondyles* for	Bone of upper arm. *Shaft* elongated, slightly flat and curved. Proximal end greatly expanded bearing a convex *head* bordered by two *tuberosities*, a large *pneumatic foramen* and a prominent *deltoid*	Bone of upper arm. *Shaft* rather small but stout and rod-like. Proximal end with a large rounded *head*, two *tuberosities* (greater and lesser), a *bicipital groove* and a slight *deltoid ridge*. Distal end

Bones	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
	a prominent *deltoid ridge*. *Tuberosities* absent. Distal end with a round condyle or *capitulum* and ridges for articulation with radio-ulna.	articulation with radius and ulna.	*ridge*. Distal end bears two *condyles* with an *epicondylar groove* for articulation with radius and ulna.	bears pulley-like *trochlea*, and fossae perforated by *supra-trochlear foramen*, for articulation with ulna.
3. Radius & ulna	Bones of forearm Fused lengthwise to form a short compound bone called *radio-ulna*. Proximal end concave to receive capitulum of humerus. *Ulna* projected into a short conical *olecranon process* forming elbow joint Distal end flat, broad, covered by *cartilage* and forming two *articular facets* for carpals.	Bones of forearm. Separate and elongated. *Radius* somewhat slender, smaller and distally bears a concave articular facet and a *styloid process*. *Ulna* is stouter, bearing proximally an *olecranon process* and distally a convex articular *facet* for carpals.	Separate bones of forearm. *Radius* is shorter, straight and slender. Its proximal end is concave to receive a condyle of humerus, while distal and is knob-like. *Ulna* is longer, stouter and outwardly curved. Its proximal and is concave and forms *olecranon process* while distal convex end articulates with carpals.	Bones of forearm. Separate, elongated, somewhat curved and tightly bound together. *Radius* is smaller. *Ulna* is longer, proximally bearing a prominent *olecranon process* and a concave *sigmoid notch* for trochlea of humerus. Distally two bones bear *epiphyses* and articulate with carpals.
4. Carpals	Bones of wrist. 6 small bones arranged in 2 rows of 3 each. *Pisciform* bone absent.	9 carpals in wrist arranged in two rows of 3 and 5 with a contrale in between. *Pisciform* bone present.	Only 2 free carpals of proximal row, *radiale* and *ulnare*, attached to radius an ulna respectively. Distal carpals fused with metacarpals. *Pisciform* bone absent.	8 carpals in wrist arranged in 3 rows of 3, 1 and 4 respectively, Pisciform bone present.
5. Metacarpals	5, slender, rod-like elongated bones of hand. But first metacarpal of pollex or thumb is rudimentary.	Manus or palm is supported by 5 elongated metacarpals.	Manus contains a single bone, the *carpo–metacarpus*, formed by the fusion of distal carpals and 3 metacarpals. First metacarpal rudimentary while second and third elongated and fused at the two ends.	Manus contains 5 elongated, rod-like metacarpals. However, first metacarpal of thumb or pollex is very much reduced.
6. Phalanges	Short bones of 4 fingers. Pollex or thumb lacking. Phalangeal formula 0,2,2,3,3. Terminal phalanx clawless.	Short bones of 5 fingers. Phalangeal formula 2, 3, 4, 5, 3. Last phalanx bears a horny claw.	Short bones of 3 clawless fingers. Phalangeal formula 1, 2, 1.	Short bones of 5 clawed fingers. Phalangeal formula 2, 3, 3, 3, 3.

(Contd.)

Bones	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
		[II] HIND LIMB BONES		
1. Bones	Bones included are : 1. Femur 2. Tibio-fibula 3. Tarsals 4. Metatarsals 5. Phalanges	Bones included are : 1. Femur 2. Tibia & fibula 3. Tarsals 4. Metatarsals 5. Phalanges	Bones included are : 1. Femur 2. Tibiotarsus & fibula 3. Tarsometatarsus 4. Phalanges	Bones included are : 1. Femur 2. Tibia-fibula 3. Tarsals 4. Metatarsals 5. Phalanges
2. Femur	Single bone of thigh. *Shaft* long, slender, slightly curved. Both ends expanded & covered with calcified cartilage. Proximal end bears a rounded *head* which forms a ball-and-socket joint with acetabular cavity of pelvic girdle. Distal end articulates with tibio-fibula.	Single bone of thigh. *Shaft* long strong with expanded extremities. Proximal end bears a rounded prominent *head* for acetabulum and two processes called *lesser* and *greater trochanters*. Distal end pulley-like with 2 condyles and one tuberosity for articulation with tibia and fibula respectively.	Single bone of thigh. *Shaft* long, cylindrical stout, slightly curved and with broad ends. Proximal end with a prominent rounded *head* for acetabulum, a *great trochanter* and between them a facet for articulation with antitrochanter of ilium. Distal end pulley-like with two prominent *condyles* and a *groove* for tibio-tarsus.	Bone of thigh. *Shaft* long, strong, cylindrical and expanded at both ends. Proximal end with a distinct rounded *head* for acetabulum and 3 trochanters (lesser, greater and third). Distal end pulley-like with 2 *condyles* and a groove for tibio-fibula.
3. Patella	Absent	Absent	A small sesamoid bone, *patella*, present at the knee joint.	Patella present at the knee-joint.
4. Tibia & fibula	Shank has a single compound bone, *tibiofibula*. *Longest* bone in the body. *Shaft* slightly curved with broad and flat two ends covered with cartilage, and a longitudinal median groove. Proximal end of tibial part with a *cnemial* or *tibial crest*. Distal end bears facets for astragalus and calcaneum of tarsus.	Shank contains two separate bones. *Tibia* is stout, slightly curved and proximally bears a small *cnemial crest* and two concave facets for distal condyles of femur. *Fibula* is slender whose distal convex end articulates with tarsus.	Shank contains two separate bones. Tibia and proximal tarsals become fused into an elongated, strong, compound *tibiotarsus*, the *longest* bone in body. Its proximal end bears a prominent *cnemial crest* and 2 concave articular facets for distal condyles of femur. Distal pulley like end articulates with tarsus. *Fibula* is reduced, slender, swollen proximaly but gradually tapers distally without reaching up to ankle.	Bones of shank region. *Tibia* is large, stout and straight. Its proximal end bears a low but sharp *cnemal crest* and two concave facets for distal femoral condyles. *Fibula* is small, slender, proximally free but distally fused with tibia forming the compound *tibio-fibula* which is the *longest* bone in the body.
5. Tarsals	4 ankle bones or tarsals arranged in 2 rows of 2 bones each. Proximal tarsals elongated but united at the two ends. Outer *calcaneum* or fibulare is thick and stout. Inner *astragalus* or tibiale is thin and curved.	Ankle contains 5 tarsal bones, 2 in proximal row and 3 in distal row.	No free tarsal bones. Proximal tarsals fused into tibiotarsus while distal tarsals fused with tarso-metatarsus.	Ankle contains 6 tarsal bones. Proximal row includes 2 large bones called astragalus and calcaneum. A single middle bone is called centrale or navicular. Distal row contains 3 tarsal bones.

Bones	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
6. Metatarsals	Sole of foot contains 5 elongated, rod-like metatarsals corresponding to 5 toes.	Foot carries 5 elongated rod-like metatarsals each supporting a toe.	Distal tarsals and 2, 3, and 4 metatarsals of foot fuse into a single stout straight and compound bone, *tarsometatarsus*. Its proximal end bears 2 concavities for tibio-tarsus. Distal end bears 3 pulleys, each representing one metatarsal. First metatarsal rudimentary.	Foot carries 4 elongated metatarsals, one for each toe. First metatarsal absent as there is no hallux or first toe.
7. Phalanges	There are 5 clawless toes. Phalangeal formula 2, 2, 3, 4, 3.	5 clawed toes present. Phalangeal formula 2, 3, 4, 5, 3.	4 clawed toes. Fifth toe absent. Phalangeal formula 2, 3, 4, 5.	4 clawed toes as hallux absent. Phalangeal formula 3, 3, 3, 3.

***Table 8.* Comparative Account of Digestive System of Vertebrate Types.**

Characters	FISH Dogfish (*Scoliodon*)	AMPHIBIA Frog (*Rana*)	REPTILIA Lizard (*Uromastix*)	AVES Pigeon (*Columba*)	MAMMALIA Rabbit (*Oryctolagus*)
		[I] ALIMENTARY CANAL			
1. Major parts of alimentary canal	1. Buccal cavity 2. Pharynx 3. Oesophagus 4. Stomach 5. Intestine 6. Cloaca	1. Buccal cavity 2. Pharynx 3. Oesophagus 4. Stomach 5. Intestine 6. Cloaca	1. Buccal cavity 2. Pharynx 3. Oesophagus 4. Stomach 5. Intestine 6. Cloaca	1. Buccal cavity 2. Pharynx 3. Oesophagus 4. Stomach 5. Intestine 6. Cloaca	1. Buccal cavity 2. Pharynx 3. Oesophagus 4. Stomach 5. Intestine 6. Cloaca
2. Mouth opening	On Ventral side of head. Small, crescentic or semioval, bound by jaws.	Terminal along anterior end of head. Large, semicircular, slit-like bounded by jaws.	Terminal along anterior end of head, Large, semicircular, slit-like, bounded by jaws.	Terminal, V-shaped slit with a wide gape, bounded by jaws and horny beaks.	Sub - terminal, small, transverse slit, bounded by jaws.
3. Jaws and lips	Lower jaw movable. Lips absent. Jaws covered by spiny skin.	Lower jaw movable. Lips hard, immovable, scalesless.	Lower jaw movable. Lips hard, immovable, covered by scales.	Lower jaw movable Lips absent but horny sheaths or beaks present covering jaws.	Lower jaw movable. Lips movable. hairy. Upper lip cleft, bears vibrissae.
4. Teeth	Sharp, similar (*homodont*) and backwardly directed teeth present in several rows on skin of both jaws. Teeth are modified placoid scales and replaced by new ones (*polyphyodont*) during life.	Teeth small, conical, attached to bones or *acrodont*, *homodont*, *polyphyodont* and present on upper jaw only in a single row	Teeth small, conical, *acrodont* and *pleurodont*, found on both jaws in a single row.	Teeth completely absent in both jaws.	Teeth of several types (*heterodont*) with roots in sockets of jaw bones (*thecodont*) and occur in 2 sets in life (*diphyodont*). Present on both jaws.

(*Contd.*)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
5. Diastema	Absent	Absent	Absent	Absent	A toothless space called *diastema* present between incisor and premolar teeth.
6. Dental formula	Not represented	Not represented	Not represented	Not represented	Teeth represented by a dental formula written as : $i\frac{2}{1}$, $c\frac{0}{0}$, $pm\frac{3}{2}$, $pm\frac{3}{3} = 28$.
7. Function of teeth	Grasping prey	Holding prey	Grasping and holding prey.	—	Cutting, holding and mastication of food.
8. Buccal cavity	Spacious. Dorso-ventrally flattened.	Large, wide and shallow.	Narrow in front, but broad posteriorly.	Narrow, roughly triangular	Large, spacious.
9. Vestibule	Absent	Absent	Absent	Absent	Mouth opens into a narrow space bounded by jaws, lips and cheeks, called *vestibule*.
10. Palate	Absent. Skull forms roof of bucccal cavity	Absent. Skull forms roof of buccal cavity.	Absent in lizards & snakes. A false or pseudopalate present in crocodilians.	Palate incomplete, formed by lateral folds which do not meet mesially.	A secondary palate present forming roof of buccal cavity.
11. Tongue	Small, non muscular, nonglandular, non-protrusible, attached at base. Not used in food capture. Taste buds lacking.	Large, muscular, sticky. Anterior end attached. Posterior end free bifid, highly protrusible and used for capturing insect prey. Covered with few taste buds.	Large, roughly triangular, muscular, glandular, attached mid-ventrally. Anterior tip free, bifid and protrusible. Covered with fine papillae having taste buds.	Tongue large, narrow, somewhat triangular, attached and non-protrusible. Covered with fine horny processes with scanty taste buds.	Large, muscular, attached mid-ventrally. Groved mid-dorsally. Anterior tip free, rounded and protrusible. Covered with 4 kinds of papillae containing taste buds.
12. Internal nares	Absent	Small, two. Open on buccal roof anteriorly, just in front of vomerine teeth.	Small, two rounded, open near anterior end on roof of buccal cavity.	Small, slit-like, open rather posteriorly into buccal cavity or pharynx.	Do not open into buccal cavity but much posteriorly in the roof of pharynx.
13. Pharynx	Buccal cavity merges insensibly into a large posterior pharynx.	Buccal cavity passes without demarcation into a short pharynx.	Buccal cavity merges posteriorly into a broad pharynx.	Buccal cavity merges behind into pharyngeal cavity.	Pharynx is short, narrow and differentiated into *nasopharynx*, *oropharynx* and *laryngopharynx*.
14. Gill slits	Pharyngeal wall on either lateral side has a pit-like *spiracle* and 5 vertical *gill slits*.	Spiracles and gill slits absent.	Spiracles and gill slits are lacking.	Spiracles and gill slits are absent.	Spiracles and gill slits are lacking.

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
15. Eustachian openings	Absent	A wide eustachian opening lies on roof, laterally near jaw angle, on either side.	A pair of openings of eustachian tubes lie on side of roof.	Middle of roof behind internal nares contains a single eustachian opening.	Sides of naso-pharyngeal wall are pierced by a pair of oval eustachian openings.
16. Glottis	Absent since there is no trachea and no lungs.	Floor carries a median slit-like opening or glottis leading into laryngo-tracheal chamber.	A median slit-like glottis on floor leads into trachea.	Floor of pharynx carries an oval glottis with tumid lips.	Floor of laryngo-pharynx has a median vertical slit-like glottis leading into larynx.
17. Epiglottis	Absent	Absent	Absent	Absent	An anterior bilobed cartilaginous flap or epiglottis guards against food entering glottis.
18. Other bucco-pharyngeal structures	Mucous lining of pharynx contains dermal *denticles*.	In male frog only, floor of pharynx carries an *opening* of *vocal sac* on either lateral side near jaw angle. *Eye balls* bulge internally on roof into buccal cavity.	Mucous lining of pharynx is thrown into distensible *longitudinal folds*.	Nasal chambers open through internal nares into roof of pharynx.	Nasal chambers open through *internal naris* into roof of laryngo-pharynx.
19. Oesophagus	Short and wide tube with thick muscular wall, longitudinal mucous folds and opening into cardiac stomach with a *sphincter* or *oesophageal valve*.	Short, wide, muscular with longitudinal mucous folds highly distensible and not clearly demarcated from pharynx and stomach.	Long, narrow, muscular tube with longitudinal mucous folds. Highly distensible. Without a crop.	Long, wide, muscular, thick-walled and distensible. In front of sternum, its middle part forms a large, bilobed, thin-walled elastic sac, crop or food reservoir.	Long, narrow, muscular, elastic tube, without crop, of uniform diameter, opening into stomach.
20. Stomach	Large, muscular, U-shaped or S-shaped. Clearly divided into a long, broad, proximal *cardiac stomach* and short, narrow, distal *pyloric stomach*. Junction of the two marked by a *blind sac* and a *sphincter valve*. Longitudinal mucous folds well developed in cardiac part.	Stomach large, broad, simple, curved, muscular sac, on left side of body cavity. Anterior cardiac and posterior pyloric parts not marked off externally. Blind sac and cardiac valve absent.	Stomach long, tubular or spindle like, curved muscular tube lying on left side. Cardiac and pyloric parts indistinct externally. Longitudinal mucous folds well developed in cardiac part.	Stomach small and divided into 2 distinct parts : an anterior narrow, tube- like glandular *proventriculus*, and a posterior broad, muscular, biconvex *gizzard* internally lined by thick, horny epithelium.	Stomach large, bean-shaped, lying transversely on left side. Distinguished into 3 regions : *cardiac*, *fundic* and *pyloric*.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
21. Bursa entiana and gizzard	Pylorica stomach opens through a *pyloric valve* into a small, globular, thick-walled muscular sac, the *bursa entiana*. Gizzard absent.	No bursa entiana and gizzard.	Bursa entiana and gizzard absent. there are no pebbles or stones in the cavity.	Bursa entiana absent. Cavity of gizzard has pebbles or stones to help in grinding food.	Bursa entiana and gizzard absent. Stones are also lacking inside.
22. Intestine	Short but straight and wide tube not differentiated into small and large intestines.	Long, coiled and narrow tube differentiated into small and large intestines.	Long, coiled, narrow and clearly differentiated into small and large intestines.	Long, coiled, narrow and clearly marked into small and large intestines.	Long, coiled, narrow and well differentiated into small and large intestines.
23. Small intestine	No external differentiation between duodenum and ileum.	Duodenum and ileum well marked.	Duodenum and ileum well marked.	Duodenum and ileum well marked.	Duodenum and ileum well marked.
24. Duodenum	Absent.	Straight tube forming 'U' with stomach. Receives bile and pancreatic juice through a common hepatopancreatic duct.	Straight tube receiving separate bile and pancreatic ducts.	U-shaped tube receiving 2 bile ducts and 3 pancreatic ducts, separately.	Distinct U-shaped loop receiving 1 bile duct and 1 pancreatic duct.
25. Ileum	Not differentiated.	Small and coiled.	Short and coiled.	Long and coiled.	Extremely long and coiled.
26. Valves & villi	Mucous lining of intestine folded into a longitudinal *scroll* or *spiral valve*. Villi absent.	Mucous lining forms several longitudinal folds, but spiral valve and villi are absent.	Inner longitudinal folds present but valves and villi are absent.	Inner surface bears numerous small finger like processes or villi. Spiral valve absent.	Villi are well developed and numerous. Spiral valve absent.
27. Sacculus rotundus	Absent	Absent	Absent	Absent	Distal end of ileum expanded to form sacculus rotundius.
28. Caecum	Absent	Absent	A large caecum and an *ileo-colic valve* present between small and large intestines.	Junction of two intestines marked by the presence of a pair of short conical *rectal* or *colic caeca*.	A large thin-walled tubular and spirally constricted caecum present into which sacculus opens through an *ileo-caecal valve*.
29. Vermiform appendix	Absent	Absent	Absent	Absent	Distally caecum ends blindly as vermiform appendix.
30. Large intestine	Last part of intestine forms a short *rectum* of narrow diameter, opening into cloaca	It forms a short but broad *rectum* opening into cloaca.	Short and forms an anterior thin-walled narrow *colon* and a posterior thick-walled broad *rectum* opening into cloaca.	Forms a short but broad *rectum* only which leads into cloaca.	Very long and forms an anterior sacculated *colon* and a posterior beaded *rectum*.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
31. Rectal glands	A tubular rectal gland of unknown function opens dorsally into rectum.	No rectal gland.	No rectal gland.	No rectal gland.	No rectal gland.
32. Cloaca, abdominal pores & bursa Fabrici	Rectum opens behind into a simple cloaca through anus guarded by *anal sphincter*. It also contains *urinogenital apertures* and a pair of *abdominal pores* from peritoneal coelom. *Bursa Fabrici* absent.	Rectum opens through anus into a single sac like cloaca, also containing urinogenital apertures. *Anal sphincter* present but *abdominal pores* and *bursa Fabrici* absent.	Rectum opens into a tripartite cloaca divided into 3 linear chambers : *corodaeum*, *urodaeum* and *proctodaeum*. *Anal sphincter* present but *abdominal pores* and *bursa Fabrici* absent.	Rectum opens behind through anus guarded by *anal sphincter* into a tripartite cloaca made of 3 linear chambers, as in a lizard. *Abdominal pores* are absent. In young birds only a small thick-walled blind pouch, *bursa Fabrici*, present dorsally on proctodaeum.	Cloaca absent. Rectum leads directly to outside by anus provided with an anal sphincter. No *abdominal pores* and no *bursa Fabrici*.
33. Cloacal aperture	Cloaca opens by a mid-ventral longitudinal slit between pelvic fins.	Cloaca opens at the hind end of trunk between hind limbs through a circular cloacal aperture.	Cloacal aperture is a mid-ventral transverse slit at the base of tail.	Proctodaeum opens at the base of tail ventrally by a transverse slit with tumid lips.	No cloacal aperture.
			[II] DIGESTIVE GLANDS		
1. Mucous glands	Absent in aquatic forms	Present in internal epithelial lining of bucco-pharyngeal cavity and oesophagus. Secrete *mucus* to lubricate passage of food.	Mucous glands are scanty.	Mucous glands few. Present mainly in buccal cavity and on tongue.	Mucous glands present throughout the lining of digestive tract.
2. Salivary glands	Absent	Absent	According to Keith, a few mucus-secreting salivary glands are present in buccal cavity.	*Buccal glands* of mouth cavity probably secrete *mucus*, but they are not salivary glands.	4 kinds of salivary glands with separate ducts lead into buccal cavity. They secrete *saliva* and an enzyme *ptylin*.
3. Gastric glands	Present in stomach. Gastric juice contains pepsin and HCl.	Present in stomach lining secreting pepsinogen and HCl.	Present in mucous lining of stomach	Present in lining of proventriculus secreting peptic enzymes and HCl.	Present and secrete pepsinogen, renin and HCl.
4. Pancreas	A compact, whitish and bilobed gland found between cardiac and pyloric stomach.	Much branched, irregular, cream-coloured gland lying between stomach and duodenum.	Narrow, elongated, whitish gland present between pyloric stomach and duodenum.	A pinkish, band-like narrow gland lying between two limbs of duodenum.	Irregular, diffused pinkish gland surrounded by duodenal loop.
5. Pancreatic ducts	A single duct opens independently into the proximal end of intestine.	Small pancreatic ducts open ino bile duct.	A single pancreatic duct opens independently into duodenum.	3 pancreatic ducts open independently into the distal limb of duodenum.	A single pancreatic duct leads into the distal limb of duodenum.

(Contd)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
6. Liver	Massive, yellowish, bilobed gland in abdominal cavity.	Large, reddish brown and 3-lobed : right, left and median.	Large, dark red and bilobed. Right lobe extended upto gonad. A minor 3rd lobe present according to some workers.	Large, compact, dark red and bilobed. Right lobe is larger.	Large, dark red and made of 5 lobes : right & left central, left lateral, caudate and spigelian.
7. Gall bladder	Y-shaped, thin-walled gall bladder attached to right liver lobe.	Large, spherical, greenish, situated ventrally between two main liver lobes.	A subspherical gall bladder present ventrally between right and left liver lobes.	Gall bladder absent in pigeon.	Elongated, dark green gall bladder embedded ventrally in posterior part of right central lobe.
8. Bile ducts	A single bile duct opens independently into the beginning of intestine.	Bile duct passes through pancreas, receiving pancreatic ducts. Thus a combined hepato-pancreatic duct opens into duodenum.	Two bile ducts lead from liver to open into duodenum.	Two bile ducts open one in proximal, the other in distal limb of duodenum.	A single bile duct empties into proximal limb of duodenum rear pylorus.
		[III] FOOD & FEEDING HABIT			
1. Habit	Carnivorous and predaceous.	Carnivorous and predaceous.	Chiefly herbivorous. Somtimes insectivorous.	Chiefly herbivorous. At times insectivorous.	Herbivorous. Also coprophagous.
2. Food	Crabs, lobsters, worms and fishes.	Living insects, worms, molluscs, crustaceans, small fish and tadpoles.	Grasses, flowers, fruits, succulent leaves, and at times insects.	Grains, pulses, seeds, sometimes insects, snails, slugs, etc.	Green leaves, vegetables, grasses, cereals, roots, barks, etc.

Table 9. **Comparative Account of Respiratory System of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Type of respiration	*Aquatic* as it lives permanently water.	*Amphibious*, i.e., *aquatic* as well as *aerial*, as it lives both on land and in water.	*Aerial*, as it lives permanently on land and breathes in air.	*Aerial* or pulmonary, breathes air.	*Aerial* or *pulmonary* as it is terrestrial and breathes in air.
		[I] RESPIRATORY TRACT			
2. Parts of respiratory tract	Includes mouth, buccal cavity, pharynx, internal gill-slits, gill pouches and external gill-slits. Internal nares, glottis and laryngo-tracheal chamber absent.	Includes external nares, nasal chambers, internal nares, bucco-pharyngeal cavity, glottis and laryngo-tracheal chamber. Gill slits and gill pouches absent.	Includes external nares, nasal sacs, internal nares, buccal cavity, pharynx, glottis, trachea and bronchi. Gill slits and gill pouches absent.	Includes same parts as in lizard.	Includes same parts as in lizard or pigeon.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
3. Passage of water or air	Water enters through mouth and leaves through external gill slits.	Air enters through external nares and leaves also through them. Mouth not used for entry of air.	Air enters and leaves through external nares. Mouth not used for respiration.	Air enters and leaves through external nares. Mouth not used for respiration.	Air enters as well as leaves through external nares. Mouth not used for respiration.
4. External nares	Ventral, crescentic apertures, each divided by a skin flap. Exclusively olfactory. Not used in respiration.	Dorsal on tip of snout. Small, circular apertures without valves. Used in respiration.	Dorsal on tip of snout. Small oval apertures with a valve. Olfactory as well as respiratory.	Dorsal at base of upper beak. Narrow slit-like, without valve and covered by a sensitive skin fold or cere. Used in respiration.	Dorsal above mouth. Large oval openings without valves. Olfactory as well as respiratory.
5. Nasal chambers	Separate, large, with folds but without turbinals. Internal nares opening into mouth absent.	Separate, small, without turbinals. Open into anterior part of buccal roof by two internal nares.	Separate, small, without turbinals and open anteriorly into buccal cavity by two internal nares.	Separate, small, without turbinals and open into pharynx by two internal nares.	Separate, elongated, with turbinals and open into laryngopharynx by a single internal nares.
6. Glottis & epiglottis	Glottis and epiglottis absent.	Floor of pharynx carries a median slit-like aperture or glottis leading into laryngo - tracheal chamber. Epiglottis absent.	A median slit like glottis on floor of pharynx leads into trachea. Epiglottis absent.	Floor of pharynx carries an oval glottis with tumid lips. Epiglottis absent.	Floor of laryngopharynx has a median vertical glottis leading into larynx and protected by a bilobed cartilaginous flap or epiglottis.
7. Larynx and trachea	Absent	Fused forming a laryngo-tracheal chamber containing vocal cords. Thyroid cartilage absent.	Larynx and trachea separate. Vocal cords and thyroid cartilage absent in pharynx.	Larynx and trachea separate. Larynx without vocal cords and thyroid cartilage.	Larynx and trachea separate. Larynx contains vocal cords and thyroid cartilage.
8. Syrinx	Absent	Absent	Absent	Present at lower end of trachea and serves for sound production.	Absent
			[II] RESPIRATORY ORGANS		
9. Respiratory organs	Only gills present for aquatic respiration.	Gills present in tadpole larva for aquatic respiration and lungs in adult for aerial respiration.	Gills absent. Only lungs present in the adult.	Gills absent. Only lungs present in adult.	Gills absent. Only lungs present in adult.
10. Gills and gill clefts	Include 5 pairs of pharyngeal *gill pouches* containing 5 pairs of lamelliform *gills*	Tadpole larva develops 5 pairs of *gill pouches* and 4 pairs of *gill clefts*. 3 pairs of filamentous *external gills* appear for aquatic respiration. Gills later become *internal* as in fishes but disappear during metamorphosis.	Embryo develops temporary pharyngeal gill pouches and gill slits which later disappear.	Embryo develops temporarily 4 pairs of pharyngeal gill pouches and 3 pairs of gill slits.	Embryo develops temporarily 4 pairs of gill pouches but gill slits do not form.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
11. Lungs	Absent altogether	2 lungs, ovoid, thin walled, elastic hollow sacs of pinkish colour, suspended freely inside peritoneal cavity. Without lobes.	2 lungs, elongated, fusiform, thin-walled elastic hollow sacs of orange colour, lying in thoracic cavity. Without lobes.	2 lungs, small, ovoid, compact, inelastic bright red, attached dorsally to thoracic vertebrae and ribs. Without lobes.	2 lungs, large, soft, elastic, spongy, pink in colour, each enclosed in a lateral *pleural cavity* of thorax. Right lung made of 4 lobes, left lung of 2 lobes.
12. Peritoneum		Lungs completely enclosed by peritoneum.	Completely surrounded by peritoneum	Dorsal attached side of lung not covered by peritoneum.	Surrounded by peritoneum on all sides.
13. Alveoli		Alveoli providing surface for gaseous exchange few in number. Therefore central cavity of lungs large.	Inner septa low and *alveoli* shallow. Central cavity smaller.	Lungs without alveoli but with an intricate system of ramifying and anastomosing *air capillaries.*	Inside lungs, terminal branches of bronchioles end into grape-like clusters of small, blind *alveoli,* highly vascular.
14. Air sacs		Air sacs absent.	Air sacs absent.	A system of large, thin-walled, elastic, non-vascular *air sacs* around and connected with the lungs.	Air sacs absent.
15. Bucco-pharyngeal respiration	Absent	Epithelial lining highly vascular so that bucco-pharyngeal respiration very effective.	Absent	Absent	Absent
16. Cutaneous respiration	Absent	Moist and richly vascular skin serves efficiently for exchange of gases.	Absent	Absent	Absent
		[III] RESPIRATORY MECHANISM			
17. Breathing movements	During *inspiration* buccal floor is lowered by a series of *hypobranchial muscles.* During *expiration* buccal floor is raised by *constrictor* and *interbranchial muscles.*	*Inspiration* due to lowering of bucco-pharyngeal floor is brought about by *sternohyal muscles* white *expiration* by raising the floor by *petrohyal muscles.*	Both *inspiration* as well as *expiration* are brought about by *ribs* and *intercostal muscles.*	*Inspiration* and *expiration* occur due to activity of *sternum, intercostal muscles* and *abdominal muscles.*	*Inspiration* and *expiration* are caused by the action of *diaphragm* and *intercostal muscles.*
18. Efficiency	Highly vascularized gills serve as efficient organs for gaseous exchange in water.	Mixed air entering lungs and less number of alveoli account for inefficiency of pulmonary respiration, wihich is supplemented by bucco-pharyngeal and cutaneous respiration.	Less number of alveoli and stay of residual foul air account for poor aeration of blood by lungs.	Presence of open air capillaries, air sacs and absence of residual foul air make avian lungs most efficient among all vertebrates.	Presence of large number but blind alveoli and residual foul air make mammalian lungs less efficient than those of birds.

Table 10. **Comparative Account of Hearts of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** *(Scoliodon)*	**Frog** *(Rana)*	**Lizard** *(Uromastix)*	**Pigeon** *(Columba)*	**Rabbit** *(Oryctolagus)*
1. Position of heart in body	Heart lies mid-ventrally beneath pharynx in pericardial cavity separated from peritoneal cavity by a partition, called *septum transversum*, perforated by a *pericardio-peritoneal canal.*	Heart lies mid-ventrally beneath oesophagus in thoracic cavity. Septum transversum is absent.	Heart lies mid-ventrally above sternum in thoracic cavity. There is no septum transversum.	Heart lies mid-ventrally in thoracic cavity surrounded by lobes of liver.	Heart lies enclosed in a median pericardial cavity of thorax, between the pleural cavities containing lungs.
2. Pericardium	Heart lies protected within a 2-layered membranous *pericardium.*	Heart lies enclosed by a thin, transparent, 2-layered sac, the *pericardium.*	Heart lies protected within a 2-layered, thin, transparent sac, the *pericardium.*	Heart enclosed by a thin, 2-layered, transparent, membranous sac, the *pericardium.*	Heart completely surrounded by a 2-layered membranous sac, the *pericardium.*
3. Size, shape and colour	Small, S-shaped, dorso-ventrally bent and raddish brown.	Small, somewhat conical or triangular and reddish in colour.	Small, roughly triangular and reddish in colour.	Comparatively larger, conical in shape and reddish in colour.	Larger pear-shaped and reddish in colour.
4. Chambers	Consists of a linear series of 4 chambers : sinus venosus, auricle, ventricle and conus, all distinguished externally. But only auricle and ventricle are true chambers, hence *2-chambered.*	*3-chambered*, made of 2 auricles and 1 ventricle. Auricles not demarcated externally. Besides, sinus venosus and truncus arteriosus also present.	*3-chambered*, made of 2 auricles and one incompletely divided ventricle, all faintly demarcated externally. Sinus venosus also present.	*4-chambered*, made of 2 auricles and 2 ventricles. Ventricles not distinguishable externally.	*4-chambered*, made of 2 auricles and 2 ventricles, all distinguishable externally.
5. Sinus venosus	Triangular, extending transversely over posterior region of ventricle and fused with pericardial wall. Receives venous blood from body by two *ducti Cuvieri* laterally and two *hepatic sinuses* posteriorly.	Triangular, dark coloured, attached dorsally over auricles and ventricles. Receives venus blood by 3 venae cavae : two anterior *precavals* and one posterior *postcaval*, joining at its angles.	Sinus venosus is large, bilobed, attached transversely to dorsal surface of auricles. Formed by the union of 2 *precavals* and 1 *postcaval.*	Sinus venosus absent, said to be incorporated into right auricle. Thus 3 caval veins open directly into right auricle.	Sinus venosus absent and merged into right auricle. Their union marked externally by a groove, *sulcus terminalis*, and internally by a muscular ridge, crista terminalis. 3 venae cavae open directly into right auricle.
6. Sinus-atrial aperture	Sinus opens into posterior end of auricle by a sinuatrial aperture guarded by a pair of membranous *valves.*	Sinus opens into dorsal wall of auricle by a large, oval, sinu-atrial aperture guarded by a pair of flaplike *valves.*	Sinus opens into right auricle through an oval aperture with muscular *lips* and *without valves* according to Bhatia. (1929).	Sinus venosus absent. However, opening of postcaval into right auricle guarded by a muscular *Eustachian valve.*	Sinus venosus absent. However, opening of postcaval into right auricle guarded by a rudimentary *Eustachian valve.*
7. Atria or auricles	Atrium or auricle somewhat triangular. Undivided internally due to lack of an *interauricular* septum.	Auricles somewhat rectangular. Do not form auricular appendages. Internally divided completely into right and left auricles by an *inter-auricular septum.*	Two auricles divided completely by an *inter-auricular septum.* Right auricle gives off a small *diverticulum* from its dorsal antero-medial surface.	Two auricles divided by an *inter-auricular septum.* Dorsal anteromedial diverticulum absent.	Two auricles completely separated by an *inter auricular septum.* Right auricle without diverticulum.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
8. Atrial wall	Thin-walled, spongy, moderately muscular.	Thin walled, without muscular processes.	Thin-walled, inner lining forming a network of low muscular ridges.	Comparatively thick-walled with inner surface raised into muscular ridges.	Comparatively thick walled. Inner surface raised into a network of muscular ridges called *musculi pectinati*.
9. Auricular appendix	Each auricle laterally projects beyond ventricle as ear like *auricular appendages.*	Absent	Absent	Absent	Each auricle produced behind into a swollen flap, the *auricular appendix*, slightly covering the ventricle of its side.
10. Pulmonary veins	Absent and therefore do not open into auricle.	A common pulmonary vein opens into left auricle.	A common pulmonary vein opens into left auricle	Four pulmonary veins open by a common aperture into left auricle.	Two pulmonary veins open by a common opening into left auricle.
11. Auriculo-ventricular aperture & valves	Atrium opens into ventricle through its dorsal wall by a single auriculo-ventricular aperture guarded by a pair of membranous valves.	Both auricles open into ventricle posteriorly through a common large auriculo-ventricular aperture guarded by 2 pairs of flaplike valves.	Both auricles communicate behind with ventricle through separate right and left auriculo-ventricular apertures due to backward extension of interauricular septum into ventricle, each guarded by a valve of one semilunar flap.	There are two separate circular auriculo-ventricular apertures. Right valve is made of a large muscular fold, while left valve is *bicuspid*, made of two membranous flaps.	There are two separate auriculo-ventricular apertures. Right aperture is guarded by a *tricuspid valve* made of 3 triangular flaps or cusps, while left *bicuspid* or *mitral valve* consists of 2 flaps only.
12. Ventricles	Small, pearshaped thickwalled undivided chamber lying ventral to sinus and auricle. *Interventricular septum* not found.	Small, conical, thick-walled undivided chamber lying posterior to auricles. No *interventricular septum.*	Small, conical thickwalled chamber lying behind auricles. Incompletely divided by a prominent oblique *muscular ridge* or septum into a larger dorsal part, *cavum dorsale*, and a smaller ventral part, *avum pulmonale*.	Two right and left, large, thick-walled ventricles, completely separated by a vertical *interventricular* septum.	Two large and thick-walled right and left ventricles completely separated by a vertical *interventricular septum.*
13. Chordae tendineae	Cavity of ventricle traversed by numerous muscular strands, *chordae tendineae*, giving it a spongy texture.	Flaps of auriculo - ventricular valve attached to wall of ventricle by thread like *chordae tendineae*.	Free edges of auriculo – ventricular valves attached to inner wall of ventricle by firm cords, the *chordae tendineae.*	Flaps of auriculo - ventricular valves attached to papillary muscles by *chordae tendineae*	Free edges of valvular flaps connected to papillary muscles by long, tough connective tissue strands, *chordae tendineae*.
14. Columnae carneae	Absent	Irregular strands or ridges given from inner wall of ventricle.	Prominent ridges raised from inner surface of wall of verticle.	Bars of muscles traversing cavities of ventricles.	Small irregular muscular ridges projecting from wall of ventricles.
15. Papillary muscles	Absent	Absent	Absent	These are prominent muscular projections from inner wall of ventricles.	These are large, conical, nipple-shaped muscular elevations from inner wall of ventricles.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
16. Conus or truncus arteriosus	Conus arteriosus is a stout, undivided, muscular tube given anteriorly by ventricle. Its cavity contains 2 rows of 5 a semilunar valves each, 3 larger and 2 smaller. *Spiral valve* absent.	Truncus arteriosus is a pear-shaped tube arising anteriorly from right ventral side of ventricle. It's cavity is divided by 3 semilunar valves into a distal chamber, *synangium* and a proximal chamber, *pylangium*. Latter is further divided by a *spiral valve* into *cavum pulmocutaneum* and *cavum aorticum*.	Conus or truncus arteriosus absent.	Conus or truncus arteriosus absent.	Conus or truncus arteriosus absent.
17. Aortic arches	Conus leads anteriorly into a *ventral aorta* which gives off 5 pairs of lateral arotic arches.	Truncus bifurcates anteriorly into right and left trunks each dividing into 3 aortic arches : *common carotid*, *systemic* and *pulmocutaneous*. Ventral aorta absent.	Ventral aorta absent. 3 aortic arches arise directly from ventricle : *pulmonary* from cavum pulmonale and *right* and *left systemic* from cavum dorsale.	Ventral aorta absent. Only 2 aortic arches arise : *pulmonary* from right ventricle and *right systemic* leaving left ventricle.	Ventral aorta absent. Only 2 aortic arches present : *pulmonary* arising from right ventricle and *left systemic* from left ventricle.
18. Foramen Panizzae	Absent	Absent	Present at the point of contact where two systemic arches cross each other.	Absent.	Absent
19. Working	Heart receives only venous blood from body and sends it to gills only for aeration. Called *venous heart* with a *single circulation*.	Heart receives venous as well as oxygenated bloods. It supplies mixed blood to different regions of body. Called *transitional heart* with a *single circulation*.	Mixing of venous and oxygenated bloods occurs in incompletely divided ventricle. Hence *transitional heart* with *single circulation* and less efficient.	Heart completely 4-chambered without mixing of venous and oxygenated bloods. Hence with *double circulation* and more efficient.	Heart 4-chambered as in birds. Hence with *double circulation*, venous blood going to lungs and oxygenated blood to body, and more efficient.

Table 11. **Comparative Account of Brain in Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** (*Scoliodon*)	**Frog** (*Rana*)	**Lizard** (*Uromastix*)	**Pigeon** (*Columba*)	**Rabbit** (*Oryctolagus*)
1. Cranium	Brain enclosed within a cartilaginous cranium.	Cranium bony.	Cranium bony.	Cranium bony.	Cranium bony.
2. Size & main parts	Brain simple, elongated, flattened, thrice as long as broad, and made of same 3 basic parts-forebrain, midbrain & hindbrain.	Brain simple, elongated, flattened, nearly 3 times longer than broad. Made of same 3 main parts-forebrain, midbrain & hindbrain.	Elongated as in frog, but comparatively larger and broader. Similarly made of forebrain, midbrain and hindbrain.	Brain relatively larger and more complex than in reptiles. A little longer than broad. Made of usual 3 main parts.	Brain relatively largest complex and most advanced. Nearly twice as long as broad. Made of usual 3 main parts.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
3. Meninges	Brain protected by a single membrane, *meninx primitiva*.	Brain protected by 2 membranes : a thin inner *piamater* and a thick outer *duramater*.	Brain protected by 2 membranes : *piamater* and *duramater*, as in frog.	Brain protected by 2 meninges : *pia-arch-noid* and *duramater*.	Brain protected by 3 membranes : *piamater, arachnoid* and *duramater*.
			[I] FOREBRAIN		
			A. OLFACTORY LOBES		
4. Position	Attached to antero-lateral angles of cerebrum, hence widely separated.	Attached side by side in front of cerebrum, demarcated by slight constrictions.	Attached in front of cerebrum without constrictions, and side by side.	Attached anteriorly to cerebral hemispheres and largely covered by them.	Attached distinctly to anterior end of cerebrum.
5. Shape and size	Large, bilobed, highly developed. Hence brain called *nose brain*. Sense of smell highly developed.	Small and spherical due to poor sense of smell in frog.	Small in proportion due to poor sense of smell.	Small, conical due to poor sense of smell.	Small, elongated due to poor sense of smell.
6. Parts	Differentiated into a slender stout *olfactory tract* or *peduncle* and a bilobed *olfactory bulb*.	No differentiation between tract and bulb.	Each drawn out into a narrow, slender *peduncle* bearing distally a small nodulelike *olfactory bulb*.	No distinction into olfactory *peduncles* and olfactory *bulbs*.	*Olfactory tracts* remain covered beneath cerebrum. Clubshaped *bulbs* visible dorsally.
7. Relation with olfactory sac	Olfactory bulb closely applied to large olfactory sac.	Not closely applied to olfactory sac.	Not closely applied to small nasal sac.	Not closely applied to olfactory sac.	Closely applied to nasal sac.
8. Olfactory ventricles	Cavities called *rhinocoels* spacious.	*Rhinocoels* small and narrow.	*Rhinocoels* narrow.	*Rhinocoels* absent.	*Rhinocoels* present.
			B. CEREBRAL HEMISPHERES		
9. Size & shape	Cerebrum large, somewhat rectangular. It has no median groove dividing it into right and left cerebral hemispheres of higher vertebrates.	A deep median longitudinal fissure divides cerebrum into two long, oval, *cerebral hemispheres*.	Two oval cerebral hemispheres divided by a mid-longitudinal groove.	Two very large, pyriform cerebral hemispheres separated by a deep sagittal fissure. Cover olfactory lobes in front and diencephalon behind.	Large, pyriform, greatly developed, separated by deep sagittal fissure. Overlap olfactory lobes in front and midbrain behind.
10. Neuropore	It bears a small mid-ventral opening, the *neuropore*, for terminal nerves to emerge out.	Neuropore absent.	Neuropore absent.	Neuropore absent.	Neuropore absent.
11. Surface	Smooth, without folds, fissures and lobes.	Smooth, without folds, fissures and lobes.	Surface smooth. No folds, fissures and lobes.	Relatively smooth, devoid of folds, fissures and lobes.	Surface bears fissures (sylvian, rhinal etc.) and divided into lobes (frontal, parietal, temporal, hippocampal).
12. Cerebral cortex	Absent. Grey matter forms lining of lateral ventricles.	Shows beginning of cerebral cortex.	Poorly developed.	Relatively poor than in mammals.	Very well developed.
13. Pallium	Roof of cerebrum (*pallium*) poorly developed.	Pallium developed better than in fish.	Pallium shows an increase over that of amphibians.	Relatively poor than in mammals.	Very well developed.

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
14. Corpora striata	Ventro-lateral walls of cerebrum (*corpora striata*) poorly developed.	Developed better than in fish	Thick, well developed.	Thick, very conspicuous.	Comparatively less developed.
15. Corpus callosum	Absent	Absent	Absent	Absent	Special transverse band of nervous tissue interconnecting two cerebral hemispheres internally.
16. Lateral ventricles	Also called *paracoels*, spacious and unbranched.	*Paracoels* or lateral ventricles unbranched.	*Paracoels* unbranched.	*Paracoels* unbranched.	Well developed and branched.
			C. DIENCEPHALON		
Shape & Size	It is small, narrow and dorsally covered beneath anterior extension of cerebellum.	It is short, rhomboidal and not covered dorsally by cerebellum.	It is small, rounded and covered dorsally by cerebral hemispheres and optic lobes.	Dorsal surface covered by cerebrum and cerebellum.	It is completely covered dorsally below backward extension of cerebral hemispheres.
17. Epiphyseal apparatus	From dorsal roof arises a long and slender *pineal stalk* carrying a small rounded *pineal body*. No parietal organ.	*Pineal stalk* is short. In tadpole, it bears a small spherical *pineal body*. It adult frog, pineal body separates and lies above skull. No parietal organ.	Epiphyseal apparatus includes an anterior *parietal organ* and a posterior *pineal body*.	Pineal stalk short and nearly vertical. *Pineal body* small, spherical and delicate. Parietal organ absent.	Pineal stalk slender and inclined posteriorly. Pineal body small, rounded. No parietal organ present.
18. Infundibulum	It is ventral hollow projection behind *optic chiasma*. It consists of a large *median lobe* and 2 lateral smaller *inferior lobes*, produced behind into a thin-walled *saccus vasculosus*.	Infundibulum is a large median bilobed projection. Inferior lobes and saccus vasculosus are absent.	A small infundibulum given off ventrally behind optic chiasma. But inferior lobes and saccus vasculosus are not present.	Infundibulum small and without lobi inferiores and sacci vasculosi.	Infundibulum short and without lobi inferiores and sacci-vasculosi.
19. Pituitary body	Median infundibular lobe bears, posteriorly an oval prominent *hypophysis*, and together form the *pituitary body*.	Infundibulum bears posteriorly a flattened oval *hypophysis* and together form *pituitary body*.	Infundibulum and a posterior *hypophysis* together constitute *pituitary body*.	Ventral infundibulum and *posterior hypophysis* form *pituitary* which lacks an intermediate lobe.	Infundibulum and *hypophysis* form *pituitary body* also having an intermediate lobe.
20. Corpus albicans	Absent	Absent	Absent	Absent	Behind pituitary lies a small rounded body, *corpus albicans* or *corpus mammillare*.

(Contd)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
21. Middle commissure	Cavity or *diacoel* bounded laterally by *optic thalami* but *middle commissure* connecting them lacking.	*Optic thalami* present but *middle commissure* absent.	*Optic thalami* present but *middle commissure* absent	*Middle commissure* absent.	*Optic thalami* connected across *diacoel* by a *middle commissure*.
			[II] MIDBRAIN		
22. Optic lobes	Dorsal side consists of two large, hollow (*optocoels*) *optic lobes* or *corpora bigemina*, which remain mostly concealed by cerebellum. Control vision.	Dorsal surface made of 2 large uncovered lateral, rounded and hollow optic lobes or *corpora bigemina* with *optocoels*. Inhibit spinal cord reflexes of opposite side of body.	2 medium, oval dorso-lateral hollow optic lobes or *corpora bigemina* which remain uncovered.	2 optic lobes or *corpora bigemina*, lateral, very large, spherical, hollow, laterally displaced due to meeting of cerebrum and cerebellum and connected together by a transverse *optic commissure*.	Optic lobes divided forming 4 small almost solid spherical bodies, called *corpora quadrigemina*, mostly covered by cerebral hemispheres.
23. Crura cerebri	Floor or crura cerebri poorly developed and mostly concealed ventrally by inferior lobes and saccus vasculosus.	These run longitudinally beneath optic lobes connecting diencephalon and medulla. Partially covered by pituitary.	Thickened floor forms crura cerebri which are comparatively less developed.	Bands of ventral crura cerebri thickened as in lizard.	Crura cerebri far better developed than in lower vertebrates.
			[III] HIND BRAIN **A. CEREBELLUM**		
24. Shape & size	Large, elongated, rhomboidal dorsal structure overlapping midbrain and diencephalon anteriorly and medulla posteriorly.	Small, narrow, dorsal transverse band just behind optic lobes.	Small, flat, semicircular ridge. Remains uncovered.	Very large elongated antero-posteriorly, covering midbrain in front and medulla behind.	Very large, transversely elongated, partly overlapping medulla behind and midbrain in front.
25. Division	Made of 3 lobes divided by 2 transverse furrows	It is undivided.	Remains undivided.	Divided into 3 lobes: a large median *vermis*, and two small lateral *flocculi*.	Divided into 5 lobes: a median *vermis*, two *lateral lobes* each terminating into a *flocculus*.
26. Surface	Dorsal surface bears irregular folds.	Surface is smooth, without folds.	External surface is smooth.	Surface folded all over.	Surface much folded.
27. Ventricle	Cavity or *epicoel* extensive.	Cavity small	Cavity small	Solid	Narrow and branched.
28. Arbor vitae	Absent	Absent	Absent	Absent	White matter looks tree-like, called *arbor vitae* in grey matter.
29. Pons varolii	Absent	Absent	Absent	Absent	It is a stout, ventral transverse nervous band connecting two lateral sides of cerebellum.

(Contd.)

Characters	Dogfish *(Scoliodon)*	Frog *(Rana)*	Lizard *(Uromastix)*	Pigeon *(Columba)*	Rabbit *(Oryctolagus)*
			B. MEDULLA OBLONGATA		
30. Shape & Size	Large, hollow (*metacoel*), triangular gradually tapering behind, partly concealed in front under cerebellum.	Small, conical hollow uncovered.	Small, triangular, hollow and uncovered.	Small, hollow, concealed beneath cerebellum.	Broad, triangular, hollow, tapering and covered partly by cerebellum.
31. Restiform bodies	Medulla bears antero-laterally a pair of irregular, thin-walled, hollow outgrowths, the *restiform bodies*.	Absent	Absent	Absent	Absent
32. Ventral flexure	Absent	Absent	Medulla and spinal cord meet at a ventral flexure.	Well-marked as in lizard.	No ventral flexure.
			[IV] CRANIAL NERVES		
33. Number	10 pairs	10 pairs	12 pairs. XI is spinal accessory and XII is hypoglossal.	12 pairs as in lizard.	12 pairs as in lizard and pigeon:

Table 12. **Comparative Account of Urinogenital Systems of Vertebrate Types.**

	FISH	AMPHIBIA	REPTILIA	AVES	MAMMALIA
Characters	**Dogfish** *(Scoliodon)*	**Frog** *(Rana)*	**Lizard** *(Uromastix)*	**Pigeon** *(Columba)*	**Rabbit** *(Oryctolagus)*
			[I] URINARY AND EXCRETORY SYSTEM		
1. Excretory organs	Include a pair of *kidneys*, a pair of *urinary ducts*, and a *urinogenital sinus*. No bladder.	Include a pair of *kidneys*, a pair of *ureters* a *urinary bladder* and *cloaca*.	Include a pair of *kidneys*, paired *ureters*, a *urinary bladder* and *cloaca*. No bladder.	Include a pair of *kidneys*, a pair of *ureters* and *cloaca*.	Include a pair of *kidneys*, paired *ureters*, a *bladder* and *urethra*
2. Kidneys	Adult kidneys greatly elongated antero - posteriorly, ribbon-like flat, and attached to dorsal abdominal wall. Each kidney has 2 distinct parts Anterior narrow part is *non-excre Tory*, genital in male but non-genital in female. Posterior broader part is functional kidney and called *opisthonephros*.	Adult kidneys are elongated, oval, flat and attached dorsally one on either side of vertebral column in posterior abdominal cavity. They are not differentiated into parts and are *mesonephric*.	Adult kidneys are small, irregular, attached dorsally and lie in pelvic region at the base of tail. Each kidney is *bilobed*. Anterior broad lobes remains free while posterior narrow lobes become united forming a V-shaped structure. Kidneys are *metanephric*.	Adult kidneys are small, flat, dorsally attached in pelvic region, embedded in hollows of pelvis. Each kidney is *trilobed*, made of anterior, middle and posterior lobes Kidneys are *metanephric*.	Adult kidneys are small, beanshaped and attached much anteriorly and asymmetrically in anterior abdominal cavity. Kidneys are *metanephric* and not divided into lobes.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
3. Histology of kidneys	Covered ventrally by *peritoneum*, not differentiated into *cortex* and *medulla* and made of a compact mass of coiled *uriniferous tubules*.	Same as in fishes	Same as in fishes and amphibians.	Kidney covered ventrally by *peritoneum*, differentiated into *cortex* and *medulla* and contains a very large number of *uriniferous tubules*.	Each kidney covered ventrally by *peritoneum*, differentiated into an outer *cortex* and inner *medulla*, and made of much convoluted *uriniferous tubules*.
4. Uriniferous tubules	Have a special urea absorbing segment. Loop of Henle absent.	Lack a urea-absorbing segment and loop of Henle.	Lack urea-absorbing segment and loop of Henle.	Lack urea absorbing segment, but water absorbing loop of Henle present.	Absorb urea through glomerular filteration and tubular reabosrption and also have water absorbing loop of Henle.
5. Peritoneal funnels	Nephrostomes present.	Nephrostomes present.	Nephrostomes absent.	Nephrostomes absent.	Nephrostomes absent.
6. Ureters	Kidney ducts or mesonephric ureters of both sides run over ventral surface of kidney and open into a urinogenital sinus, which leads into cloaca. Ureters open separately in male but by a common aperture on a urinary papilla in female.	Mesonephric ureters arise and run along outer side of kidneys and open behind by separate apertures directly into cloaca. A urinogenital sinus is absent.	Metanephric kidney ducts or ureters run ventrally over kidneys and open dorsally and separately into middle chamber of cloaca, called *urodaeum*. Urinogenital sinus absent.	As in reptiles, uretters are metanephric. They run ventrally over kidneys and open behind separately into urodaeum through its roof. Without pelvis.	Metanephric ducts (ureters) arise from inner middle concavity or hilus of kidney and open dorso-laterally into urinary bladder. Cloaca absent. Ureters begin from a wide funnel-like cavity in kidney, called *pelvis*.
7. Urinary bladder	Absent	A large thin-walled membranous elastic bilobed urinary bladder opens ventrally into cloaca by a sphinctered aperture.	Small, thin-walled, inelastic, undivided sac opening ventrally into coprodaeum of cloaca.	Absent	Large, median, pear-shaped, muscular sac. Its neck, called *urethra*, opens at the tip of penis in male and into vestibule of female which opens to outside through vulva.
8. Nature of excretion	Predominantly ammonotelic because excrete more ammonia than anything else.	*Ureotelic*, excreting predominantly urea along with water.	*Urecotelic*, excreting semisolid uric acid and urates which are not much soluble in water.	Like reptiles, birds are also *urecotelic* excreting mainly uric acid and urates in a semi-solid state.	*Urecotelic* since chief excretory product in urine is urea dissolved in water.
			[II] MALE REPRODUCTIVE SYSTEM		
1. Sexual dimorphism	Found, as in male fish inner portions of pelvic fins form *claspers* for transferring spermatozoa during copulation.	Not distinct. However, in male frog, base of first inner finger forms a thick *nuptial pad* during breeding season to clasp female in amplexus	Poorly developed, shown by the swellings of hemipenes mid-ventrally behind cloaca in male, and by more conspicuous *pre-anofemoral pores* in male.	Sexual dimorphism is absent in pigeon	Sexual dimorphism is well marked due to presence of *penis* and *scrotal sacs* containing testes only in male.

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
2. Male reproductive organs	Include a pair of testes, vasa efferentia, paired vasa deferentia, epididymes, seminal vesicles, urogenital sinus, sperm sacs and pelvic claspers.	Include two testes, several vasa efferentia, two urinogenital ducts and cloaca.	Include one pair each of testes, vasa deferentia and copulatory sacs, and cloaca.	Include 2 testes, 2 vasa deferentia, 2 seminal vesicles and cloaca.	Include 2 testes, 2 epididymes, 2 vasa deferentia, urethra, penis and some accessory glands.
3. Testes	Very long, cylindrical, attached mid-dorsally to abdominal wall by a double peritoneal fold or *mesorchium*.	Ovoid or rod-like, light yellow, attached to antero-ventral surface of kidneys by *mesorchium*.	Oval, white, bodies, attached much ahead of kidneys to dorsal abdominal wall by *mesorchium*. Right testis somewhat anterior to left one.	Oval, white bodies attached by *mesorchium* antero-ventrally to kidneys. Right testes slightly smaller.	Small, oval, white bodies. Remain inside abdominal cavity in young. But descend outside abdomen in *scrotal sacs* during breeding season in adult.
4. Rectal gland	Posterior ends of testes attached by a nonglandular tissue to a rectal gland.	*Rectal gland* absent.	*Rectal gland* absent.	*Rectal gland* absent.	*Rectal gland* absent.
5. Scrotal sacs	Absent	Absent	Absent	Absent	Present
6. Spermatic cord and gubernaculum	Absent	Absent	Absent	Absent	Each testes attached by anterior end to dorsal abdominal wall by a *spermatic cord* and by posterior end to wall of scrotal sac by *gubernaculum*.
7. Vasa efferentia	Leave anterior end of testis to join *Wolffian* or *mesonephric duct* called vas *deferens*.	Leave from inner end of testis and enter kidney to join *Bidder's canal* which in turn opens into *ureter* or *urinogenital duct*.	Leave from outer-posterior surface of testis and form a much convoluted mass, the *epididymis*.	Leave from inner border of testis to form an *epididymis*.	Leave inner border of testis to form an *epididymis*.
8. Epididymis	It is the anterior extremely coiled and narrow part of vas deferens all along the ventral surface of anterior genital part of kidney.	Vas deferens does not form an *epididymis*.	Formed by anterior part of vas deferens as a thick undifferentiated, convoluted mass along the outer surface of testis.	Poorly developed. Formed by anterior part of vas deferens as a coiled mass lying along the inner surface of testis.	Epididymis well developed and has 3 distinct parts: *caput*, *cauda* and *corpus epididymes* attached to the anterior, posterior and inner sides, respectively, of testis.
9. Vasa deferentia	Each vas deferens or Wolffian duct serves only as genital duct and opens independently into urinogenital sinus.	Each vas deferens unites with ureter of its side forming a *urinogenital duct*, opening separately into roof of cloaca.	Both vasa deferentia open independent of ureters dorsally into roof of urodaeum or middle chamber of cloaca.	As in lizard, two vasa deferentia open independent of ureters into urodaeum.	Two vasa deferentia, arising from cauda epididymis of their side, open into neck of urinary bladder or urethra.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
10. Seminal vesicle	Terminal part of each vas deferens expands into a wide straight tube or *seminal vesicle* for storage of sperms.	In some species of frog, terminal part of urinogenital duct enlarges forming a temporary *seminal vesicle*.	Seminal vesicles not formed.	Small seminal vesicle formed for temporary storage of spermatozoa.	Small, slightly bifurcated blind sac, called *uterus masculinus* or *seminal vesicle* opens dorsally and independently into urethra.
11. Sperm sacs	A pair of club-shaped blind sperm sacs of doubtful function open into urinogenital sinus.	Sperm sacs absent.	Sperm sacs absent.	Sperm sacs absent.	Sperm sacs absent.
12. Copulatory organs	Copulatory apparatus includes a pair of *siphons* for flushing spermatozoa with sea water, and a pair of grooved *pelvic claspers* for transferring spermatozoa into cloaca of female during copulation.	Copulatory apparatus absent. Fertilization external, in water, where ova and spermatozoa are shed during amplexus.	A pair of eversible vascular *copulatory sacs* present mid-ventrally at the base of tail. During copulation they become everted through cloaca as cylindrical *hemipenes* to convey spermatozoa into cloaca of female.	Copulatory apparatus absent. During copulation male bird rides on back of female, their cloacae are closely apposed and transfer of sperms effected quickly.	It includes small erectile cylindrical *penis* in front of anus of male. It serves to transmit sperms into vagina of female during copulation
13. Accessory sex glands	Do not occur.	Do not occur.	Tubular preano-femoral glands produce a horny secretion which forms temporary spines for grasping female during mating.	Do not occur.	Male has one pair each of prostate, Cowper's, perenial and rectal glands. Their secretions either attract the female or contribute to semen.
			[III] FEMALE REPRODUCTIVE SYSTEM		
1. Female reproductive organs	Include a pair each of ovaries, oviducts, shell glands, uteri and epigonal organs and a single rectal gland, a vagina and a cloaca.	Include a pair of ovaries, a pair of oviducts and a cloaca.	Include paired ovaries oviducts, vaginae, shell glands and a cloaca.	Include only left ovary, left oviduct including uterus, shell gland and vagina, and a cloaca.	Include paired ovaries, oviducts, uteri and single vestibule, vagina, clitoris and some accessory glands.
2. Ovaries	Ovaries are paired, irregular, small, lobulated bodies attached just behind liver to dorsal abdominal wall by a double peritoneal fold called *mesovarium*.	Ovaries are a pair of large irregular, multilobed, hollow, blackish bodies attached near kidneys to dorsal abdominal wall by *mesovarium*.	Ovaries are small, paired, white, void bodies suspended by *mesovaria* well ahead of kidneys. Right ovary is attached somewhat anterior to the left one.	Left ovary is a large irregular white body attached ventral to anterior lobe of left kidney by *mesovarium*. Its surface has numerous *egg follicles* or *sacs* each with a developing ovum.	Two ovaries are small, oval, white bodies attached symmetrically and dorsally behind kidneys by *mesovaria*.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
3. Epigonal organs and rectal glands	Ovaries are connected by elongated epigonal organs posteriorly to a rectal gland of unknown function.	Epigonal organs and rectal gland absent.	No epigonal organs and no rectal gland.	Both epigonal organs and rectal gland lacking.	There are no epigonal organs and rectal gland.
4. Oviducts	Oviducts or *Mullerian ducts* are a pair of large but straight ducts, opening posteriorly into cloaca, Their narrow anterior ends form *oviducal funnels* which meet mid-dorsally just behind septum transversum and open into abdominal cavity by a single *slit-like opening*.	Oviducts are very long and much coiled glandular tubes opening behind into cloaca. Their anterior ends form separate *oviducal funnels* with separate openings or *ostia*, at the bases of lungs.	Oviducts are 2 long, wide, thin walled, much plaited tubes opening behind sepa rately into urodaeum. Anterior broad end of each forms a large *oviducal funnel* with a large externally directed ciliated opening or *ostium*, much ahead of ovaries.	Left oviduct is a long and wide tube with thick walls opening behind into urodaeum of cloaca. It opens anteriorly near let ovary by a large *oviducal funnel* with a wide fimbriated *ostium* facing inwards.	Two oviducts are large, coiled tubes meeting behind into vagina, and called *Fallopian tubes*. Anterior end of each opens near ovary by a small *oviducal funnel* with fimbriated *ostium*.
5. Shell glands	A little distance behind funnel, oviduct forms a small enlargement or *shell gland*. It secretes a thin membrane over descending fertilized eggs.	Shell glands are absent.	While passing over kidney, each oviduct forms a slight dilation or *shell gland* into which fertilized eggs are covered by shells.	Behind ostium, left oviduct is divided into several parts: magnum, is thymus, uterus and vagina. Uterus secretes the hard calcareous egg shell.	No shell glands present in oviducts.
6. Uterus	In the region of kidney, each oviduct forms a wide *uterus* inside which the embryos develop.	Before entering cloaca, each oviduct expands into a thin-walled *ovisac*, erroneously called *uterus* which is absent.	Uteri are absent.	Uterus demarcated as stated above but *true uterus* for development of embryos absent.	Fallopian tubes are followed by much wider, longer convoluted, vascular and muscular *uteri* where embryos develop.
7. Vagina & vestibule	Two uteri unite posteriorly into a common median vagina opening into cloaca. Vestibule absent.	Vagina absent. So-called uteri or ovisacs open directly into cloaca. Vestibule absent.	Short terminal part of each oviduct, called *vagina*, opens dorsally into urodaeum. Vestibule lacking.	The last part of single left oviduct, called *vagina*, also opens in the roof of urodaeum. There is no vestibule.	Both uteri meet into a common long, wide and median *vagina*. It opens with urethra into common *urino-genital sinus* or *vestibule*.
8. Vulva	Vulva absent. Instead cloaca opens directly to outside through a large median shallow groove.	No vulva present. Cloaca opens directly to exterior through a small circular cloacal aperture.	No vulva. Cloaca opens through a transverse slitlike aperture.	No vulva. Cloaca opens midventrally by a transverse cloacal aperture.	Vestibule opens to outside ventral to anus, through a longitudinal slit-like aperture called *vulva*.

(Contd.)

Characters	Dogfish (*Scoliodon*)	Frog (*Rana*)	Lizard (*Uromastix*)	Pigeon (*Columba*)	Rabbit (*Oryctolagus*)
9. Special glands	No special glands associated with female genital tract.	No glands as in fish	No glands as in fish and amphibians	No special glands as in fish, amphibians and reptiles.	Special female sex glands include Cowper's, perineal and rectal glands.
10. Milk glands	Absent	Absent	Absent	So-called pigeon's milk, fed to young ones, is secreted by crop glands.	Mammary glands secrete milk and open on 4 or 5 pairs of ventral teats or nipples in female rabbit.
			[IV] LIFE HISTORY		
1. Breading Season	Throughout the year.	During rainy season from July to September.	During March & April in northern India.	All the year round. Particularly during spring and summer.	All the year round specially from January to June.
2. Fertilizations	Internal, inside oviduct, after copulation in water.	External, in water, where ova and sperms are shed during mating	Internal, inside oviduct, after some courtship preceding copulation on land	Internal, inside oviduct, after much courtship preceding copulation on land.	Internal, inside oviduct, after mating without courtship on land.
3. Eggs	3 to 7 small and uniformly white eggs retained inside uteri. (*Ovoviviparous*).	Innumerable small eggs, half black and half white, laid in water in a common jelly forming a *spawn* (*Oviparous*).	10 to 15 large, dirty white shelled eggs laid in a burrow (*Oviparous*).	Usually 2 large oval white shelled eggs laid in a crude nest. (*Oviparous*).	Microscopic eggs retained inside uteri. (*Viviparous*).
4. Incubation	No	No	No	Both parents incubate eggs in turns.	No
5. Development	Uterine, 3 to 7 young ones develop in each uterus at a time and nourished through a *yolk sac placenta*. There is no *metamorphosis*.	Development occurs in water and includes an aquatic tadpole larval stage which undergoes metamorphosis to become terrestrial adult.	Development outside body in eggs on land. There is no metamorphosis. Newly hatched young are similar to adult parents.	Development in shelled eggs outside body and without metamorphosis. Newly hatched young are naked and helpless and fed on pigeon's milk to grow and become fit to fly in about 3 weeks.	Development inside uteri. Gestation period lasts for 30 days. New born young blind, naked and fed on milk by mother before they become fit to leave the burrow in about 4 weeks.

Glossary

Abdomen. Major posterior body division of trunk, behind diaphragm in mammals.

Acetabulum. Cup-shaped socket on each side of pelvis into which head of femur fits.

Adaptation. Fitness of an organism for its particular environment.

Adaptive convergence. Superficial morphological similarity in distantly related forms correlated with identical environmental conditions.

Adaptive radiation. Evolution and spread of a single line of descent of organisms into several different forms, each adapted to a particular habitat.

Adrenalin. A hormone secreted by the medulla of ductless adrenal glands, one anterior to each kidney.

Aerial. Living or occurring in air.

Afferent. Any structure (vessel or nerve) leading towards a centre. Opposite of efferent.

Affinities. Relationships of organisms, especially of phylogenetic nature.

Albino. An individual, such as the white rat, showing albinism or lack of normal pigment of skin, hair and eyes.

Albumen. A water-soluble protein substance, such as the white of reptile's or bird's egg.

Allantois. One of the extra-embryonic membranes arising as a pouch from hindgut in the embryos of amniotes (reptiles, birds and mammals).

Alveolus. A small cavity or chamber. Ex., tiny air sacs of lungs, bony socket of a tooth in mammals.

Ammocoetes. The larval stage of lamprey.

Amniota. A group of vertebrates (reptiles, birds and mammals) in which extra-embryonic membranes (amnion and allantois) surround the developing embryo.

Amphibious. Capable of living both in water and on land, as frogs and toads.

Amphicoelous. Concave at both ends, as centrum of 8th vertebra of frog.

Ampulla. A small bulb-like enlargement, as ampullae of semicircular canals of an ear.

Anamniota. A group of vertebrates without amnion—cyclostomes, fishes and amphibians.

Anatomy. Study of structure of animals and plants as made out by dissection.

Arboreal. Pertaining to trees, as tree-living

Archenteron. Primitive digestive cavity of metazoan embryo formed by invagination in gastrula stage.

Autotomy. Automatic or spontaneous breaking off of a part by an animal, as tail in some lizards.

Axillary. Pertaining to armpit (axilla), as axillary artery and vein.

Azygos. An unpaired anatomic structure, as azygos vein of mammals and azygos lobe of lung.

Backbone. The vertebral column in vertebrates.

Bicuspid. A structure with two rounded cups or surfaces, as bicuspid tooth or bicuspid valve.

Bilateria. The metazoans with bilateral symmetry.

Bile. A fluid secreted by vertebrate liver that helps in digestive process.

Bioluminescence. Emission of light by living organisms, as the result of chemical reactions.

Blastocoel. Fluid filled segmentation or central cavity of blastula.

Blastoderm. Layer of cells surrounding blastocoel in a blastula.

Blastodisc. Germinal area on a large yolked egg that gives rise to embryo.

Blastomere. Any one of the cells resulting from early cleavage of zygote.

Blastopore. Mouth-like opening of archenteron of gastrula to the exterior.

Blastula. Early embryonic stage consisting of a single-layered hollow ball of cells.

Bolus. A ball-like mass of something, such as food in rabbit and ruminants.

Bowman's capsule. A double-walled epithelial cup at the beginning of a kidney tubule surrounding glomerulus.

Brachial. Pertaining to arm of a vertebrate, as branchial artery or branchialis muscle.

Branchial. Pertaining to gills, e.g., branchial artery.

Buccal. Pertaining to oral, cheek or mouth cavity.

Bulbus arteriosus. Enlarged bulb-like base of ventral aorta, especially in bony fishes.
Bulla. A hollow bony growth such as tympanic bulla.
Caecum. A blind sac or pouch of vertebrate intestine.
Canaliculi. Tiny canals in bone connecting lacunae with one another or with Haversian canals.
Cardiac. Pertaining to or near heart.
Carnivorous. Animals eating or living on flesh of other animals.
Carotid. Principal artery supplying to head.
Carpals. Bones of carpus or wrist.
Caudal. Pertaining to tail.
Cenozoic. Geological era from the Mesozoic to the present (about 75 million years).
Centrum. Main ventral body of a vertebra which bears numerous processes for muscle attachment.
Cephalic. Pertaining to or situated near head.
Cervical. Pertaining to neck region.
Chiasma. A crossing, such as crossing of optic nerves known as optic chiasma.
Choana. A funnel or opening, such as between nasal passages and pharynx.
Chondrin. Substance that forms cartilage
Chondrocranium. Cartilaginous skull of cyclostomes, elasmobranchs and embryos of higher vertebrates.
Chorion. Outer embryonic membrane of amniotes. In mammals, it unites with allantois forming placenta.
Chyle or chyme. Liquid food discharged from stomach into duodenum (*chyme*), and absorbed through lacteals (*chyle*).
Clitoris. An erectile small organ of female of most mammals, homologous with penis of male.
Cloaca. Common passage or receptacle for discharge of digestive, excretory and reproductive products in most vertebrates except mammals.
Cochlea. Coiled portion of internal ear containing organ of hearing.
Coelom. Body cavity in triploblastic animals lined with peritoneum (mesoderm).
Cold-blooded. Lacking capacity to regulate body temperature, poikilothermic. Ex. Fishes, amphibians, reptiles.
Columella. A small rod-like bone in middle ear cavity of most vertebrates.
Conus arteriosus. A heart chamber in fish, frog, etc.
Coronary. Pertaining to heart, as coronary artery or nerve.
Corpuscle. A small structure, such as a blood cell or bone cell.
Cortex. Outer portion of an organ, such as of kidney or brain.
Cotylosaur. A primitive group of fossil, ancestral, stem reptiles.
Cranial. Pertaining to skull or brain, such as cranial nerves.
Cutaneous. Pertaining to skin.
Defecation. To discharge faeces through anus
Dermis. Inner connective tissue layer of skin, beneath epidermis, mesodermal in origin.
Diaphragm. A muscular partition dividing thoracic and abdominal cavities in mammals.
Diastole. Relaxation or dilation of heart chambers.
Digastric. A muscle with two bellies. Ex. the digastric muscle which lowers mandible.
Digitigrade. Walking on the toes. Ex. cats and dogs.
Dimorphism. Having two forms or types of individuals in the same species.
Dinosaur. An extinct type of reptiles.
Dioecious. Having male and female sexes in separate individuals. Unisexual.
Diurnal. Related to daytime, opposed of *nocturnal* which pertains to night.
Diverticulum. A blind pouch or pocket given out from a tube.
Duodenum. First part of small intestine just posterior to stomach.
Duramater. Tough outermost membrane covering brain and spinal cord.
Eccentric. Away from the center.
Ecology. Study of interrelationships between organisms and their environments.
Ectoderm. The outer germ layer or cell layer of an early embryo.
Effector. Any part of body, a muscle or gland, transforming motor impulses into motor action.
Efferent. Leading away from a center. Opposite of afferent.
Egg. The nonmotile gamete or germ cell formed by the female.
Embryo. A newly forming individual in early stages of development, before hatching or birth.
Embryogeny. Process of development of the embryo.
Embryology. Science which deals with early developmental stages of organisms.
Embryonic membranes. Cellular membranes (amnion, chorion, allantois) that surround the embryo of amniotes necessary for its metabolism.

Emulsification. Process of dividing fat into very small particles in a liquid.
Enamel. The hard outer layer of a tooth.
Endocrine. Pertaining to ductless glands.
Endoderm. Innermost germ layer of gastrula.
Endoskeleton. Internal bony or cartilaginous supporting framework of an animal.
Endostyle. Ventral ciliated groove in pharynx of protochordates, used for getting food, homologous with thyroid gland of vertebrates.
Enterocoel. Coelom formed by outpouching of mesodermal sacs from archenteron of gastrula.
Endosteum. Connective tissue lining bone marrow cavity.
Enteron. Digestive cavity lined by and derived from endoderm.
Enzyme. A protein substance produced by living cells, causing an acceleration of a chemical reaction (hydrolysis, oxidation, reduction, etc.), without itself being changed in the process. Also known as *biocatalysts*.
Epiboly. Growth of a fold of blastoderm over surface of embryo, forming an archenteron, during gastrulation.
Epididymis. A mass of coiled efferent tubules near testis and leading into vas deferens.
Epiglottis. A cartilaginous projection in front of glottis and prevents food from entering it during swallowing.
Epiphysis. Tip of a long bone. Also pineal body.
Erythrocytes. Red blood cells or corpuscles
Eustachian tube. Passage way connecting pharynx and middle ear cavity in higher (land) vertebrates.
Exocrine. A gland which releases its secretion through a duct.
Exoskeleton. Hardened supporting structures on the outside of the body of an animal.
Expiration. Exhaling or breathing out CO_2 and H_2O.
Extensor. Any muscle (or tendon) that straightens out a joint. Opposite of flexor.
Fauna. Animal life characteristic of a certain region or period of time.
Fertilization. Union of a mature ovum and a mature sperm to form a zygote.
Foetus. An advanced embryo or unborn young of any viviparous animal.
Fissure. Any groove, furrow, cleft or slit.
Flexor. Any muscle that bends a joint. Opposite of extensor.
Follicle. A small cellular sac or covering, such as ovarian follicle.
Foramen. An opening in a structure (bone, membrane or partition). Pleural *foramina*.
Fossa. A pit or depression found in a bone.
Fossil. Any relic or remains of prehistoric forms of life.
Fossorial. Adapted for digging.
Gametogenesis. Development of mature germ cells or gametes.
Gastrula. An early embryonic stage, following blastula, consisting of two germ layers, ectoderm and endoderm.
Gastrulation. Process of invagination of blastula forming two-layered gastrula.
Germ layers. Three basic cell layers (ectoderm, endoderm and mesoderm) formed in early triploblastic embryo of multicellular animals, from which all the adult organs and tissues arise.
Gestation. Period between fertilization and birth, i.e., period of pregnancy, in which young is carried in uterus before birth.
Gill. A respiratory organ in aquatic animals.
Girdle. A structure of bones supporting skeleton of appendages.
Gizzard. An enlarged muscular part of alimentary canal for grinding ingested food.
Glomerulus. A tuft of capillaries contained in a Bowman's capsule of vertebrate kidney.
Glossopharyngeal. Carnial nerve IX supplying tongue and plarynx.
Glottis. A slit-like opening from pharynx into larynx or trachea in a vertebrate.
Gregarious. Habitually living in company, in flocks or herds, of numerous individuals.
Grey matter. Portion of brain and spinal cord containing nerve cells.
Guano. Organic base of excretory waste of sea birds used as a fertilizer.
Gullet. Passage to stomach. Synonym for oesophagus.
Gustatory. Pertaining to the sense of taste.
Habitat. The natural environment in which an animal lives.
Haversian canal. Small canals through which blood vessels and nerves ramify in bones.
Hemoglobin. Oxygen-carrying red pigment of blood or protein containing iron.
Hepatic. Pertaining to liver.
Hepatic portal system. A system of veins conveying blood from digestive tract to capillaries in liver.
Herbivorous. Feeding only or mainly on plant material.
Hermaphroditism. Possession by an individual organism of both male and female reproductive organs.
Heterocercal. Asymmetrical type of tail, internally as well as externally, as in sharks and sturgeons.
Hibernation. Passing of winter in a dormant or inactive state with reduction of metabolism.

Histology. Study of microscopic structure of tissues and organs.
Holoblastic. Pertaining to total cleavage in which an entire egg cell divides.
Homocercal. Fish tail externally symmetrical but internally asymmetrical, as in most teleosts.
Hyaline. Glassy or semitransparent.
Hydrostatic. Term applied to an organ which regulates specific gravity of an aquatic animal, in relation to water.
Hyoid. Refers to a Y-shaped group of bones and cartilage at the base of tongue.
Hypoglossal. Cranial nerve XII supplying some of the tongue muscles.
Hypophysis. The pituitary gland.
Ichthyosaur. A type of extinct aquatic reptile.
Ileum. Posterior (and longest) part of small intestine.
Inspiration. Taking of O_2 into an animal organism
Insulin. A hormone secreted by pancreatic Islets of Langerhans.
Integument. Outermost covering of body; skin.
Intercostal. Means between ribs.
Interstitial. Pertaining to intercellular spaces, as cells among tubules in a testis.
Invagination. Inpushing of a cellular layer into a cavity, as of a blastula forming a two-layered gastrula.
Involution. A rolling in or turning inward of cells over a rim, as in gastrulation.
Islets of Langerhans. Patches of endocrine cells in pancreas; secrete the hormone insulin.
Jejunum. Middle part of intestine between duodenum and ileum in mammals.
Jugular. Pertaining to throat, as jugular vein.
Jurassic. Second period of Mesozoic Era, named for Jura Mountains.
Keratin. A nitrogenous substance forming chemical basis of horns, hairs, nails, feathers and epidermal scales.
Kidney. Chief excretory organ in vertebrates.
Kupffer cells. Specialized cells in liver.
Labyrinth. Part of vertebrate inner ear composed of semicircular canals, utriculus, sacculus and cochlea.
Labyrinthodont. A group of fossil stem amphibians from late Palaeozoic.
Lacrymal. Pertaining to tears, as lacrymal gland and lacrymal bone.
Lacteal. Pertaining to milk. Also refers to lymph vessels in intestinal villi of vertebrates.
Larva. Immature, free-living stage in life cycle of various animals.
Larynx. Enlarged upper end of trachea into which glottis opens, in all vertebrates except birds. Contains vocal cords; voice box.
Leucocyte. A white blood cell or corpuscle with beaded nucleus.
Ligament. A sheet of tough, elastic, connective tissue fibres, that connects one bone to another.
Lingual. Pertaining to tongue, as lingual artery.
Loop of Henle. A hair-pin like portion of a kidney tubule.
Luciferase. An enzyme involved in light production in organisms.
Lumbar. Region of back just posterior to ribs in vertebrates.
Lumen. Cavity in a gland, duct, vessel or organ.
Luminescence. Production of light as a result of chemical reactions within cells.
Lung. A respiratory organ of air-breathing vertebrates.
Lymph. Fluid found in lymph vessels or tissues, containing fat, white blood cells and plasma.
Lymphocytes. A leucocyte having non-granular cytoplasm and large unlobulated nucleus, concerned with production of antibodies.
Macromere. Relatively large yolk-laden cells in early cleavage stages of some animals
Macrophage. A cell which ingests and destroys solid bodies such as bacteria and red blood cells.
Malpighian body. Structure of vertebrate kidney composed of Bowman's capsule plus contained glomerulus.
Mammary. Refers to breast, such as mammary glands.
Marrow. Central cavity of bone largely composed of connective and vascular tissues.
Marsupium. External abdominal pouch for carrying young in marsupial mammals.
Matrix. In animal histology, an intercellular substance of tissues.
Medulla. Distinct central portion of many organs, in contrast to cortex or outer portion.
Medullary plate, groove, and tube. Neural plate, groove or tube. Successive stages in embryonic development of vertebrate central nervous system.
Medullated. A nerve fibre covered with a fatty or myelin sheath.
Meninges. Three membranes (duramater, arachnoid and piamater) covering brain and spinal cord.
Meroblastic. Cleavage of eggs with much yolk (reptiles and birds) in which only protoplasm disc divides into blastomeres, leaving yolk undivided. Also called teloblastic or discoidal.
Mesenchyme. A loose embryonic connective tissue derived chiefly from mesoderm.
Mesentery. A thin, double epithelial membrane that supports alimentary canal and other organs in abdominal cavity.

Mesoderm. Middle layer of embryonic cells between ectoderm and endoderm.
Mesonephros. Embryonic kidney of amniotes. Adult kidney of cyclostomes, fish and amphibians.
Mesorchium. Mesentery that supports testes.
Mesozoic. Middle geological era in the past.
Metacarpals. Proximal bones of hand.
Metamorphosis. Profound changes of form during development from larva to adult animal.
Metatarsals. Proximal bones of foot.
Metazoa. All multicellular animals with cells arranged in tissues.
Micron. One-thousandth part of a millimeter. Represented by μ (Greek letter mu).
Migration. A periodic movement of an animal species from one region to another.
Mimicry. Resemblance of one organism to another of a very different character.
Mitral. Mitre-shaped; refers to valve between left auricle and left ventricle of vertebrate heart.
Monoecious. Having both male and female gonads in the same individual; hemaphroditic.
Monophyletic. From a single known evolutionary derivation.
Morphology. Study of general form and structure of animals.
Morula. An early embryo, resembling a solid ball of about 16 cells or blastomeres.
Muscularis mucosae. Thin layer of smooth muscle between tunica and submucosa in the wall of oesophagus, stomach and intestine.
Myomere. A muscle segment or somite.
Myotome. A muscle segment or somite of embryos and lower vertebrates.
Neoteny. Indefinite prolongation of immature condition of an animal, like amphibian axolotl.
Nephron. Structural and functional unit of kidney.
Neuroglia. Special type of connective tissue found in nervous system.
Neuron. Nerve cell including cell body and processes (axon and dendrites) over which nervous impulses pass.
Niche. The constellation of environmental factors required by a species.
Nictitating membrane. A third eyelid found in most reptiles and birds.
Nocturnal. Active at night. Opposed to diurnal.
Nomenclature. A system of naming organisms.
Notochord. Rod-like cellular skeletal axis found in chordate embryo or adult, mid-ventral to nerve cord.
Occipital. Pertaining to base of skull of vertebrate.
Olfactory. Refers to the sense of smell.
Omnivorous. Subsisting on all kinds of food, plants as well as animals.
Ontogeny. Development of an individual from fertilized egg to adult condition.
Oogenesis. Origin and development of mature ovum from primordial germ cell.
Oology. Study of birds' eggs.
Operculum. The gill cover in bony fish and tadpoles.
Ophthalmic. Pertaining to eye.
Opisthocoelous. Concave behind as the centrum of some vertebrae.
Optic. Refers to eye or vision.
Optimum. The most favourable condition.
Organogeny. Development of specialized tissues and organs in embryogeny.
Ossicle. A small bone, as a patella or ear ossicle.
Osteoblast. A bone forming cell.
Otolith. A small calcareous mass found in the auditory organ of many animals.
Oviparity. Condition of laying eggs that hatch outside the body of mother.
Ovoviviparous. Producing eggs which hatch within the parent's body without nutrition.
Paedogenesis. Sexual reproduction by embryonic or larval stage.
Palaeontology. Science dealing with the study of fossils.
Pancreas. A digestive gland producing enzymes and insulin and opening by a duct into duodenum.
Pecten. A highly vascular, pigmented and fan-shaped structure found in the eye of birds.
Pectoral. Refers to upper thoracic region to which forelimbs are attached.
Pelvic girdle. 3-bone structure of hip to which hind limbs are attached.
Penis. Male copulatory organ which transfers sperms into genital tract of female.
Pentadactyle. Limb having 5 fingers, toes or digits.
Pericardium. A membranous sac enclosing the heart.
Peristalsis. Rhythmic involuntary contractions by which alimentary canal propels its contents.
Peritoneum. Thin serious membrane which lines the coelom and covers the viscera.
Phagocytosis. Process of leucocytes ingesting and destroying bacteria and other foreign materials.

Phalanges. Bones of digits, Singular phalanx.
Phylogeny. Evolutionary history of the species or race (higher group).
Pia mater. Thin inner membrane closely investing brain and spinal cord.
Pineal body. A dorsal outgrowth of diencephalon of vertebrate brain.
Pinna. Projecting part of external ear in mammals.
Pituitary body. An endocrine gland located on ventral surface of diencephalon.
Placenta. A vascular structure, embryonic and maternal, through which embryo and foetus are nourished while in uterus.
Plantigrade. Walking with entire sole of foot on land, as in man and bear.
Platelets. Small bodies in blood; seem to act as centres of coagulation.
Plesiosaur. A long-necked extinct marine reptile of Mesozoic times.
Pleural cavity. Part of coelom in mammals containing lungs and lined by pleura.
Poikilothermous. Cold-blooded.
Polyphyletic. Derived from more than one ancestral type.
Precocious. Characterized by early maturity, as in some birds.
Predator. An animal which pursues and eats other animals (predaceous).
Prehensile. Adapted for grasping or holding
Procoelous. Concave in front, as in centrum of typical vertebrae of frog.
Pterosaur. An extinct flying Mesozoic reptile.
Puberty. It is the time of beginning of sexual maturity in an individual.
Pulmonary. Pertaining to lungs, as pulmonary artery and vein.
Pyloric. Pertaining to posterior portion of stomach, the pylorus.
Quadruped. A 4-footed animal; a tetrapod
Ramus. A branch, as of a blood vessel, bone or nerve.
Recapitulation theory. The conception that the life history of an individual (ontogeny) tends to recipitulate the stages passed through the evolution of the race (phylogeny). Biogenetic law.
Reflex action. An involuntary response to a stimulus without involving brain.
Regeneration. Replacement or repair of parts lost or damaged.
Renal. Pertaining to kidney.
Rete. A network, as rete testis or rete mirabile.
Retrogression. Going backward by an animal during development to a condition characterizing animals lower in scale of life. Ex. *Herdmania*.
Rudimentary. Not completely developed or having no function.
Rugae. Ridges or folds as in the lining of vertebrate stomach.
Ruminants. Cud-chewing herbivorous mammals like cattle, sheep, deer, etc. Their stomach has 4 chambers.
Sacral. Refers to sacrum, the posterior part of vertebral column, attached to pelvic girdle.
Sagittal. Median antero-posterior plane in a bilaterally symmetrical animal.
Salivary. Pertaining to certain oral glands that secrete saliva.
Scansorial. Related to or adapted for climbing.
Scrotum. Pouch containing testes in males of most mammals.
Sebaceous gland. Small oil glands of skin connected with hair follicles in mammals.
Secondary sexual characters. External characters in which male and female of a species differ, but not directly concerned with reproduction.
Sedentary. Forms remaining attached at one place.
Semen. Sperm-containing fluid of male animals.
Semicircular canals. Canals in vertebrate ear, associated with sense of equilibrium.
Semilunar. Means crescent-shaped, as valves in vertebrate heart.
Seminiferous tubules. Long, coiled, testicular ducts which produce spermatozoa and carry semen.
Serosa. Outside embryonic membrane, the chorion.
Sertoli cell. Nurse cell in lining of seminiferous tubule. It nourishes developing spermatozoa.
Sessile. Permanently fixed, not moving; sedentary.
Sexual dimorphism. Two sexes of a given species differing in secondary sexual characters.
Sinus-auricular node. Portion of right auricle of heart which initiates heart beat.
Sinus venosus. Accessory chamber of heart in fish, amphibians and reptiles.
Somite. A serial segment or metamere of an animal.
Spermatogenesis. Production of spermatozoa from primordial germ cells lining seminiferous tubules.
Sphincter. A circular muscle regulating an opening.
Spiral cleavage. Cleavage in which blastomeres are spirally arranged.

Swim bladder. Long, thin-walled dorsal sac in some bony fishes; acts as a hydrostatic organ.
Symphysis. Union between two parts.
Syrinx. Voice box of a bird.
Systole. Contraction phase of the cardiac cycle.
Tactile. Pertaining to the sense of touch.
Tadpole. Larval stage of a chordate like a sea squirt or frog.
Tarsals. Bones of ankle or tarsus.
Taxonomy. Science dealing with classification of living things.
Tegumentary. Pertaining to skin.
Telolecithal. Egg cell with yolk massed at one pole.
Tendon. A white fibrous inelastic cord connecting a muscle to a bone or another muscle.
Terrestrial. Living on ground.
Tetrapoda. 4-legged vertebrates or quadrupeds. Ex. amphibians, reptiles birds, and mammals.
Therapsid. Extinct Mesozoic mammal-like reptiles from which true mammals evolved.
Tricuspid. Refers to the valve between right auricle and right ventricle of heart.
Triploblastic. Derived from 3 embryonic germ layers—ectoderm, endoderm and mesoderm.
Trophoblast. Embryonic cells which invade wall of uterus in mammals.
Turbinal. A bone found in nasal cavity.
Tympanic membrane. The vibrating eardrum involved in hearing mechanism in vertebrates.
Umbilical cord. Connective tissue cord containing blood vessels that unites mammalian embryo or foetus with placenta.
Uncinate. Hooked.
Unguiculate. Having claws, as a cat.
Ungulate. Having hoofs, as a deer or horse
Unguligrade. Walking entirely on hoofs or ends of digits, as in horse.
Urea. A nitrogenous metabolic waste, with formula $CO(NH_2)_2$, found in urine of mammals.
Ureter. Duct carrying urine away from kidney to urinary bladder or cloaca.
Urethra. Tube carrying urine from urinary bladder to outside in both sexes in mammals.
Uriniferous tubule. Coiled excretory kidney tubule extending from Malpighian body to collecting tubule, nephron.
Urostyle. Long, rod-like, terminal bone of vertebral column of frog and toad.
Uterus. Dilated, muscular, posterior region of oviduct in which young of mammals develop, womb.
Vagina. Passage from uterus to outside in female. It receives penis of male in mating.
Vagus. X cranial nerve in vertebrates.
Vermiform apendix. Small, tubular, blind pouch projecting from caecum of large intestine in some mammals.
Vertebrate. Animals with a vertebral column or backbone made of segmental vertebrae.
Vestigial. A remnant of an ancestral structure that has lost its original form and function.
Villus. A minute finger-like process from intestinal lining of vertebrates or chorion of placenta.
Viscera. Internal organs of abdominal, thoracic and cranial cavities.
Vitamins. Refers to several unrelated organic substances in foods, needed in small quantities for normal metabolic activity.
Viviparous. Giving birth to living young ones.
Vocal cords. Ligaments in larynx concerned with sound production.
Volant. Capable of flying.
Warm-blooded. Animals (birds and mammals) with a regulated constant body temperature. Homoeothermous.
White blood corpuscles. See leucocytes.
White matter. Portion of central nervous system without nerve cells.
Wisdom tooth. One of the most posterior molar teeth in a human.
Wolffian duct. Excretory duct of mesonephros. May carry seminal fluid in male.
Zoogeography. Branch of Zoology dealing with geographic distribution of animals.
Zygapophyses. Processes from neural arch of a vertebra for articulation with those of adjacent vertebrae.
Zygote. Fertilized egg, formed by union of male and female gamates.

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