स्वाध्याय स्वमन्थन स्वावलम्बन

UTTAR PRADESH RAJARSHI TANDON OPEN UNIVERSITY

(Established vide U.P. Govt. Act No. 10, of 1999)

UGZY-02
ANIMAL DIVERSITY-II

FIRST BLOCK
Diversity in Chordates

Indira Gandhi National Open University

UP Rajarshi Tandon Open University

Shantipuram (Sector-F), Phaphamau, Allahabad - 211013

Uttar Pradesh
Rajarshi Tandon Open University
School of Sciences

UGZY -02
ANIMAL DIVERSITY-II

Block
1
DIVERSITY IN CHORDATES

BLOCK – I DIVERSITY IN CHORDATES

The living chordates show enormous structural and functional diversity and are adapted to varied environments and modes of life. Yet they all share certain characteristic features that are the result of their common ancestry and these have undergone progressive modifications during evolution. In this block we have four units that present an overview of the classification of chordates, which is also a method of understanding their evolution.

Unit 1 **Introduction to Chordates** explores the relationship between the living chordates and other animal groups. We have described the hemichordates and the primitive chordate groups that are possible ancestors of vertebrates and have listed important features that are necessary to identify the chordate. You will learn that all chordates possess, atleast during the embryonic stages a flexible notochord, a dorsal nerve cord, paired gill slits and pharyngeal pouches: and most are markedly cephalised i.e., the major sense organs tend to concentrate in the anterior part of the body. In this unit we also discuss the various hypotheses relating to the origin of vertebrates as no clear fossils have been found to link them to an invertebrate ancestral type.

Unit 2 **Agnatha, Fishes and Amphibians** discusses the salient characters and classification of the anamniote groups of vertebrates – the jawless fishes, the true fishes and the organisms that can live both in water as well as on land i.e., the amphibian. You will learn that jawless fishes are ancestral to fishes and can be regarded as the earliest vertebrates i.e., animals belonging to the chordate group that have a cartilaginous or bony endoskeleton, the anterior portion of which forms a cranium housing the brain and a vertebral column through which the nerve cord passes. In this unit we also describe how amphibians were the first group of vertebrates to leave the water for a life on land – a major evolutionary step, though they still spend a part of their life in water. This process led to a series of changes in the vertebrate body plan to suit a terrestrial existence.

Unit 3 **Reptiles and Birds** describes how once in terrestrial habitats, vertebrates radiated into some of the most remarkable animals that have inhabited this earth. Reptiles were the first completely terrestrial vertebrates, which survive well and even reproduce out of water. Far-reaching structural changes were needed for life on land. There was a progressive change in the jaw that allowed new ways of feeding and changes in the limbs, which were more suitable for a terrestrial life. Dinosaurs are the best known and most spectacular examples of reptiles that once roamed the earth.

Derived from reptiles are the animals we call bird and mammal both highly specialised for constant activity. Since their origin birds have become adapted to many different habitats and their morphological characteristics are defined by their requirements of flight. They are the only terrestrial vertebrates capable of moving over long distances. This unit describes the classification and natural history of reptiles and birds.

In Unit 4 **Mammals** you will study the important characters of mammals which have been responsible for their success on this earth. This unit gives an interesting account of non-placental mammals. You will read about the special adaptations that have taken place in bats for flight and in whales for an aquatic mode of life. This unit also deals with the increasingly differentiated dentition in mammals and evolution of human beings. India is quite rich and diverse in its vertebrate fauna; we have tried to give examples of Indian species wherever possible, for we feel that our students should be familiar with them. We also list some of the threatened mammalian species of India.

The geological time periods featuring the biological evolution have been given as Appendix-I and a brief classification of vertebrates as Appendix-II at the end of this block. We would strongly advice you to keep referring to them as you read through the course.

Objectives

After studying this block you will be able to:

- List the characteristic features possessed by all chordate groups,
- identify the characters that separate the vertebrates from the primitive protochordates,
- list the salient feature that would distinguish members of different vertebrates classes and
- describe the important adaptation found in vertebrates for a life on land and in water.

ANIMAL DIVERSITY – II

Most of the animals that we are familiar with – fishes, amphibians, reptiles, birds and mammals belong to the phylum Chordata. Though they form only a small group of about 5% of all the animal species described so far, chordates live in virtually all kinds of habitats on the earth. In the aquatic habitat exist fishes weighing 0.1 g. when fully mature, to whales weighing upto 100,000 kg. While in the sky, migrating birds fly over the Himalayas, the highest mountain ranges. Among chordates, birds can live at high altitudes where mammals cannot withstand the lack of oxygen because the lungs of birds are more effective in extracting oxygen from the air than mammalian lungs. The diversity of adaptation and behaviour in chordates is as complex as their body forms are fascinating. How they may have originated and evolved is also an intriguing story.

In Animal Diversity I you were made familiar with the enormous diversity among the non-chordates or invertebrates. Animal Diversity II is the second course of this entire package of 3 courses. The course aims at providing the students an opportunity of studying the vast diversity of living chordates and their special adaptations, interrelationship and evolution. The number of living vertebrates today is only a small proportion of the species that may have existed in earlier geological periods and of these most have no living counterparts today. The number of species has been declining steadily since the Pliocene and Pleistocene. Discovering some new one and some otherwise thought to be extinct mammals, in the recent past, suggests that there are still many more species of chordates awaiting to be discovered and described.

The course proceeds with a class by class approach of chordates. While discussing distinctive characters of each class an attempt is made to ensure that you neither lose sight of the basic unity in structure among different chordates nor of the fact that structural modifications are a result of their long evolutionary history. Throughout the course we dwell upon the comparative approach towards the study of animals, tracing the similarities that bear clear witness to their common ancestry. We describe the various body structures, emphasising the relationship between form, function and adaptation. This approach is followed for all organ systems, for function is structure in action, and is the reason for the existence of the structure. Reference to human structures is made wherever necessary with the view of fitting man into the vertebrate organisation and plan and to provide some interesting details in the form of marginal remarks.

Block – I **Diversity in Chordates** consists of 4 units. It begins with a description of the basic features that characterize chordates. Emphasis is laid on the unifying principles of various chordate classes to trace their ancestry. Classification of the various vertebrate chordates with regard to their relationship to each other and their distinctive features have been discussed.

Functional Anatomy of Chordate part – I and part – II form the 2nd and 3rd blocks of this course. The 8 units of these blocks deal with the issues of how different vertebrates obtain the material they need, eliminate waste, integrate their activities, reproduce and meet the challenges of their survival.

We conclude with Block – 4 **Adaptations and Behavioral Patterns**. Behaviour of vertebrates is as diverse and complex as their body forms. We discuss the basic concepts, and explain the different experimental approaches to animal behaviour showing how behaviour, function and anatomy are related.

As with all other courses wherever desirable, some interesting piece of information in relation to a particular topic has been added as marginal remark. Each unit in the course contains the learning objectives, text summary and self assessment questions. You are advised to attempt all the self assessment questions as well as the terminal questions as they help you to self test retention and understanding of the important concepts in the unit.

We presume you have already studied LSE-01, LSE-05 and LSE-09 before embarking on to this course. Difficult terms have been explained in the glossary at the end of each block along with a list of references for gaining additional information on the subject. A geological time table is given at the end of the Block. It would be useful to consult it while going through the units.

UNIT 1 INTRODUCTION TO CHORDATES

Structure

1.1 INTRODUCTION

We are more familiar with chordates than with any other group in the animal kingdom. The reason for this is obvious in the fact that we as well as several domesticated animals like, cow, sheep, goat, dog etc., are members of this group. Chordates are the most diverse and successfully adapted to various kinds of habitats. However, the basic plan of organisation is more alike among the chordates than it is in several non-chordates groups. The study of chordates continues to be of great importance to biologist because it illustrates the biological principles like development, ancestry, inter-relationships and evolution very well. Many chordates are constructed of hard parts that survive to yield a respectable history in the fossil records which have made them especially useful in defining ideas about evolutionary processes. Advanced chordates are also some of the most intricate animals even to appear. They, therefore, introduce to us questions about the complexity of biological organisation and their evolution.

Objectives

After studying this unit you will be able to:

- enumerate the distinctive characters of chordates and explain how these are characteristically different from the non-chordates.
- classify the chordates giving suitable examples,
- describe the natural history and basic adaptive features of hemichordates and protochordates, and
- outline the affinities, ancestry and evolution of hemichordates and protochordates in relation to other groups in the animal kingdom.

1.2 PHYLUM HEMICHORDATA

Initially hemichordates were considered a subphylum of the chordates. The basis for this was the presence of rudimentary notochord and gill slits. But the hemichordate notochord is in reality a buccal diverticulum and not homologous with chordate notochord. Therefore, the hemichordates are now put as a separate phylum. However, in our course of Diversity we are dealing Hemichordata with the Chordata as it bears certain characters in common with true chordata though lacking a true notochord.

Characteristics of Hemichordata

Hemichordates (Hemi - half + Chorda - chord) are soft bodied, marine animals; bottom dwellers, found usually living in U-shaped burrows in sand or mud in shallow waters; worm like or short and compact with stalk. The body has three parts - proboscis, collar and trunk (protosome, mesosome and metasome). Coelomic pouch is single in proboscis but paired in collar and trunk with buccal diverticulum in posterior part of proboscis. Circulation through dorsal and ventral vessels and dorsal heart; respiration through gill slits; excretion by a single glomerulus connected to blood vessels. Nervous system consists of subepidermal nerve plexus thickened to form dorsal and ventral nerve cord, with connective ring in the collar and the dorsal nerve cord of collar is hollow in some. The phylum Hemichordata consists of two classes: class Enteropneusta and class Pterobranchia.

1.2.1 Class Enteropneusta

Commonly known as acorn worms, these are worm like, sluggish animals that live in burrows or under stones, eg. *Balanoglosus*, *Saccoglossus* (Fig. 1.1) and *Ptychodera*.

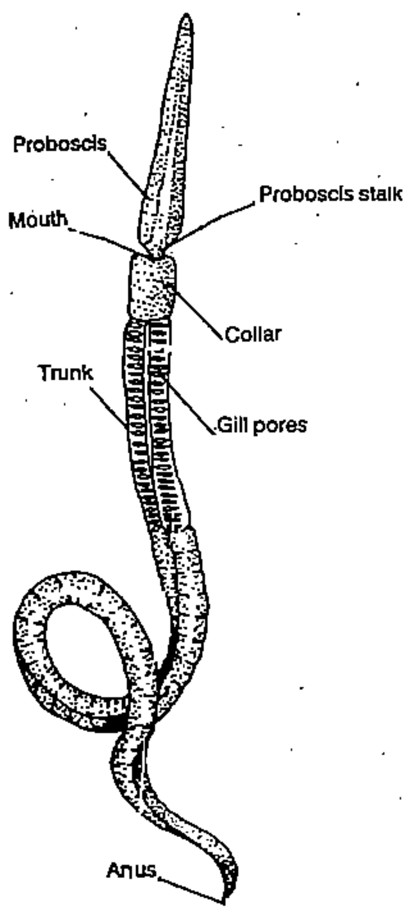


Fig.1.1: External characters of acorn worm *Saccoglossus*.

Body is mucous-covered and divided into a preoral proboscis, a round collar behind the mouth and a long trunk. The proboscis probes its surroundings and collects food in mucous strands on its surface. The food particles are then carried by cilia to the groove at the edge of the collar, directed underside to the mouth and swallowed (Fig.1.2 a). Large particles can be avoided by closing the mouth with the edge of the collar (Fig. 1.2 b). Bottom dwellers use proboscis and collar for building U-shaped mucous-lined burrows.

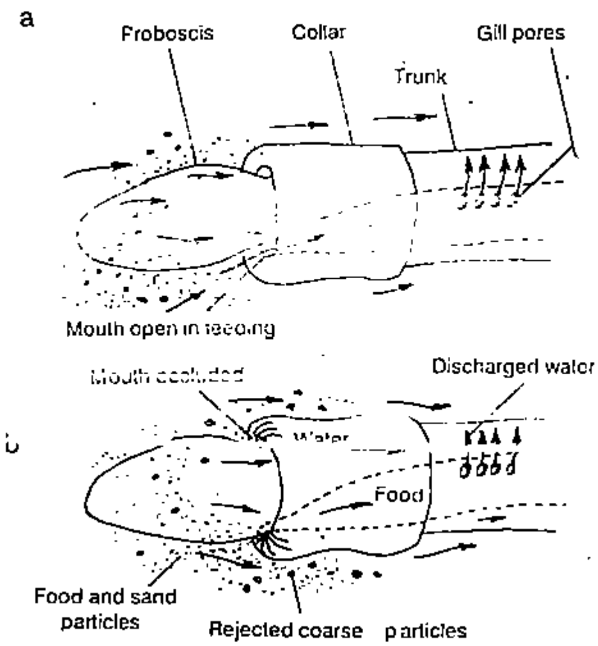


Fig.1.2: Water currents carrying food particles in enteropneust hemichordate. (a) Side view showing the open mouth and direction of currents indicating that food particles are directed towards the mouth and digestive tract. Particles not taken in, move outside the collar and water leave through the gill pores, (b) Mouth is closed and in this state all particles are kept out which pass over the collar.

Buccal diverticulum is a slender blindly ending pouch of gut that reaches into the buccal region. It is this gut part that was formerly considered to be nerve cord.

A small coelomic sac (protocoel) exists at the posterior end of the proboscis into which buccal diverticulum extends. A thin canal connects the protocoel with the proboscis pore and then to the outside. The paired coelomic cavities of the collar also open through pores (Fig.1.3). Water is taken through the pores into the coelomic sacs and the proboscis stiffened in this way is used for burrowing. By contractions of body wall musculature excess water is driven out through the gill slits allowing the animal to move forward, and the food passes into the alimentary canal for digestion.

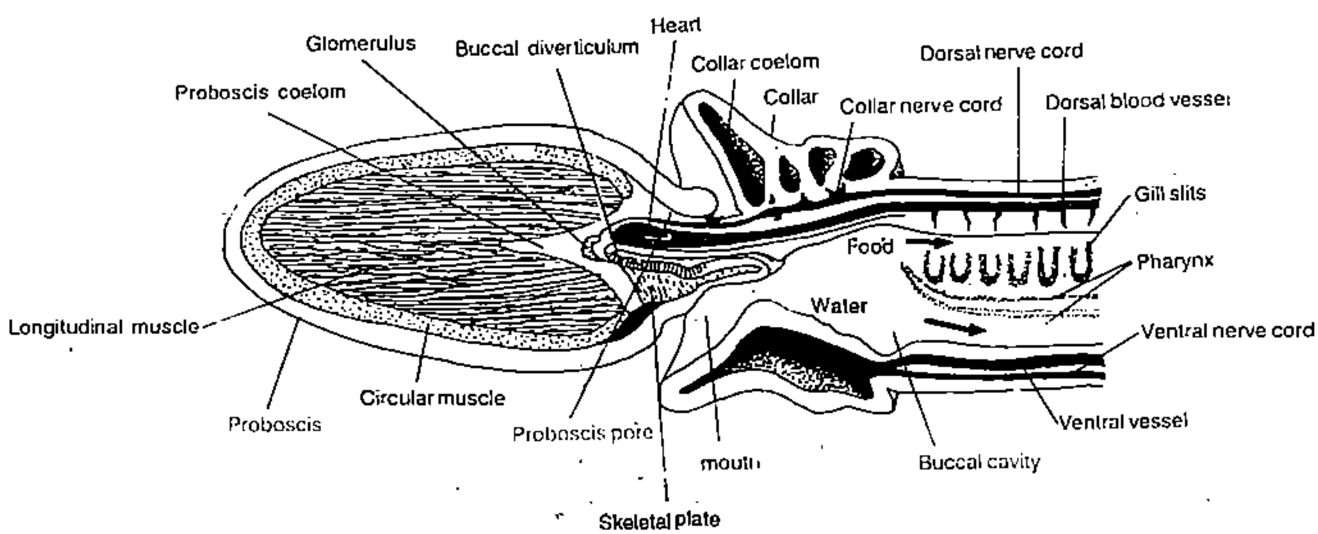


Fig.1.3: Longitudinal section through anterior end of a hemichordate (showing internal structures).

A row of gillpores located dorsolaterally on each side of the trunk open into series of gill chambers that in-turn are connected to a series of gill slits. Gills are absent. Water moves from mouth through the pharynx to the gill slits and branchial chambers and then to out side (Fig.1.2 a). Oxygen is removed from the indrawn water and carbon dioxide released into it. The gaseous exchange occurs in the vascular branchial epithelium and at body surface.

Hemichordates are mainly ciliary-mucous feeders. Pharynx that lies behind the buccal cavity acts as a strainer or filter separating food particles from the water. Food particles trapped in the mucous are brought to the mouth by the ciliary action on the proboscis and collar. The food particles, then strained out of the water that leaves through the gill slits, pass through the ventral part of the pharynx and oesophagus to intestine where digestion and absorption occurs.

Circulatory system is open and consists of a median dorsal vessel above the gut and a median ventral vessel below the gut, both connected by open spaces. The dorsal vessel expands into heart and a group of sinuses above the buccal diverticulum (Fig.1.3). This group of sinuses is called as glomerulus as it is assumed to have an excretory function. The colourless blood flows anteriorly above the gut in the dorsal vessel and then posteriorly through the ventral vessel, passing through the extensive open spaces to the gut and body wall.

Nervous system is subepidermal (intraepidermal) consisting of plexus of nerve cells and fibres that are thickened to form dorsal and ventral nerve cords. Both the cords are connected with a ring posteriorly to the collar. The dorsal cord in some species contains one or two cavities and continues in the collar region giving out many fibres in the proboscis. This feature is suggestive of the dorsal hollow nerve cord of chordates, however the nervous system as a whole is simpler than in most of the chordates. Neurosensory cells that are present throughout the epidermis and photoreceptor cells are the sensory receptors.

Sexes are separate. Gonads are arranged in rows, dorsolaterally on each side of anterior part of the trunk. Fertilization is external in sea-water. In some species there is a free swimming, pelagic and ciliated larva called tornaria (Fig.1.4).

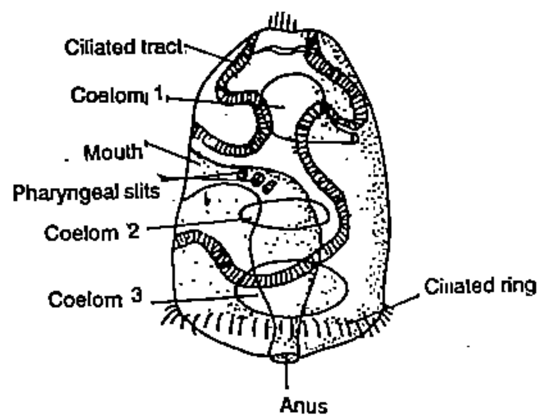


Fig.1.4: Tornaria larva : larval stage of a hemichordate.

1.2.2 Class Pterobranchia

Pterobranchs are sessile, sluggish hemichordates and live in the tube made up of their own secretions. Their size varies from 1 to 7 mm. in length, although the stalk may be longer. The basic plan of class Pterobranchia is similar to that of the Enteropneusta. However, certain structural differences are correlated with the sedentary life style of pterobranchs. Several genera are recognised but details of only two genera *Cephalodiscus* and *Rhabdopleura* are known.

Many individuals of *Cephalodiscus* (Fig.1.5) live together in anastomosing gelatinous tubes, attaching themselves to the walls of the tubes by extensible stalk. The zooids however live independently and can move about their trunk in and out of the tubes. Typical of hemichordates, the body of *Cephalodiscus* consists of three parts — proboscis, collar and trunk. There is only one pair of gill slits. The alimentary canal is U-shaped and the anus is placed near the mouth.

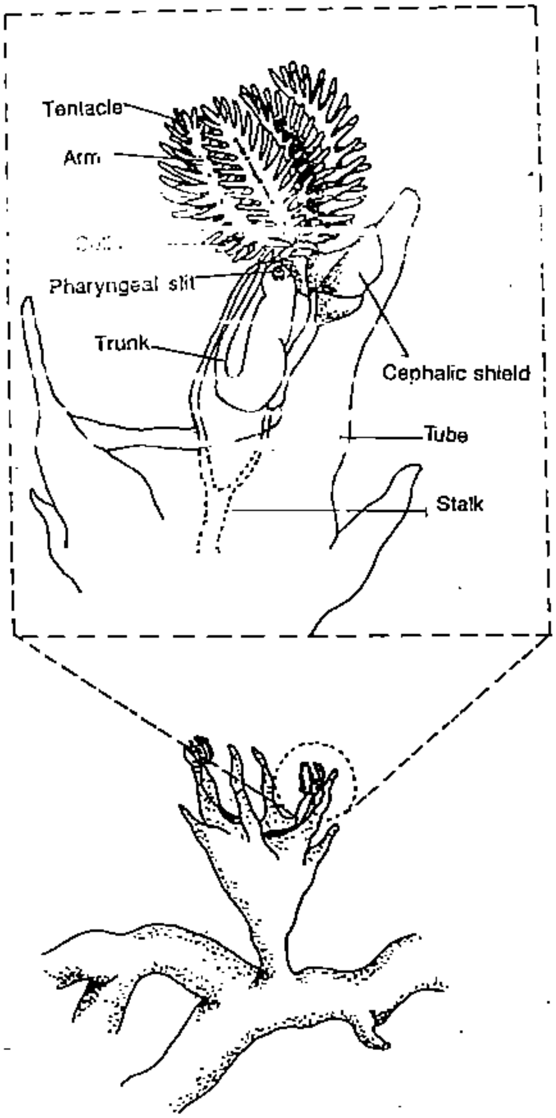


Fig.1.5: Structure of pterobranch hemichordate *Cephalodiscus*, that lives in tubes in which they can move about.

The proboscis is shield shaped. Beneath the proboscis there are five to nine pairs of branched arms with tentacles, containing the coelomic extensions. The animal collects the food with the help of the ciliated grooves present on the arms and tentacles. This whole structure is called lophophore. Sexes are separate in some species, while some are monoecious. Asexual reproduction, wherever occurs is by budding.

The members of *Rhabdopleura* form a colony of zooids that are connected by a basal stolon and enclosed in the tubes (Fig.1.6 a). Collar contains two branching arms (Fig. 1.6 b). Glomeruli and gill clefts are absent. Nervous system is similar to that in Enteropneusta except for the absence of tubular nerve cord in the collar. Asexual reproduction occurs by budding from the creeping stolon.

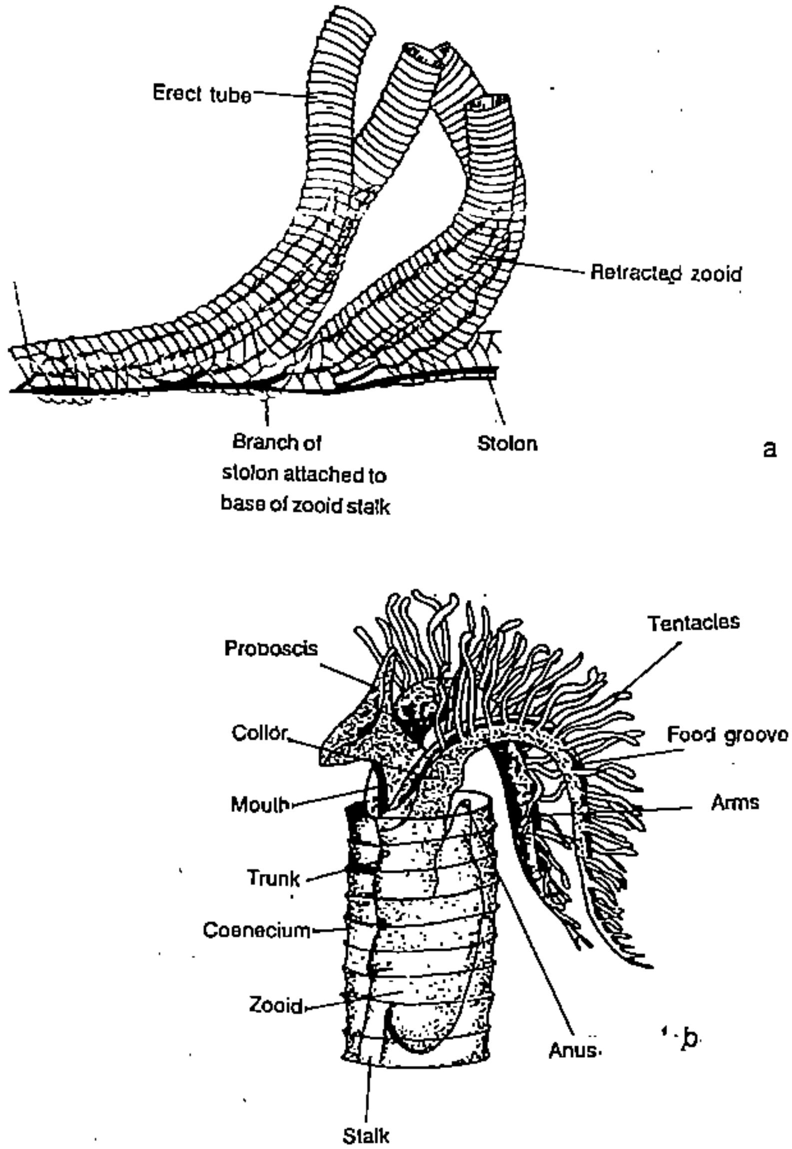


Fig.1.6 : a) Portion of a colony where individuals of pterobranch hemichordate *Rhabdopleura* live in branching tubes connected by stolon; b) structure of *Rhabdopleura*.

SAQ 1

i) List out any three characteristics of Hemichordata.

....

....

....

ii) Write one major difference between Enteropneusta and Pterobranchia.

....

....

....

1.2.3 Basic Adaptive Features

The two major groups of Hemichordata are diverse in their habit. The main adaptive feature in the free swimming form is found in the efficiency of proboscis which also aids

... a way, life in burrows offers safety from predators. The gill slits are primarily used for filter feeding and secondarily for breathing. The colonies of the sessile forms are well protected by chitinous material. The presence of large, branched lophophore bearing ciliated bands in *Cephalodiscus* and *Rhabdopleura* is very well adapted to feeding and thus contributes to the success of the species. The multiple gonads provide reproductive efficiency. In addition., the capacity to regenerate the lost parts contributes to the survival of the race. The free swimming larva during the development enables wider distribution and thus contributes further to the success of the species.

1.2.4 Affinities

Let us now consider the inter-relationships of the hemichordates with other members of the animal kingdom. The systematic position and phylogenetic relationship of hemichordates has been a puzzle among zoologists over decades. Hemichordates show following affinities with different phyla.

Affinities with annelids :

1. Bilateral symmetry.
2. Adults with similar morphology, burrowing and feeding habits.
3. In both digestive tract is straight and tubular.
4. Similar mode of blood circulation.
5. Similarities between the tornaria larva of enteropneusts and the trochophore larva of polychaetes including the apical tuft of cilia, apical sense organs and larval gut.

There are, however, serious objections to relate the hemichordates with annelids such as :

1. Annelids do not possess gill slits.
2. Excretion in annelids is carried out by means of nephridia. On the other hand, glomeruli take up the role of excretion in enteropneusts.
3. The coelom is schizocoelous type in annelids while in hemichordates it is enterocoelous type.
4. In hemichordates the cleavage is holoblastic whereas in annelids it is spiral.
5. Nephridia are present only in the trochophore.

In addition complete absence of branchial respiration and notochord argues against any phylogenetic relationship between hemichordates and annelids.

Relationship with Pogonophora :

Hemichordates and pogonophores (beard worms) have many similar structures - such as, 1) tentacular apparatus; 2) septum, separating the mesosome and metasome; 3) intraepidermal nervous system; 4) pericardial sac; 5) gonads in the trunk.

Inspite of the above similarities there are many structural differences. Pogonophora differ in the following characters: 1) tentacles originate from the protosome and protocoel extends in all tentacles. 2) the main component of the nervous system is located in the protosome. 3) absence of gill slits and digestive tracts; 4) the gonopores are ventral in position.

Because of these differences the two groups are treated as separate and their similarities are due to remote connection with the ancestral stalk.

Relationship with Echinoderms :

Among the invertebrates echinoderms seem to be close to hemichordates. Their affinities are : 1) similar feeding habits; 2) the general plan of sub-epidermal nervous system;

3) enterocoelous origin of coelom i.e., the coelom arises as outpocketings of archenteron of the embryo and formation of the anus from the embryonic blastopore. Thus, there is a marked functional similarity between hydraulically operated water vascular system and proboscis-collar coelom; 4) both the groups show relationship in indeterminate cleavage with equipotential blastomeres; 5) marked similarities between tornaria larva and bipinnaria larva. These include presence of similar ciliary bands, sensory cilia at the apical regions, curved gut with ventral mouth and posterior anus. There are also similarities between the auricularia larva of echinoderms and the tornaria larva of hemichordates (see discussion under ancestry); 6) recent studies on the fossil echinoderms *Stylophora* furnished evidence linking echinoderms with chordates. These small nonsymmetrical forms like *Coteurnocystis* have a head resembling a long toed medieval time boot, a series of branchial slits like the gill openings of shark and a post anal tail resembling a notochord, a dorsal nerve cord and muscle blocks. Whether this evidence would sufficiently justify the concept that the echinoderms are the true ancesters of chordates needs to be further examined.

Apart from the above considerations, it is interesting to note that the energy rich compounds phosphocreatine and phosphoarginine which generally characterise vertebrates and invertebrates respectively, are present in Balanoglossus. This is the basis for some authors to postulate that the hemichordates form a connecting link between invertebrates like echinoderms and vertebrates. Subsequently this view lost its credential when both phosphocreatine and phosphoarginine were found in the muscles of many invertebrate phyla.

SAQ 2

Fill in the blanks with appropriate words.

i. Annelids and hemichordates have ______________ ____________ of circulation.

ii. ____________ ____________ in hemichordates provide reproductive efficiency.

iii. Nephridia are ______________ in hemichordates.

iv. Both hemichordates and pogonophora have intraepidermal_________________.

v. The bipinnaria larva of __________________ are similar to tornaria larva.

1.3 PHYLUM CHORDATA - GENERAL CHARACTERS

Notochord is a rod like flexible structure made up of cells enclosed in a fibrous sheath, located along the mid dorsal line between the gut tract and central nervous system where it forms the axis for muscle attachment. It is a primitive endoskeletal structure that is present in all the chordates during embryonic life. In some of the chordates (most protochordates and primitive vertebrates) the notochord persists through out the life, but in most vertebrates it is entirely displaced by vertebrae. However, the remains of notochord generally persist between or within the vertebrae.

Chordates retain many of the features of inverteberates such as bilateral symmetry, anterioposterior axis, pattern of arrangement of coelom, metamerism, and cephalisation. Despite these similarities it is difficult to establish clearly the relationship of chordates with invertebrates. The following salient features characterise the chordates:

1. Bilateral symmetry, segmented body, well developed coelom and presence of three germ layers namely ectoderm, mesoderm and endoderm.
2. The body differentiated into head, trunk and tail in majority of the forms.
3. In general all organ systems well developed and specialised in their functions.
4. The presence of a notochord (hence the name "chordate") at some stage or throughout life history in the lower forms and well developed vertebral system in higher forms.
5. A dorsal tubular nerve cord distinct from, but lying first dorsal to the notochord, with its anterior end usually differentiated into brain.
6. Pharynx perforated by numerous slits/pouches at some stage or other. These pharyngeal slits may or may not be functional.
7. Complete digestive system.

8. A ventral heart and better developed closed blood vascular system to carry nutrients from the digestive tract to the liver.
9. Presence of tail in the post anal region at some stage. The tail may or may not persist in the adult.
10. Exoskeleton often present but well developed in some members.
11. The endoskeleton either cartilaginous or bony. The endoskeleton in higher chordates consists of axial and appendicular divisions. The endoskeleton provides protection and support and serves as a frame work for the body. For example, the well developed cranium to protect the brain.

Nerve cord in most invertebrate phyla is solid and ventral to the alimentary canal, but in chordates it is tubular and dorsal to the alimentary canal. The anterior end of the nerve cord becomes enlarged to form the brain. It persists throughout the life in almost all the chordates but degenerates before maturity in some lower forms. The nerve cord in chordates is enclosed between the protective neural arches of the vertebrae and the brain is surrounded by bony or cartilaginous cranium.

1.4 HOW CHORDATES DIFFER FROM INVERTEBRATES

There are several striking differences between chordates and invertebrates. Let us compare the organisation of these two groups.

i) Although both groups have dorsal brain, the nerve cord when present is ventral in higher invertebrates and dorsal in chordates.

ii) The heart is dorsal in invertebrates and ventral in chordates. Blood flows in the dorsal blood vessel posteriorly in vertebrates and anteriorly in invertebrates

iii) Some invertebrates possess skeletal structures to protect their internal organs : however they lack a true endoskeleton. In echinoderms beneath the epidermis there is an endoskeleton of small calcareous plates called ossicles that are bound together with connective tissue. The spines and spicules that make up the spiny surface are projected from these ossicles. In chordates, there is a notochord or highly developed vertebral system. It is noteworthy that among the chordates, all vertebrates possess a frame work of bones inside their body. In some vertebrates the endoskeleton is made up of cartilage. The skeletal system of chordates is designed to perform a wider division of labour than that of any invertebrate.

iv) Initially in lower invertebrates there is single opening for mouth as well as anus, for example in Cnidarians. Later the complete digestive system from mouth to anus is developed in higher invertebrates such as in phylum Nemertina, pseudocoelomates, worms etc. Anal opening in invertebrates terminates at the posterior part of the body. In the larval and adult chordates the anus is situated near the tail anterior to the posterior part of the body. In invertebrates, in general, blastopore becomes anus and in vertebrates blastopore becomes mouth.

v) Invertebrates lack pharyngeal gill slits but chordates possess them.

From the above, it is possible to conclude that the chordates can be easily set apart from the invertebrates by several distinctive characteristics. The four chordate hall marks are notochord, dorsal tubular nerve cord, pharyngeal gill slits and post anal tail (Fig. 1.7). Both higher and lower forms display these characteristics at some stage or the other in their life history.

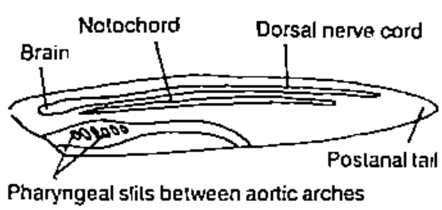


Fig.1.7: Schematic diagram showing four distinctive characters of chordata.

SAQ 3

List out three important differences between chordates and invertebrates.

....

....

....

1.5 CLASSIFICATION OF PHYLUM CHORDATA

The Chordates are divided into the following groups.

Phylum Chordata

Group - 1: Protochordata (Acrania)

Subphylum 1: Urochordata (Tunicata): Tunicates, marine animals, stalked adults, often colonial and ensheathed in the tunic; notochord and nerve cord only in free swimming larva; the larva shows all the chordate characters (Fig.1.8). The three classes that fall under this subphylum are **Ascidiacea, Larvacea** and **Thaliacea.**

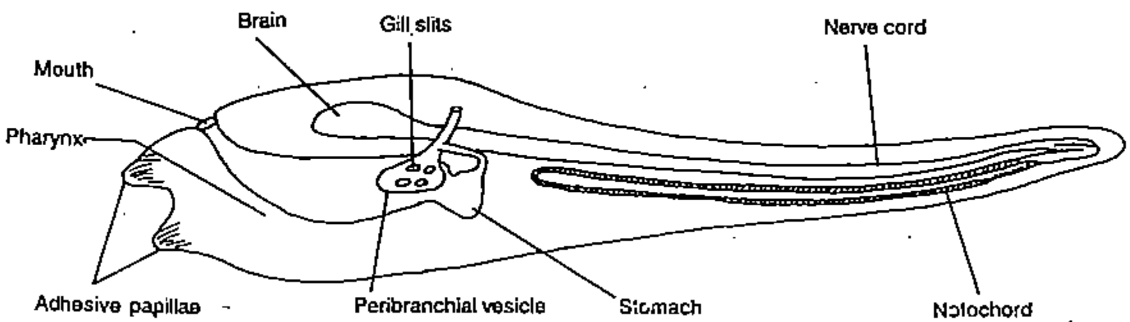


Fig.1.8: Tunicate tadpole larva showing chordate features.

Subphylum 2: Cephalochordata: Popularly known as lancelets (*Amphioxus*) : marine animals; notochord, gill apparatus and nerve cord are well developed in adults; filter feeders; food particles are carried posteriorly to the digestive tract instead of passing through the slits.

Both Urochordates and Cephalochordates are collectively known as **Protochordates.** They lack the cranium and hence they are also called **Acrania.**

Group Craniata

Subphylum: Vertebrata (Craniata) : Include all the chordates with backbone composed of a series of cartilaginous or bony vertebrae surrounding the spinal cord; notochord, dorsal nerve cord, pharyngeal gill pouches and postanal tail present at some stage of life; integument present; coelom well developed and filled with visceral systems; digestive system complete and ventral to spinal column; ventral heart with two to four chambers; closed blood vessel system; excretion by a pair of kidneys; endocrine system present; muscles attached to skeleton for facilitating movement; body consists of head, trunk and postanal tail, neck present in some (Fig 1.9) The group is divided into two superclasses on the basis of the presence of jaws.

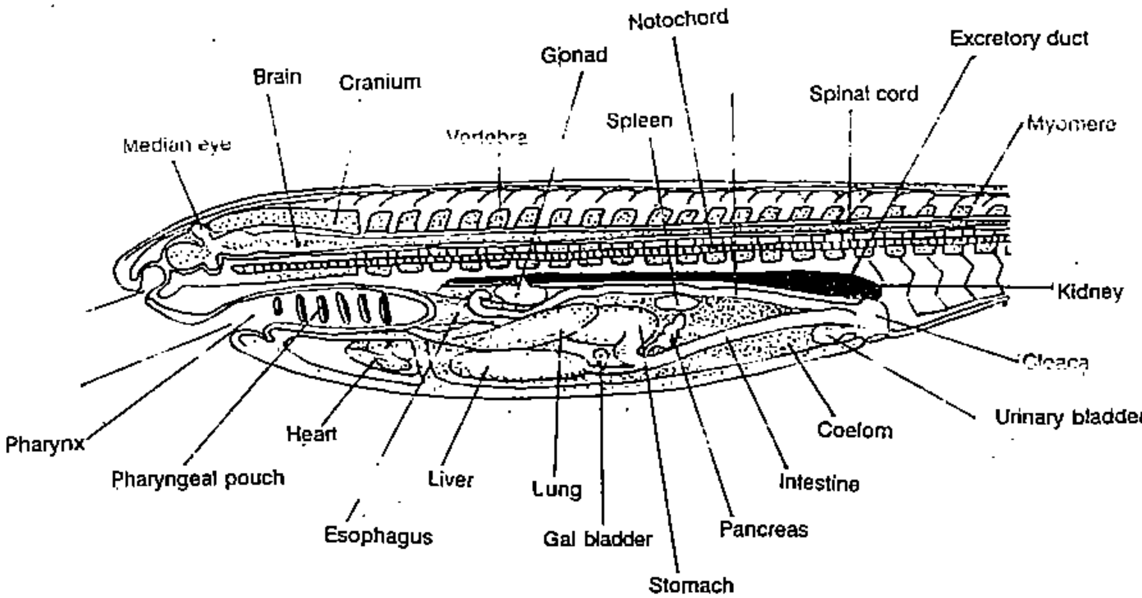


Fig.1.9: A diagrammatic sagittal (median vertical) section of a vertebrate showing the distinctive characters of the subphylum.

Superclass 1: Agnatha (without Jaws) (Cyclostomata): Hagfishes, lampreys. Forms without true jaws or paired appendages. Consists of following two classes.

Class 1: Myxini: Hagfishes. Forms with terminal mouth having four pairs of tentacles; buccal funnel is absent; nasal sac connected to pharynx via a duct; gill pouches about five to fifteen pairs; partially hermaphroditic.

Class 2: Cephalaspidomorphi: Lampreys. Forms with suctorial mouth having horny teeth; mouth not connected to nasal sac; seven pairs of gill pouches

Superclass 2: Gnathostomata: Jawed fishes, all tetrapods. All vertebrates with upper and lower jaws and usually with paired appendages. This group is divided into following classes.

Class 1: Chondrichthyes: Sharks, skates, rays, chimaeras. Body streamlined with heterocercal tail (Fig. 1.10); skeleton entirely cartilagenous; five to seven pairs of gills; gill slits opening directly to the exterior; operculum and swimbladder absent; body covered with placoid scales.

Operculum is a body flap present over the gill outlet which assists in pumping water through the mouth and out from the gills.

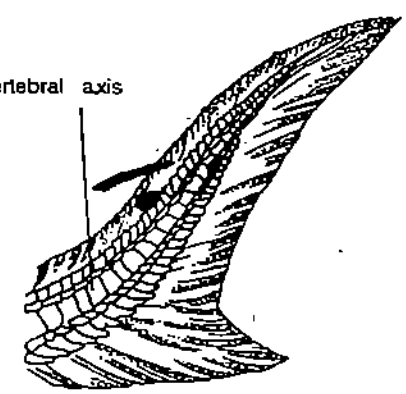


Fig.1.10: Heterocercal tail.

Class 2: Osteichthyes (Teleostomi): Bony fishes. Skeleton mostly ossified (bony); body primitively fusiform; tail outwardly symmetrical or homocercal (Fig.1.11); single gill opening on each side; operculum present; usually swim bladder or lung.

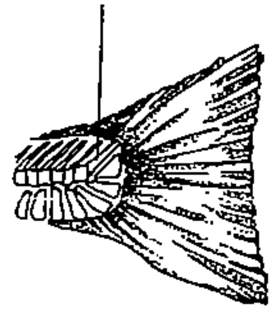


Fig.1.11: Homocercal tail.

Class 3: Amphibia: Amphibians. Ectothermic tetrapods; respiration by lungs, gills or skin; larval stage in the development: skin moist and contains mucous glands; scales absent.

Class 4: Reptilia: Reptiles. Both ectothermic and endothermic tetrapods; pulmonary respiration by lungs; larval stage absent; embryo develops in the shelled egg; dry skin; mucous glands absent; skin covered with epidermal scales.

Tetrapod is the term frequently used for amphibians and other higher four footed animal forms.

Class 5: Aves: Birds. Endothermic vertebrates; body covered with feathers; anterior limbs modified for flight; scales present on feet.

Class 6: Mammalia: Mammals. Endothermic vertebrates; young nourished by mammary glands; body covered with hair; brain well developed; diaphragm separates lungs and pericardium from other viscera.

Amnion is the innermost of the extraembryonic membranes that form fluid-filled sac around the embryo in amniotes

Based on the features of embryonic development, fishes and amphibians are grouped under anamniotes whereas reptiles, birds and mammals are referred to as amniotes. In this unit we will discuss the group Protochordata which comprises of Urochordata and Cephalochordata. About vertebrata you will read more in the following units and blocks. But before that attempt the following SAQ.

SAQ 4

Match the items given in column I with those in column II.

	I		II
a)	Protochordata	i)	Myxini
b)	Vertebrata	ii)	Bony fishes
c)	Agnatha	iii)	Amphibia
d)	Osteichthyes	iv)	Urochordata
e)	Moist skin	v)	Backbone
f)	Endothermic	vi)	Mammals

1.5.1 Subphylum Urochordata

The Urochordata (tail-chordata) comprises about two thousand species of marine chordate animals. Most of them are sessile as adults. The name 'tunicate' is because of the presence of a tough, nonliving tunic or test that surrounds the animal. Tunic is composed of a substance called tunicin which is rather unusual in animals. This is because of the fact that tunicin is very closely related to the cellulose of the plants. In most of the species only the larval form bears all the chordate hall marks. In the adult form the notochord and the tail disappear, whereas the dorsal nerve cord is reduced to a single ganglion. Urochordata are divided into three clases: **Ascidiacea, Larvacea** and **Thaliacea**. These three classes are distinguished based on the number of pharyngeal gill slits, nature of metamorphosis, solitary or colonial habit and organisation of tunic.

Class Ascidiacea: The ascidians include sea squirts and are solitary (eg. Herdmania, Ciona) (Fig.1.12), colonial or compound (eg. Botryllus).

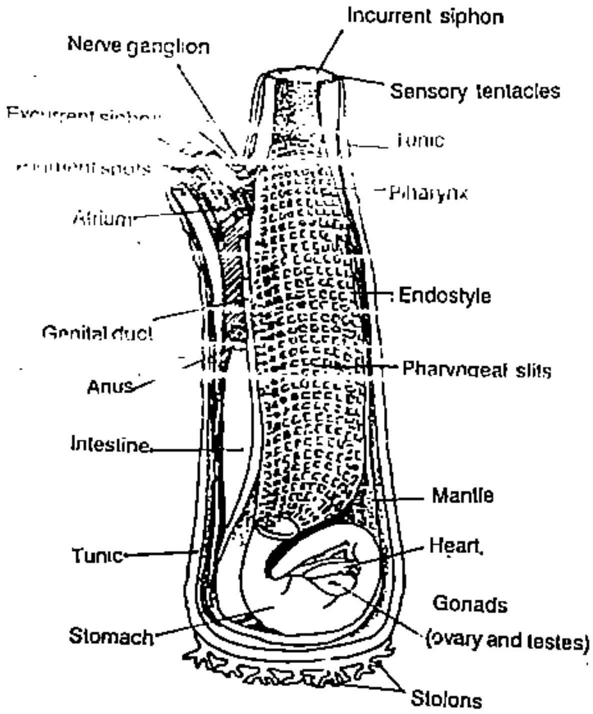


Fig.1.12: Structure of an adult ascidian: *Ciona* species.

The general form is like a vase with a vertical tube, with a terminal growth or branchial opening at its apex and a lateral tube leading to an opening called atrial opening. Water enters at the branchial opening (incurrent siphon or mouth), circulates over the gill basket inside and is ejected through the atrial opening (excurrent siphon). Gill basket is the spacious ciliated pharynx that is minutely subdivided by gill to form an elaborate basket work. During this water circuit, oxygen and food particles are removed from the water and the waste is carried out through the atrial opening. One of the special features of ascidian is the presence of endostyle (a ciliated, glandular groove of the pharynx) on the floor of branchial chamber. This structure secretes mucous in which food particles are trapped. Interestingly, the cilia lining the endostyle pass the mucous upward and over the midline of the pharynx where it is rolled into a mucous rope by a row of tentacles and the rope is then passed to the oesophagus, thence to the stomach and intestine. Nutrients are absorbed in the midgut. Faecal pellets are discharged outside through the anus located near the excurrent siphon. Some believe that the endostyle is the fore-runner of thyroid gland.

Nervous system consists of a nerve ganglion and a plexus of nerves that lie on the dorsal side of the pharynx. Beneath the nerve ganglion is the neural gland containing gonadotropic substances, believed to be analogous to the vertebrate pituitary. One of the striking features of Urochordates is that the tubular heart has pace makers at both the ends which periodically reverse the flow of the blood. Two large vessels on either side of the heart connect to the diffused system of small vessels and spaces that serve to various organs. Sea Squirts are hermophrodites and fertilization is internal. Some are oviparous, others viviparous but in forms like Clavelina there is a tadpole like larva. The larva is free swimming and does not feed. After some hours the larva fastens itself vertically with the help of adhesive papillae and undergoes metamorphosis to become the sessile adult (Fig.1.13)

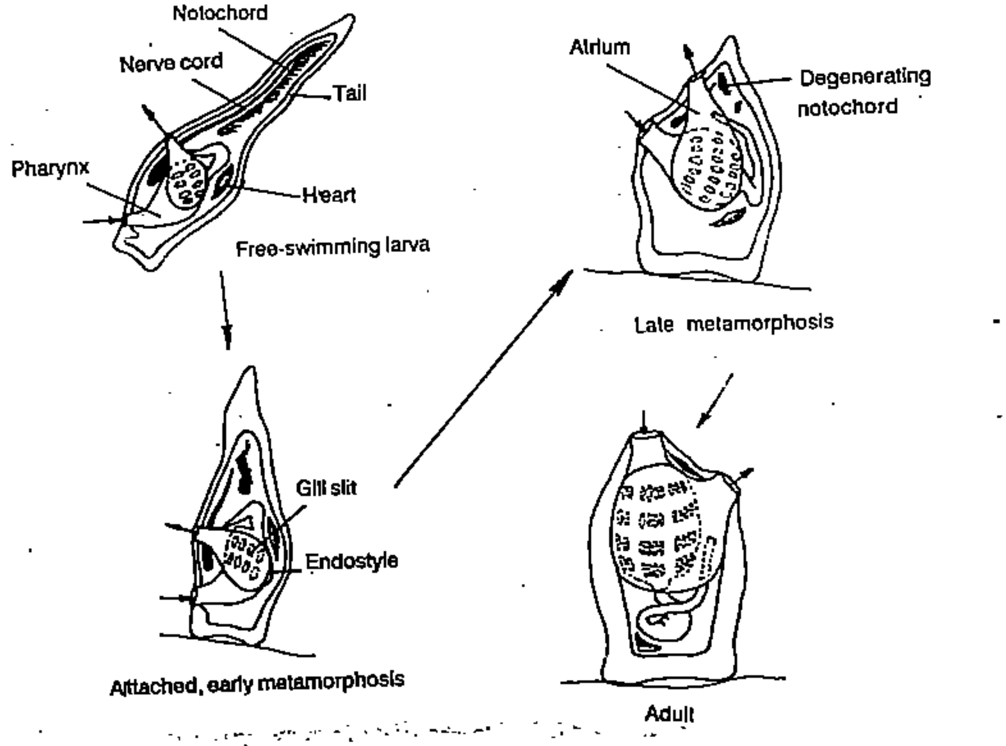


Fig.1.13: Metamorphosis of ascidian larva from a free swimming tadpole larva stage to an adult.

Class Thaliacea: The thaliaceans are barrel-shaped pelagic forms with gelatinous and transparent bodies that are almost invisible in sunlit surface waters. Their body is typically surrounded by bands of circular muscles. The incurrent and excurrent siphons are at opposite ends. The muscular contraction helps the water to pump through the body which is used for locomotion, respiration and a source of food that is filtered out on mucous surfaces. Many species of Thaliacea are luminescent. Some members like *Doliolum* (Fig.1.14) and *Salpa* exhibit alternation of sexual and asexual generation.

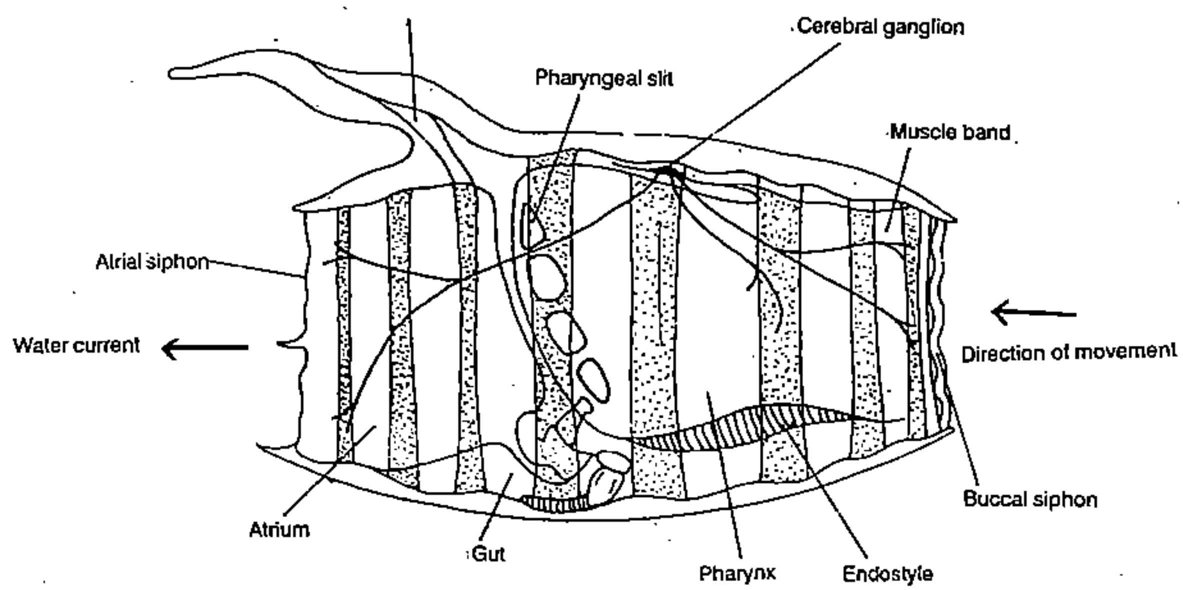


Fig.1.14: The solitary thaliacean *Doliolum*.

Class Larvacea: The larvaceans are pelagic and shaped like a bent tadpole. The test in larvacean is not composed of tunicin. They exhibit an interesting method of feeding. The individual animal builds a house that is a delicate, transparent hollow sphere of mucous interlaced with filters and passages through which the water enters (Fig.1.15). Food particles that are trapped on the feeding filter inside the house is drawn into the animal's mouth through - a straw like tube. After about every four hours, when the filter becomes clogged with waste, the animal abandons its house and builds a new one within a few minutes. The animals are neotenous that is the sexually mature animals have retained the larval body form eg. *Appendicularia, Oikopleura.*

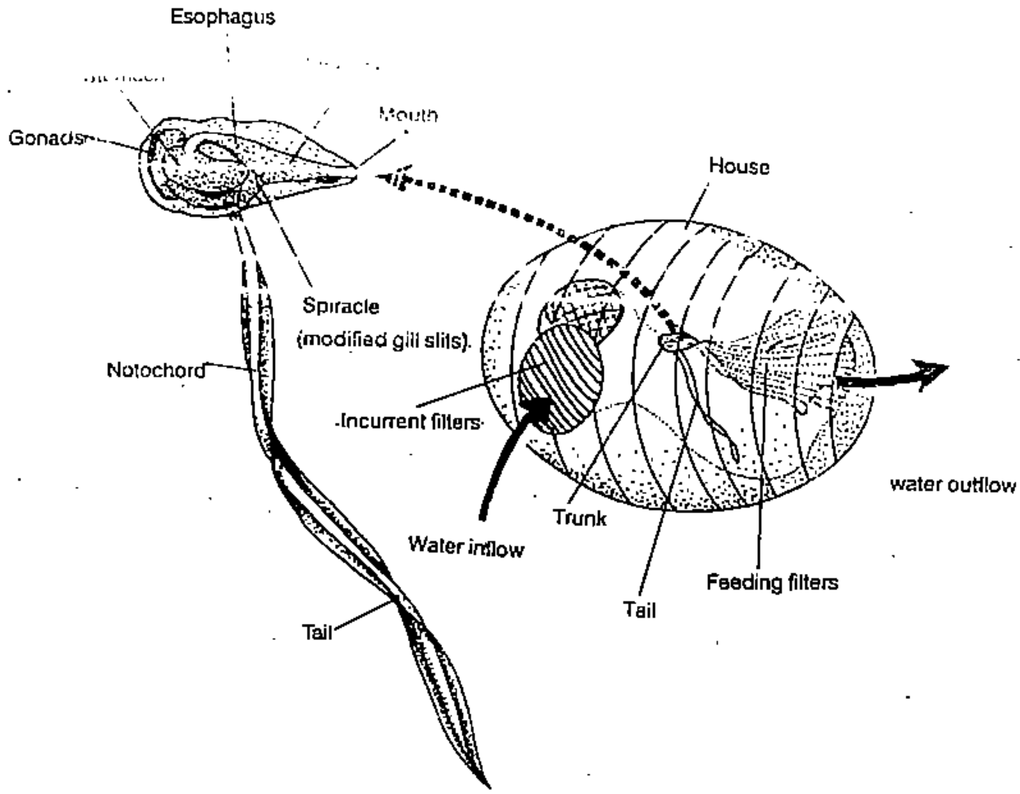


Fig.1.15: An adult larvacean (left) shown in its transparent house (right).

1.5.2 Subphylum Cephalochordata

Cephalochordates are also called as lancelets (Branchiostoma) - *Amphioxus* is the sole representative of the subphylum Cephalochordata. These are slender, laterally compressed and translucent animals about 5 to 7 cm. in length (Fig.1.16).

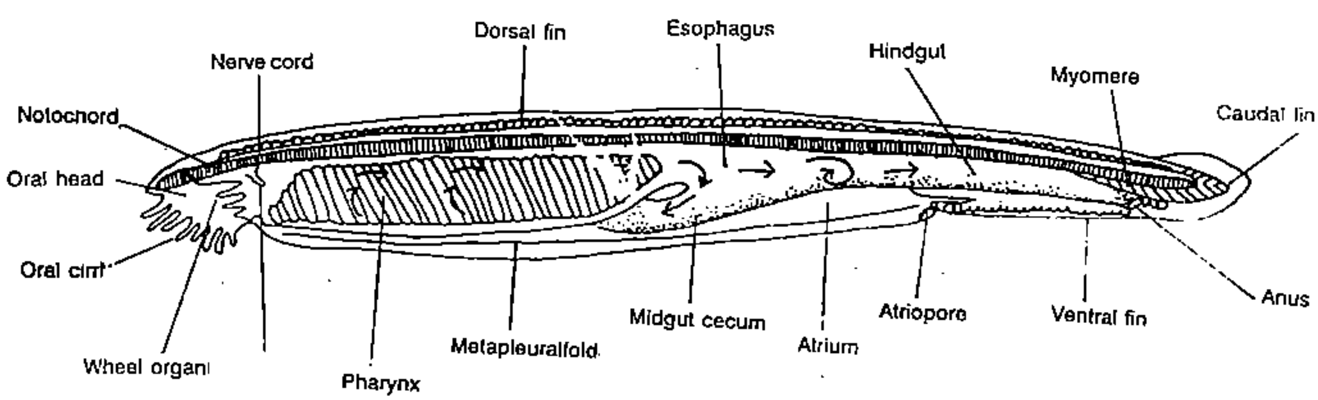


Fig.1.16: External features of *Amphioxus*.

There are about two dozen species of this genus found distributed all over the world. A striking feature of the surface of the body is the presence of V-shaped myotomes or muscle segments visible externally. It burrows in sand and spends most of its time buried tail down in sand with only its head including the mouth exposed above the surface. During breeding season it usually comes out of sand at night and swims about here and there. It feeds upon organic particles and small plankton which are brought to the mouth by the inhalant current of water. During feeding, the cilia lining the oral funnel create an inhalant current. Water is then drawn into the mouth through a membranous velum which bears twelve short tentacles. The current of water passes into a large branchial chamber formed by the pharynx, closely comparable to that of Urochordates. The branchial chamber bears gill slits (Fig.1.17), used for breathing.

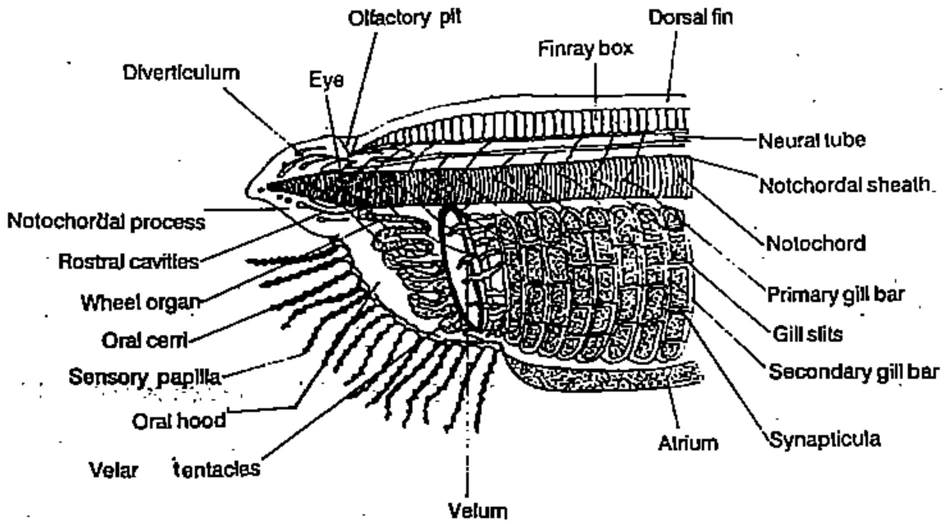


Fig. 1.17: Anterior part of *Amphioxus*.

The cilia lining the gill slits allow water to enter into a groove on the floor of the branchial chamber known as endostyle The food particles present in the water are trapped by the mucous secreted in the endostyle. The mucous then travels through two ciliated grooves to the dorsal side of the pharynx to enter into the intestine. Here the smallest food particles are separated from the mucous and passed into hepatic caecum, where these particles are phagocytized and digested intracellularly. The filtered water then passes into atrium and leaves the body by an atriopore similar to the excurrent siphon of tunicates. Circulatory system is closed and blood flow pattern is similar to that of primitive fishes, although there is no heart. Blood is pumped forward in ventral aorta, then passed upward through branchial arteries (aortic arches) in the gill bars and then to dorsal aortae which terminate into a single dorsal aorta. The blood is then served to the body tissues, collected in the veins which return it to ventral aorta. The blood is devoid of erythrocytes and hemoglobin.

Nervous system consists the nerve cord lying above the notochord. Brain is a simple vesicle at the anterior end of the nerve cord. Pairs of spinal nerve roots emerge at each myometric (muscle) segment of the trunk. Sense organs are the unpaired bipolar receptors present in the various parts of the body. Excretion is by means of nephridia — a feature not usual in chordates. In the lancelets the sexes are separate. Eggs and sperms pass to the exterior through the atriopore. Fertilisation is external and takes place in water during late spring or early summer.

SAQ 5

i. Explain the mode of feeding adopted by a larvacean.

....

....

....

....

....

ii. Fill in the blanks with appropriate words.

a) The tough nonliving covering of urochordates is called ....

b) The three classes of Urochordata are ....,..............., and ....

c) In ascidians the food particles are trapped in the .... secreted by ....

d) .... spends most of the time burried tail down in the sand.

e) Excretion is by means of .... in *Branchiostoma*.

f) In lancelets .... are separate and .... is external.

g) Digestion is .... in *Branchiostoma*.

1.5.3 Basic Adaptive Features

Urochordates also present a few important adaptations which contributed to the success of the group. The efficient ciliary mode of feeding compensates very well the disadvantage of sedentary life. Some species have developed the habit of growing as commensals on gastropods and thus they have found a way for wider distribution. Other features which confer upon urochordates, the "adaptive advantage", are large perforated pharynx with its efficient gaseous exchange and a thick leathery protective test to keep away the predators. The tadpole of Herdmania has developed several adaptive features such as streamlined body, tail supported by turgid notochord for locomotion, otoliths for maintaining equilibrium and adhesive papillae for attachment to the substratum.

The cephalochordates are adapted to their surroundings in an excellent manner. Various adaptations encountered in this group can be arranged into following categories. They are: 1) adaptations for swimming; these include the development of streamlined body, turgid notochord and expanded caudal fin in the adult. 2) ciliary mode of feeding adaptations well suited for sedentary life. 3) adaptations which conferred survival value and thereby achieved success are a) life in burrows ensured safety from the predators, b) the multiple gonads that provide means by which large number of gametes are formed and thus increase chances of fertilization. c) large and voluminous pharynx for efficient exchange of gases and d) the free swimming larva for distribution to different ecological niches.

1.5.4 Affinities

Let us now focus our attention to the affinities of urochordates and cephalochordates. The urochordates and cephalochordates show many points of resemblances. They are: 1) ciliary mode of feeding; 2) presence of atrium and endostyle, 3) pharynx perforated with numerous gill slits; 4) similar origin of notochord and neural tube.

But there are also some dissimilarities between the two groups which make it difficult to draw affinities between them. Urochordates differ from cephalochordates in the following respects: 1) the body wall containing tunicin; 2) presence of pericardium; 3) 'U' shaped alimentary canal; 4) absence of nephridia; 5) loss of chordate characters in the adult.

Urochordates show resemblances to the invertebrates like molluscs such as 1) presence of cartilage; 2) presence of chitin, this substance is also present in cephalochordates showing affinity between them; 3) presence of pericardium and pancreatic tissue; 4) ammonia as excretory product. However, tunicate tadpole larva presents several chordate features like notochord, median eye, well developed pharynx with endostyle, and a tail with expanded dorsal and ventral fins.

There are some striking resemblances between cephalochordates and echinoderms also. These are 1) enterococlous coelom, and 2) symmetrical features in anatomy. However, the affinities with invertebrates are of minor importance. *Amphioxus* is rather peculiar showing several chordate features and specialised characters.

SAQ 6

Match the items given in column I with that of column II.

	I		II
i.	Adhesive papillae	a)	Formation of large number of gametes.
ii.	Multiple gonads	b)	Urochordates and cephalochordates
iii.	Presence of atrium	c)	Tail supported by turgid notochord
iv.	Locomotion	d)	Herdmania Larva
v.	U-shaped alimentary canal	e)	Present in Urochordates

1.6 ANCESTRY AND EVOLUTIONARY TRENDS

When we try to trace the ancestry and evolutionary trends among animals, it is important to analyse once again the organisation and general plan of development common to all the groups. There is sufficient basis for comparison between echinoderms, hemichordates, protochordates and chordates. In all, the blastopore becomes anus and mouth is entirely a new opening. Hence these animals are grouped under deuterostomia (Greek *deuteros*, "second" or "later" and *stoma*, "mouth"); (second mouth). This is in marked contrast to other non-vertebrates where the blastopore forms the mouth (protostomia: primitive mouth) (Greek *protos*, "first" and *stoma*, "mouth").

Protostomes, literally meaning 'first mouth' are animals in which the mouth arises from or near the blastopore. Additionally, they tend to have spiral cleavage, a schizocoelom and a skeleton derived from the surface layer of cells. Deuterostomes, literally meaning "second mouth" are animals in which the mouth arises not from the blastopore but secondarily at the opposite end of the gut. Additionally, embryonic development of deutrostomes includes radial cleavage, an enterocoelom and a calcified skeleton, when present, derived generally from ectodermal tissues.

The origin and ancestry of chordates is not clearly established. There are several view points but they are all largely speculative. It is not certain as yet whether the end products are neotenous, free swimming derivatives of formerly sessile animals or have continuously evolved as active, free swimming animals. We have known earlier that chordates generally resemble echinoderms and their allies. However, there are also certain specialization in echinoderms such as radial symmetry, water vascular system and nerve ring to rule out the possibility that echinoderms are the ancestors of chordates. A similar view is also applicable to hemichordates. Even though hemichordates are placed close to chordates, the proboscis, collar, nature of circulatory system are features which set them completely apart from the higher chordates.

Let us now examine whether or not it is possible to consider primitive urochordates as chordate ancestor. Adults of urochordates are highly specialised : they have lost notochord, nerve cord and coelom and retain non-chordate characterstics, like tunic, atrium and siphon. Thus, these animals hardly fit into vertebrates plan. Tunicates, however, show us a stage in which branchial feeding has fully replaced tentacle feeding in a sessile adult. But they have a fishlike tadpole larva. Perhaps it would be worthwhile to trace vertebrate ancestry based on larval structure of ascidians.

The auricularia theory of Garstang (1894) explains how ascidian tadpole has arisen from auricularia larva. According to this theory the ciliated auricularia larva is evolved into a fish like creature in progressive stages, while the adults, at first sedentary, substituted gill slits and endostyle for the original lophophore. This view seems to be reasonably convincing. The theory enables one to reconstruct the course of events that led the lophophore feeder in streams and in doing so they faced, the drastic physical forces of water currents. In order to overcome the force of water currents flowing towards the sea, expectedly the larvae had to equip themselves with powerful locomotory and sensory systems. In addition necessary modifications would occur in kidney to suit the fresh water life. Around palaeozoic era some selected groups of animals exploited ecological niches of freshwater and among these are the provertebrates and arthropods. Garstang's theory further envisages that *Amphioxus* must have been the early protovertebrate and this returned (migrated) to sea for breeding purpose; and then readopted to filter feeding for marine existence. This theory is supported by authorities like N. Berill and A.S. Romer.

Amphioxus reveals several basic features of chordates, such as the presence of notochord, dorsal tubular nerve cord and pharyngeal gill slits in its organisation (Fig. 1.18). In addition, it shows secondary characteristics like the postanal tail, liver, diverticulum, hepatic portal system and the beginning of a ventral heart. The muscular layer in *Amphioxus* is thickened in the dorsal side as in vertebrates. The metameric condition of muscles bears resemblances to a similar plan in vertebrate embryos. However, some authorities like Hickman (1966) have pointed out that it is close to the primitive fish, Ostracoderm, though it is difficult to settle whether to place it before or after Ostracoderms. Besides, there are also reasons to develop pharynx with gill slits and its larva to have muscles, nerve cord and a nerve tube (Fig.1.19). Thus, the tunicate tadpole larva could be easily derived from an echinoderm larva. The most pertinent question is how vertebrates have eliminated the sea-squirt stage from their life history. According to Haeckel's concept of recapitulation, adult stages of ancestors are repeated during development of their descendents. But this view cannot be accepted as such since there is no sea-squirt stage in the development of any vertebrate. Some believe that the adult ascidians are regarded as degenerate sessile descendants of the ancient chordate form, whereas the ascidian tadpole is considered as relic of an ancient free-swimming chordate ancestor of the ascidians.

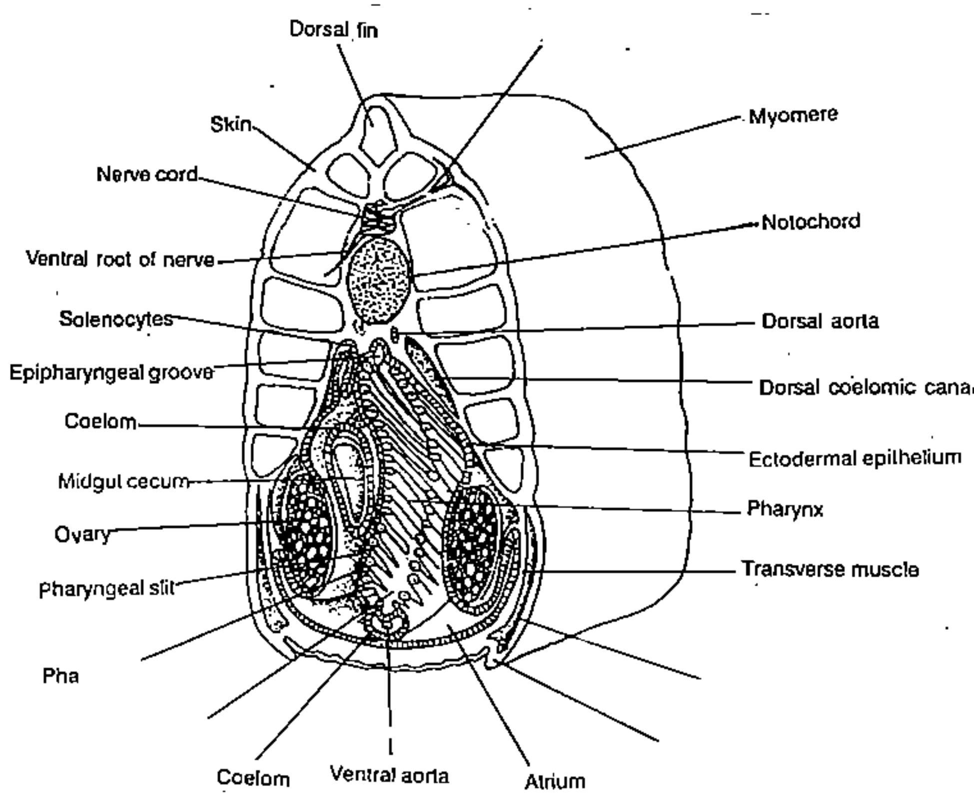


Fig.1.18: Cross section of *Amphioxus* showing chordate features.

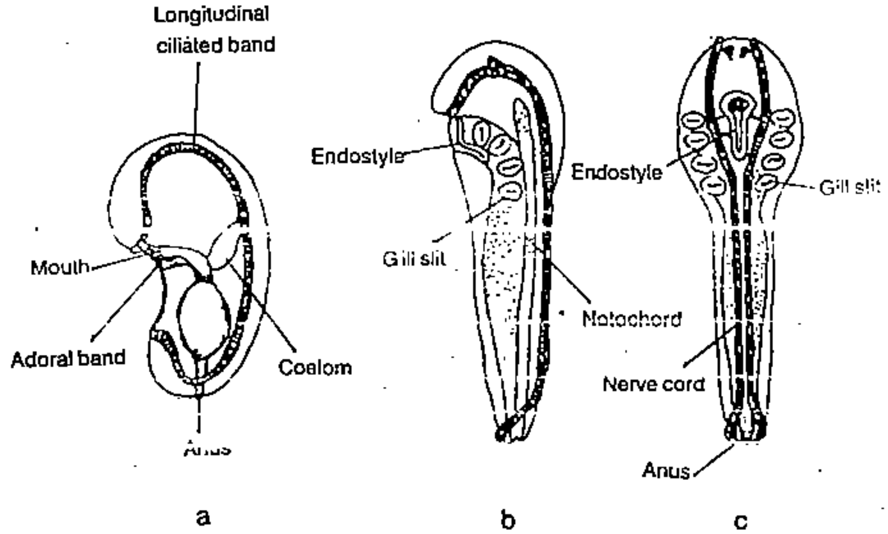


Fig.1.19: Derivation of protochordate (b-lateral view, c-frontal view) from auricularia(a)

Study of ascidian tadpole larva of urochordates further led to many speculations regarding the origin of chordates. According to the ascidian theory of chordates advanced by Garstang (1928) all ancestral chordates were marine, sessile and filter feeders. The ascidians themselves may have taken their origin from sessile hemichordates. Ascidian tadpole with its basic vertebrate organisation then evolved from the sessile form. The larva is pelagic, freeswimming and feeds upon the plankton of the oceanic waters. Soon after freeswimming life, the larva attaches to substratum, undergoes regressive metamorphosis and transforms into a sessile adult form (Fig.1.13). It is believed that some of these larvae, instead of undergoing metamorphosis become sexually mature (neoteny) and enter estuaries and rivers where they can feed upon the organic detritus. Class larvacea of tunicates belongs to this stage of evolution, Firstly, the over development of the notochord is regarded by some as an adaptation to burrowing habit. Secondly, presence of solenocyte type of protonephridia recalls primitive condition seen in polychaetes, and therefore do not bear any resemblances to glomerular-tubular nephron of vertebrates. Colbert, however, emphasises that *Amphioxus* is still the logical structural ancestor of vertebrates overruling the objections of others regarding the specialization of this form.

By and large the widely accepted view is that vertebrates are more closely related to cephalochordates than to urochordates and that the phylum Chordata is close to Hemichordata and Echinodermata. However, no known echinoderm, hemichordate, urochordate and even cephalochordate is in the main line of chordate evolution. Infact, it is difficult to pinpoint that the chordates have evolved from any known animal living or extinct. Some authors believe that the cephalochordates forms a specialized offshoot from a vertebrate ancestor. Even this view could not gain acceptance, since at no time any member of this group ever possessed cranium and features like brain and eyes.

Current view is that echinoderms, hemichordates and chordates must have diverged from a common lineage around 500 million years ago, A possible phylogenetic line suggested the relationships of the hypothetical ancestor, various groups of protochordates and vertebrates is shown in Fig.1.20.

Vertebrate **Ostracoderm**

Urochordate **Cephalochordate**

Free swimming
Larval Ancestor

Hemichrodate
Echinoderm

Primitive Sessile Filter Feeder

Larval Deuterstome Ancestor

Fig.1.20 : A possible scheme of the phylogency of chordates.

The echinoderms are linked to protochordates by similarity of the echinoderm auriculária to tornaria, of protochordate groups. Further, the palaeontological evidence, as discussed earlier, strengthens the view that both the groups are closely related. These considerations with regard to echinoderm line of phylogeny of chordates are based upon morphological, anatomical, embryological and palaentological evidences. Authors like Geoffrey (1930) in the past and more recently Siliman (1960) have pinpointed several striking similarities between molluscs and chordates. It is rather surprising that the relationship of the chordates with molluscs has not attracted the attention of phylogeneticists, although they resemble each other in several biochemical, physiological and histological characteristics. There are several characters studied by many authors and some of them are listed in Table-1.1

Table 1.1 : The biochemical, physiological and histological characters that were used to compare molluscs, echinoderms and vertebrates (chordates).

Biochemical	Physiological	Histological
Glycosaminoglycans	Respiration	Cartilage
Sialic acid	Circulation	Skeleton
Collagen	Food & digestion	Heart
Epidermal Proteins	Osmoregulation	Blood
Chitin	Nitrogen excretion	Pericardium
Phosphogens	Photoreception	Liver & Pancreas

The criterion that has been adopted in the selection of characters from these is that their presence or absence must be established in all the three main groups namely the echinoderms, molluscs and vertebrates (chordates). The main objective of the study is to determine the degree of closeness between molluscs, echinoderms and vertebrates, based upon the number of above mentioned characteristics. Lovtrup's (1977) phylogeny relies on the above mentioned characters because he considered them more evolutionary stable than morphological characters. For example, any two groups that shared more biological chemicals as compared to others were more closely related.

We finally conclude that the ancestry of chordates is an unsettled issue and any attempt to trace their phylogeny is beset with difficulties. Both the echinoderm and molluscan line of chordate ancestry can be either accepted or rejected.

SAQ 7

Explain the auricularia theory of Garstang. How it is different from his ascidian theory?

....

....

....

....

....

....

....

....

....

1.7 SUMMARY

In this unit you have learnt that:

- Hemichordates are the group of animals that are characterised by the presence of chordate features i.e. gill slits and rudimentary notochord. However, the hemichordate notochord is in reality the buccal diverticulum and not the true notochord. It is for this reason hemichordates are now considered as a separate phylum.

- The four chordate hall marks are the presence of notochord, dorsal tubular nerve cord, pharyngeal gill slits and post anal tail. Hence they are so very different from invertebrates.
- The members of the phylum chordata are diverse in their habit and organisation.
- Among the invertebrates, echinoderms are close to hemichordates. However, both the groups have their own specialisation.
- There is no known echinoderm, hemichordate, urochordate and even cephalochordate, either living or dead, in the main line of chordate evolution
- Evidences based upon biochemical, physiological and histological characteristics suggest that the chordates (vertebrates) stem from molluscan lineage but not echinoderm lineage. The available data on the ancestry of chordates is conflicting and the issue is unsettled.

1.8 TERMINAL QUESTIONS

1. What are the four hall marks of chordates?

....

....

....

2. Give atleast three basic adaptive features of hemichordates and urochordates.

....

....

....

3. Describe the mode of feeding in *Branchiostoma.*

....

....

....

4. Explain briefly how cephalochordates have adapted to their surroundings.

....

....

....

....

5. Mention atleast four important affinities between echinoderms and chordates.

....

....

....

....

....

6. Describe any fossil echinoderm that is believed to be close to chordates.

....

....

....

....

7. What are the specialisations in the anatomy of adult urochordates?

....

....

....

8. What are the lines of evidence to support the molluscan lineage of chordates?

....

....

9. What is the current view of the ancestry and evolution of chordates?

....

....

....

....

....

1.9 ANSWERS

Self Assessment Questions

1. i) 1. Body divided into three parts Proboscis, Collar and Trunk.
   2. Gill slits present.
   3. Dorsal nerve cord present. You can write about other characteristics of hemichordates from Section 1.2.

   ii) Pterobranchs live in the gelatinous tube secreted by them whereas enteropneusts live in burrows. You can read about the other differences from sections 1.2.1 & 1.2.2.

2. i) similar mode
   ii) multiple gonads
   iii) absent
   iv) nervous system
   v) echinoderms.

3. i) Nerve cord is ventral in higher invertebrates and dorsal in chordates.
   ii) Pharyngeal gill slits are present in chordates but absent in invertebrates.
   iii) Heart is ventral in chordates and dorsal in invertebrates.

4. a. iv
   b. v
   c. i
   d. ii
   e. iii
   f. vi.

5. i. The food particles coming along with water are trapped on the feeding filter in the house. The filtered food is then drawn into the animal's mouth through a straw like tube. After about four hours when filter is clogged with waste, the animal leaves the house and builds a new one.

   ii. a. tunic
   b. Ascidiacea, Larvacea, Thaliacea
   c. mucous, endostyle

d. *Amphioxus*
e. nephridia
f. sexes, fertilization
g. intracellular

6. i. d
   ii. a
   iii. b
   iv. c
   v. e

7. The auricularia theory of Garstang (1894) explains how ascidian tadpole has arisen from the auricularia larva. According to this theory the ciliated auricularia larva is converted into fish like creature in progressive stages while the adults, at first sedentary, substituted gill slits and endostyle for the original lopohore. It is expected that larvae have to equip themselves with powerful locomotory system. Garstang's theory further envisages that *Amphioxus* must have been early protovertebrates.

   According to ascidian theory of origin of chordates by Garstang (1928) all ancestral chordates were marine, sessile and filter feeders. The ascidians themselves may have taken their origin from sessile hemichordates. With ascidian tadpole it is believed that some of the larvae, instead of undergoing metamorphosis become sexually mature and entered the estuaries. The class Larvacea of tunicates belongs to this stage of evolution.

Terminal Questions

1. The four distinctive characters of chordates are the presence of notochord, dorsal tubular nerve cord, pharyngeal gill slits and post anal tail.

2. In hemichordata, the efficient proboscis which aids in burrowing, the protection offered by the chitinous material present in the skin and the regenerative capacity of the individuals in the colony are the basic adaptive features which contributed to the success of the group.

   The chief orienting factors which contributed to the success of Urochordates are: 1) The efficient and complex ciliary mode of feeding; 2) Large perforated pharynx; and 3) The active freeswimming tadpole larva.

3. The ciliary mode of feeding in *Branchiostoma* is unique. The cilia of the oral funnel, velum and velar tentacles and the pharynx participate in feeding. The cilia and tentacles set up water current which enters through oral funnel into the pharynx. The gill slits of the pharynx are employed for breathing. The cilia of the gill slits allow the water to enter into the floor of the branchial chamber. The food particles in the water are trapped by the mucous secreted by the endostyle and the food collected in the mucous is then pushed into the intestine for digestion and assimilation.

4. The cephalochordates are adapted to their surroundings in an excellent manner. Some noteworthy adaptations are : 1) Ciliary mode of feeding to suit sedentary life; 2) Streamlined body supported by notochord and expanded fins to aid in swimming; 3) The pharynx which takes up dual function namely respiration and feeding; and 4) The presence of multiple gonads to produce large number of gametes.

5. Echinoderms are close to the chordates. The following are the four important resemblances: 1) Enterocoelous origin of coelom; 2) Indeterminate cleavage with deuterostomes development; 3) Similarities between auricularia and tornaria; 4) Fossil echinoderms like Coteuronocystis with chordate features.

6. A fossil echinoderm of the Ordovician period (450 million years) belonging to the group Stylophora, namely *Coteuronocystis* has been reported recently from Scotland. It is a small non-symmetrical form with a head resembling a long toed medieval boot, a series of branchial slits like the gill openings of shark, a post anal tail with a notochord and nerve cord like structures. All these features bear superficial resemblance to chordates.

7. The main specialisations in the adult urochordates include the loss of chordate features such as notochord, nerve cord, coelom and the retention of non-chordate characteristics like atrium and siphon.

8. The biochemical, physiological and histological lines of evidence support the molluscan lineage of chordates.

9. The origin of chordates is an unsettled issue. The morphological, embryological and palaeontological evidences support the echinoderm ancestry. Equally impressive is the molluscan lineage based on biochemical, physiological and histological evidences.

UNIT 2 AGNATHA, FISHES AND AMPHIBIA

Structure

2.1 INTRODUCTION

In the last unit you were introduced to phylum Chordata. You learnt about the salient features of the phylum and the classes included in it. You also learnt about primitive chordates, the protochordates, which represent a transition between invertebrate and vertebrate animals. In this unit you will begin the study of Vertebrata. From the study of Unit I, you are aware that **Pisces (Fishes), Amphibia, Reptilia, Aves** and **Mammalia** are the five main groups of subphylum Vertebrata. Of these five groups, the first three include animals which are **poikilotherms** or cold blooded animals. The body temperature of cold blooded animals conforms to the ambient temperature or the temperature of the environment in which they live, and does not remain constant. Birds and mammals, on the other hand, have a constant body temperature and are classified as warm blooded animals or **homeotherms**. Also reptiles, birds and mammals are grouped under **amniota**, that is animals that develop an amnion during their embryonic life. Fishes and amphibians are anamniotes. In this unit you will study about the characters and classification of three different groups of animals, Agnatha - the jawless fishes, the fishes and finally the organisms which live both in water and land, the amphibians.

Amnion is the inner most of the extra embroyonic membranes forming a fluid filled sac around the embryo.

Fishes are exclusively aquatic and have mastered the aquatic environment. A great variety of forms exist in fishes and because of the numerous structural adaptations they have evolved, fishes occupy a variety of niches in the aquatic environment including the oceans's abyssal depths. About 21,400 species of fishes have been described so far. Amphibians on the other hand, have switched over to land, but have not completely forgotton their ancestral home. The transition in habitat from water to land was a slow evolutionary process that spanned over a million years. The process led to a series of alterations in vertebrate body plan that fitted these organisms to life on land. Nearly 3900 species of amphibians have been described so far.

In this unit besides various aspects of biology and classification of fishes and amphibians, you will also study another group of animals that are ancestral to fishes, commonly known as jawless fishes. Jawless fishes can be regarded as the earliest vertebrates but other from other vertebrates mainly in the absence of jaws. We shall begin the unit with the study of jawless fishes and then proceed to study fishes and amphibians.

Objectives

After studying this unit you should be able to:

- list the salient features and affinities of Agnatha,
- describe the characters of cartilaginous and bony fishes and distinguish between them,
- group the cartilaginous and bony fishes into specific subclasses,
- discuss the causes and mode of transition of amphibians from water to land,
- list the characters of Amphibia in general as well as the characters of its three orders,
- discuss adaptations of fishes and amphibians to their respective habitat.

2.2 AGNATHA — THE JAWLESS FISHES

The superclass Agnatha includes two groups of jawless fishes, the hagfishes and the lampreys (Fig. 2.1) and contains about 60 species. The major differences between Agnatha and other fishes are absence of jaws and of true paired fins. They also lack internal ossification and scales. In addition, unlike fishes, jawless fishes have eel like body form and porelike gill openings (Fig. 2.1). The agnathans are also known as **cyclostomes or ring mouthed fishes.**

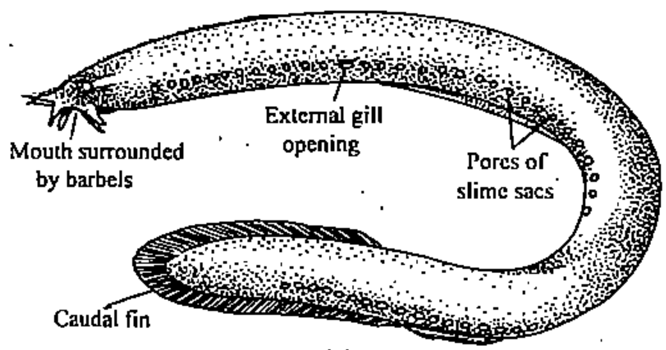


Fig.2.1 : (a) Hagfish (b) Lamprey.

2.2.1 General Characters and Classification of Agnatha

The body of both hagfishes and lampreys are rounded and in general resemble those of eels. Scales are absent and the skin is soft because of the presence of mucus glands in it (Fig.2.2). Agnatha are characterised by the lack of paired appendages. But they do have median fins that are supported by cartilaginous fin rays. The skeleton is not ossified, rather it is fibrous and cartilaginous. Lampreys have a sucker like oral disc with well developed teeth. Hagfishes possess a biting mouth that has two rows of eversible teeth. The digestive systems lacks a stomach. In lampreys intestine has a spiral fold provided with cilia. In hagfishes the fold is present but cilia are absent. There is a two chambered heart with an auricle and a ventricle. The gills are supplied with blood by aortic arches arising from the heart. Blood has erythrocytes and leukocytes. The number of gills in the hagfish and lamprey vary. There are seven pairs of gills in lampreys and five to sixteen pairs in hagfishes. Hagfishes have pronephric kidneys located anteriorly and mesonephric kidneys located posteriorly while only mesonephric kidney found in lamprey. Both lampreys and hagfishes have a differentiated brain and a dorsal nerve cord. Eight to ten pairs of cranial nerves are present. Sense organs for perceiving location, taste and hearing are present. Eyes are moderately developed in lampreys and are degenerate in hagfishes. Internal ear contains one pair of semicircular canals in hagfishes and two pairs in lampreys. Sexes are separate in Agnatha. Gonads are unpaired and gonadoducts are absent. Fertilization is external. Development does not include a larval stage in hagfishes but includes ammocoete larval stage in lampreys.

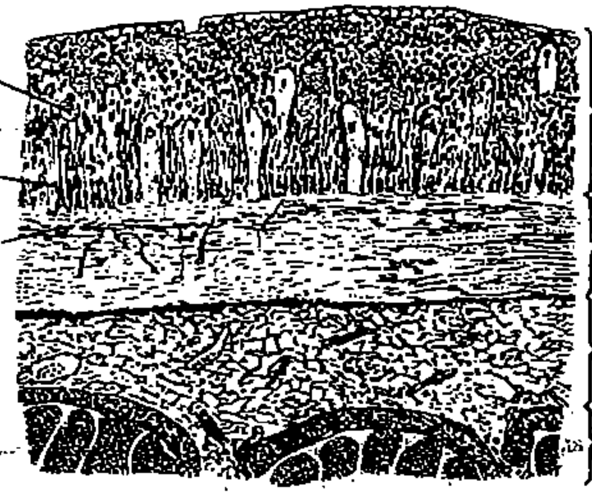
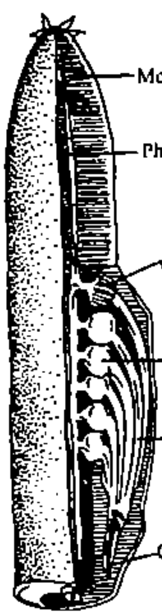


Fig.2.2 : Section of skin of Lamprey.

Both hagfishes and lampreys are included under super class **Agnatha (Cyclostomata).** These are the only living animals under the superclass Agnatha and the rest have become extinct. You will now briefly study about hagfishes and lampreys.

2.2.2 Hagfishes

Hagfishes belong to the class Myxini. There are over 40 described species of hagfishes, most of which live in Atlantic and Pacific oceans. *Bdellostoma*, *Myxine* and *Eptatretus* are some of the common genera. The hagfishes are exclusively marine and can be considered as scavengers of the sea. They feed on dead or dying fishes, molluscs, crustaceans and annelids. Hagfishes usually live buried in mud and sand. Around the mouth an array of tentacles, teeth and sucking apparatus are well developed. Gills are modified into pouches and vary in number between 6 and 14. These open into the pharynx as well as to the exterior by small tubes. In genus Myxine all tubes after joining together open to the exterior by a single aperture on each side (Fig.2.3). Water enters through the nostrils and a muscular valve pumps the water into the gill chambers, and then out behind. Skin also functions as an organ of gas exchange.



Myxine

Fig.2.3 : Arrangement of gills in *Myxine*.

Circulatory system is an open one consisting of large sinuses and accessory hearts. Blood is isoosmotic to sea water.

Around the bile duct there are insulin B cells that resemble those of vertebrates. Pituitary appears as a primitive organ with no distinction between pars intermedia and pars distalis. Pituitary does not appear to secrete tropic hormones such as thyrotropic or gonadotropic hormone. The basophil, acidophil and chromophil cells of the anterior pituitary produce hormones of the type ACTH and LTH (Refer to Unit 10 of Block - 2 LSE-5 course for an account of these hormones).

Hagfishes secrete large amounts of sticky mucous from the mucous glands located on the body. Mucous is useful in protection of the animal as well as in feeding. Some hagfishes were thought to be hermaphrodites since in certain individuals, one end of the gonad contains eggs and the other resembles testis. Since mature sperm are not found in testis they are not considered as functional testis. In vertebrates, gonads pass through a hermaphrodite stage during development. Hagfish gonad represents a stage in which the intermediate stage still persists.

Lampreys belong to class **Cephalospidomorphi**. The best known genus is *Petromyzon* which refers to stone sucking (Petros:stone;myzons:sucking) and these animals have the habit of grasping a stone with mouth to remain stable and not get washed away in a current. They are found in temperate waters of both northern and southern hemispheres and reach upto a length of one meter. Lampreys are marine forms. They are also anadromous, that is, they migrate to fresh water bodies such as rivers and streams to spawn. *Petromazon*, *Lampetra* and *Ichthyomyzon* are some of the common genera. Some are parasitic on fishes. The ammocoete larva that hatches out from the egg is a fresh water burrowing form. The larva burrows in sand for an extraordinarily long time of 3 to 7 years, hence called sand sleeper. During this period the larva may either feed on microorganism or as in some cases may parasitise fishes. Parasitic lampreys can be both marine and fresh water and are usually parasitic on fishes.

The body wall of lampreys consists of an epidermis, dermis and a bunch of collagen-elastin fibres arranged in a circle. The dermis contains pigment cells or chromatophores that impart colour to the skin. The head of lamprey bears a pair of eyes and a conspicuous round sucker. There is an unpaired nasal opening. There are seven pairs of round gill openings on the body. Paired fins are absent but the tail has a median fin which extends anteriorly as a dorsal fin.

There are numerous teeth in the sucker of lampreys. These teeth are horny epidermal thickenings supported by cartilaginous pads. The small mouth opens into a large buccal cavity. The buccal cavity at its hind end divides into two passages, a dorsal oesophagus and a ventral respiratory tube. The respiratory tube leads into gill pouches and closes behind. At the opening of respiratory tube a series of tentacles known as **velar tentacles** serve to separate the oesophagus and respiratory tube while the animal is feeding. The secretions from the paired salivary glands prevent coagulation of blood on which lampreys feed. Once the lamprey is attached to a fish, it remains so for several days and the fish often dies. Since a stomach is absent, oesophagus leads directly into intestine. Liver, gall bladder and bile duct appear as in other vertebrates and a pancreas is absent. Heart is S shaped and is three chambered. The blood that leaves the ventricle passes into ventral aorta which forms a series of 8 afferent branchial arches. The blood collected from the efferent arteries flows into paired dorsal aortae which join to form the main dorsal aorta. A series of segmental arteries arise from dorsal aorta and supply blood to various parts of the body.

Blood is collected by anterior and posterior cardinal veins and drained into the heart. A hepatic portal vein collects the blood from gut. Haemoglobin is the respiratory pigment present in blood corpuscles that are spherical and nucleated.

Brain of lamprey is small and is built on vertebrate body plan consisting of forebrain, midbrain and hindbrain (Fig.2.4) (For a detailed study of nervous system of vertebrates refer to unit 10 of Block 3 of this course). Sense organs include a pair of eyes and **lateral line receptors** (refer to Unit 10 of Block 3 of this course) found along certain lines on the head and trunk. These receptors are helpful in detecting the movement of water relative to fish. There is another specialised sense organ called **labyrinth** a specialised part of the lateral line system. Labyrinth responds to vibrations in water and records the position of the head and its angular movements. Besides the usual pair of eyes, lampreys also have a well developed third eye or pineal organ. It is believed that the pineal organ is concerned with the regulation of daily rhythm of change in colour of animals— dark during day time and pale during night. Pineal also appears to influence reproduction and the metamorphosis of the animal.

Excretion is carried out by mesonephric tubules in adult lampreys. The pronephric tubules appear to play a role in osmoregulatory function by reabsorbing salts. Sexes are separate in lampreys. Ripe ovary contains ova, each of which is surrounded by a follicular

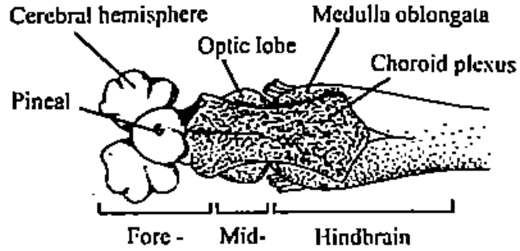


Fig.2.4: Brain of Lamprey.

epithelium. Ovum is released into the coelom. Sperms develop in testicular follicles and are also released into the coelom. Both in males and females, short channels arise from the coelom, and open at the posterior end of the mesonephric duct. Gametes find their way to the water through the mesonephric duct. Fertilisation is external. The modification of cloaca ensures fertilisation and deposition of eggs.

For spawning, lampreys migrate thousands of kilometers and reach fresh waters (anadromous migration). Spawning is preceeded by a form of nest building. The nest is built in shallow waters where bottom is both stony and sandy. The animals drag the stones by mouth to create a small depression in which the eggs are laid after copulation and external fertilisation. The ammocoete larva emerges from the egg. The larva which resemble *Amphioxus* leaves the nest and burrows into a sandy, low current area for nearly 3 to 7 years, before it metamorphoses into an adult. The life cycle of lamprey is shown in Fig.2.5. Before you commence the study of fishes, answer the following SAQ.

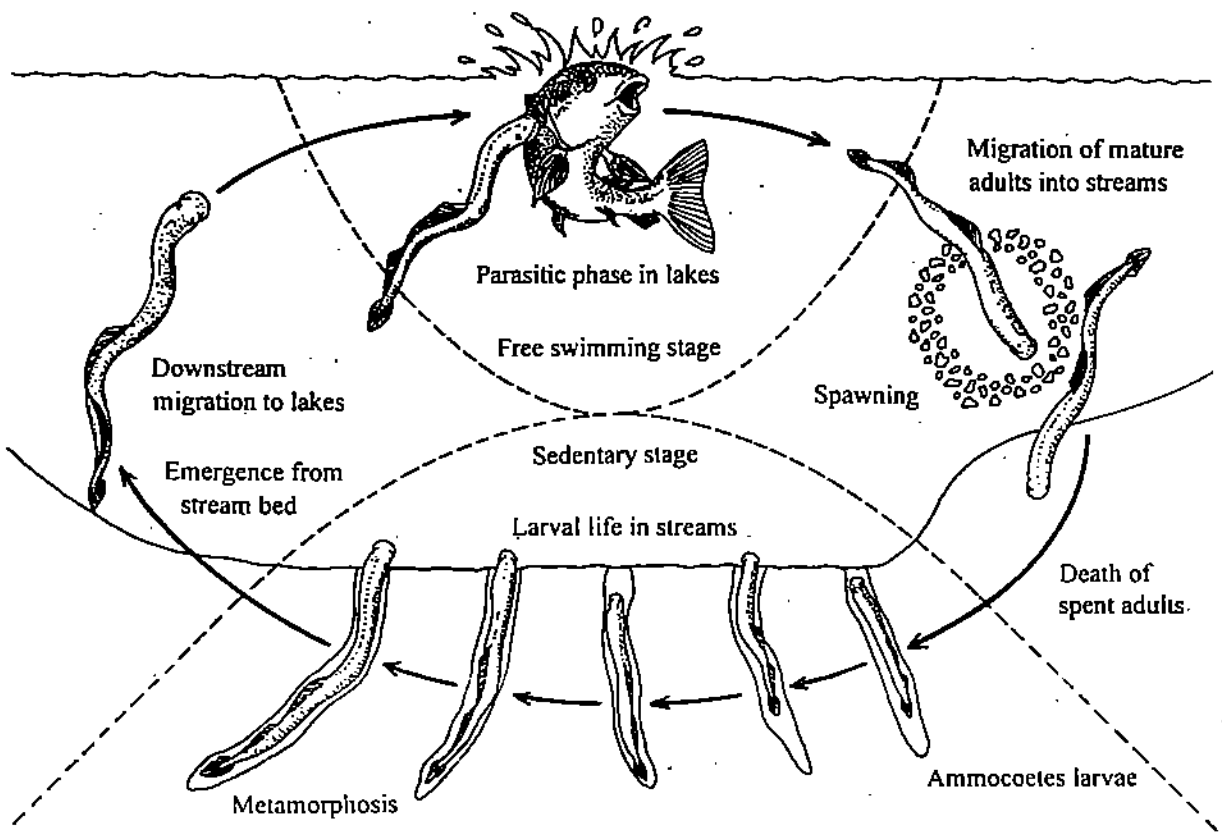


Fig.2.5: Life cycle of a Lamprey.

SAQ 1

State whether the following statements are true or false.

1. Lampreys and hagfishes have a smooth skin with mucous glands in them. T/F

3. In jawless fishes heart is a three chambered structure. T/F
4. Development in hagfishes includes a larval stage called ammocoete. T/F
5. Hagfishes are exclusively marine in their habitat. T/F
6. Hagfishes are all hermaphrodites. T/F
7. Lampreys migrate from marine environment to fresh water bodies for breeding. T/F
8. Pineal organ in lampreys is concerned with the regulation of daily rhythm of colour change in animals. T/F
9. The release of gametes in lampreys is through mesonephric duct. T/F
10. Ammocoete larvae metamorphose into adults in 3 to 7 months. T/F

2.3 PISCES

Superclass Pisces is included under the group Gnathostomata—animals with biting jaws. Amphibians, reptiles, birds and mammals—all are included under gnathostomes. Living fishes with jaws belong to either of two classes. One, **cartilaginous** fishes such as sharks and rays and two, the **bony** fishes that include both the common ray finned fishes and lung fishes. Two groups of fishes have become extinct. One group is the subclass **Acanthodii** that were provided with spines and were related to the ancestors of bony fishes. The other group class **Placodermi,** although provided with bones are considered to be related to cartilaginous fishes. We shall study in detail only the extant (living) fishes. Before we begin the study of **Chondrichthyes**—the cartilaginous fishes, let us become familiar with a brief classification of fishes.

Super class	**Pisces**
Class 1:	**Placodermi**-extinct forms
Class 2:	**Chondrichthyes**-cartilaginous fishes including sharks and rays
Subclass 1:	**Elasmobranchii**-sharks and rays
Subclass 2:	**Holocephali**-ratfishes, rabbitfishes and elephantfishes
Class 3:	**Osteichthyes**-Bony fishes.
Subclass 1:	**Acanthodii**-Fossil forms.
Subclass 2:	**Actinopterygii**-ray finned fishes.
Subclass 3:	**Sarcopterygii**-lung fishes.

2.3.1 Class Chondrichthyes

Class Chondrichthyes includes living fishes, the elasmobranches —sharks, rays and holocephalians - elephantfishes, ratfishes and rabbitfishes. Elasmobranchs are found in almost all regions of the sea. They range in size from small sharks that measure about 30 cm to dogfish (Fig. 2.6) that range in size from 30 to 60 cm to monster like sharks that measure about 17m in length. Most elasmobranchs are carnivores or scavengers. Skates and rays are mostly confined to the bottom of the sea and feed mainly on invertebrates. They have a heterocercal tail fin. (Fig. 2.7; see marginal remarks) Body is fusiform in sharks. They have median dorsal fins and paired pectoral and pelvic fins. In males pelvic fins are modified into claspers.

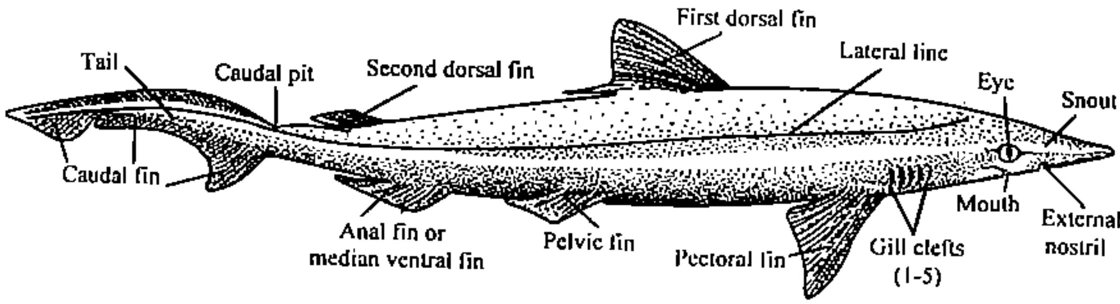


Fig.2.6: Dogfish *Scoliodon.*

Elasmobranchs have a ventral mouth, well guarded by jaws. Skin is covered with placoid scales (Fig.2.8) and has mucous glands. The entire endoskeleton of the animal is formed of cartilage. There is a notochord, and the vertebral column is made of complete and separate vertebrae.

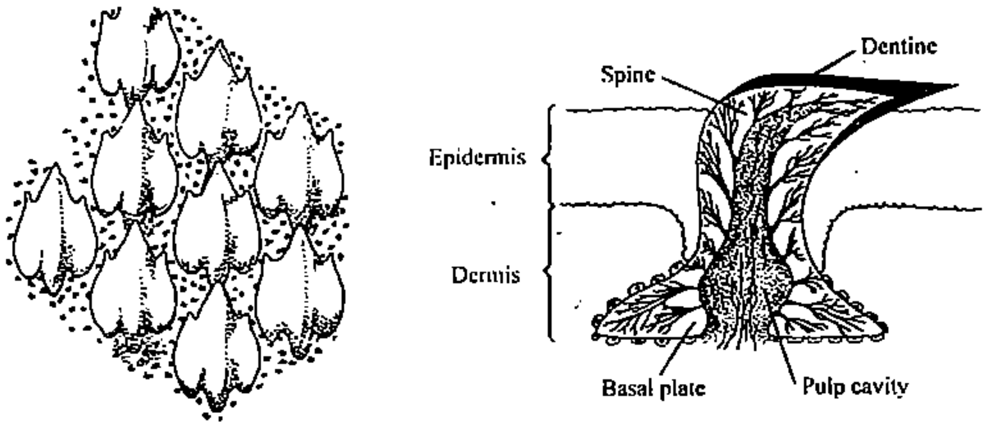


Fig.2.8: Placoid scale.

Fig.2.7: Heterocercal tail fin has a upper lobe larger than the lower, and the end of the vertebral column upturned in the upper lobe.

Appendicular skeleton—pectoral and pelvic girdles are are also present. The teeth lining the upper and lower jaws are modified placoid scales. The mouth leads into an oesophagus followed by a J shaped stomach (Fig. 2.9) and straight intestine. A structure called rectal gland (Fig. 2.9) that has an osmoregulatory function is attached to the rectum. Heart chambers - sinus venosus, auricle and ventricle are arranged one behind the other. For a detailed study of the circulatory system of fishes refer to Unit 8 Block 2 of this course.

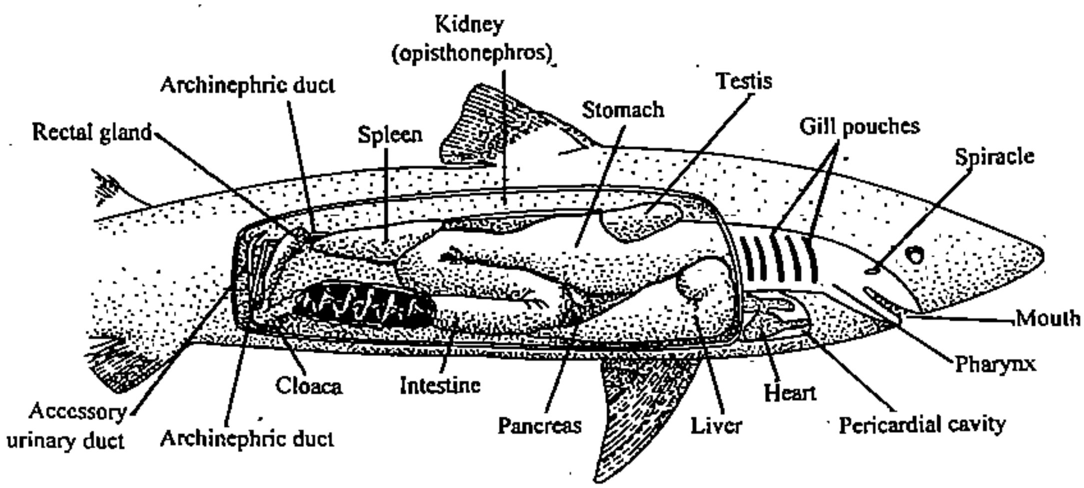


Fig.2.9: Viscera of male shark.

There are two long, slender mesonephric kidneys above the coelom (Fig. 2.10). They open into **Wolffian ducts** that in turn open into a single urinogenital sinus at the cloaca. Brain shows three distinct divisions viz., forebrain, midbrain and hindbrain and these could be further divided into five regions, telencephalon, diencephalon, mesencephalon, metencephalon and mylencephalon. There are ten pairs of cranial nerves and one pair of spinal nerves to each of the body segment. (Fig. 2.10).

Osmoregulation is achieved by retaining the nitrogenous wastes urea and trimethylamine oxide in the blood. These solutes along with the salts already present in the blood increase blood solute concentration and cause blood to be more or less isosomotic to sea water.

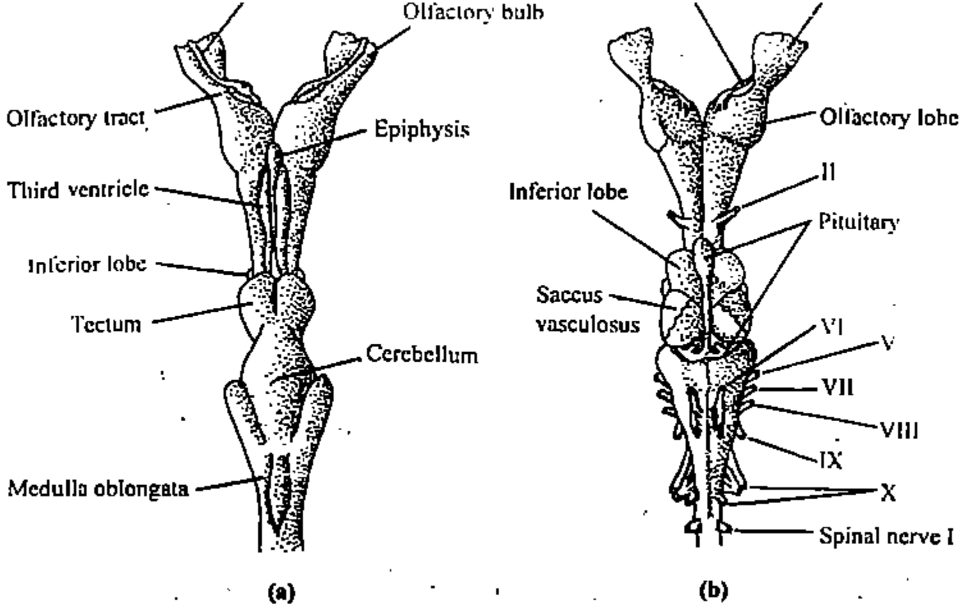


Fig.2.10: Brain of shark (a) dorsal view (b) ventral view.

In sharks sexes are separate. Mature sperms from paired testes (Fig.2.11a) pass through the Wolffian duct which opens into a single urinogenital sinus and cloaca. Male uses a clasper for depositing sperms into the female oviduct. Paired oviducts, also known as Mullerian ducts (Fig.2.11b), carry eggs released from the ovary into coelom. The duct is modified into a 'uterus' in which the developing shark embryo is attached by a primitive placenta. This arrangement is quite common in viviparous forms. In ovoviviparous forms, no such attachment of developing eggs to uterus is observed. In oviparous forms the large yolky eggs are shed immediately after fertilization.

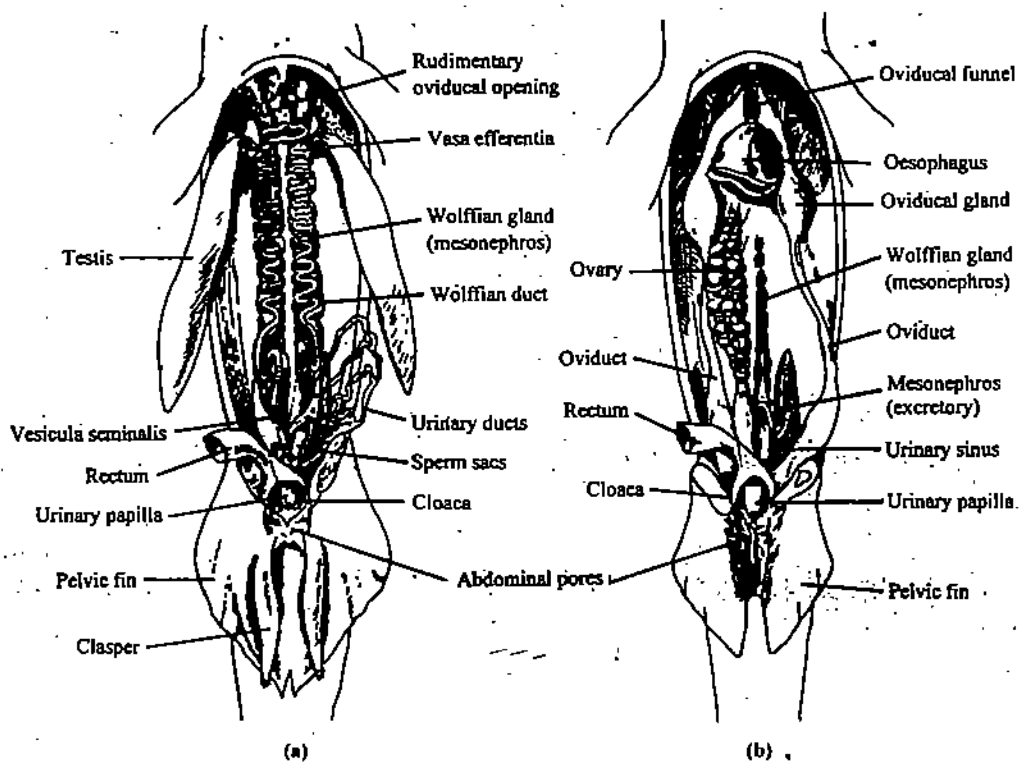


Fig.2.11: Urinogenital system of (a) a male (b) a female shark. (after Goodrich)

Rays constitute more than 50% of all elasmobranchs and there is a variety of them—skates, electric rays, sawfishes, stingrays, eagle rays and mantarays. Bottom dwelling rays have their pectoral fins greatly enlarged and fused with the head to form wing like structures for swimming (Fig. 2.12). Gill openings are ventral to head and the opercula are on dorsal side. Water enters into the mouth through the spiracles and floods the gills for gas exchange. Teeth of rays and skates are adapted for capturing food—molluscs, crustanceans and occasional small fish.

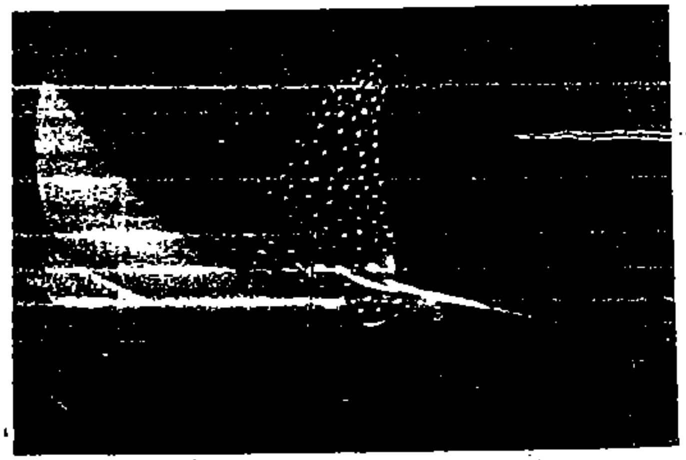


Fig.2.12: An eagle ray. Observe the fusion of pectoral fins with the head to form wing-like structures used for swimming.

2.3.2 Subclass : Elasmobranchii

Class Chondrichthyes which includes all cartilaginous fishes has two subclasses: subclass 1. **Elasmobranchii** and subclass 2. **Bradyodonti or Holocephali**. Subclass Elasmobranchii meaning plate gilled fishes includes three orders. Two of these **Cladoselachii** and **Pleuracanthodii** have become extinct, and the third **Selachii** includes all living cartilaginous fishes—the sharks, skates and rays. You will learn about other subclass **Bradyodonti** or **Holocephali** under subsection 2.3.3.

Subclass:	Elasmobranchii
Order 1:	Cladoselachii (extinct)
Order 2:	Pleuracanthodii (extinct)
Order 3:	Selachii (sharks, skates and rays)

The elasmobranchs that are living today originated during late Paleozoic era (see the Geological time table at the end of the block) probably during upper Devonian period and became abundant during Jurassic period of the Mesozoic era. Since other fishes probably had not evolved by that time, these survived on a varied diet that included invertebrates. The sharks of this period had hybodont or humped teeth and had the capacity to eat molluscs. Subsequently sharks with different teeth (Heterodontia), pointed ones in front and flattened ones for crushing molluscs at the back, evolved. *Heterodontus* (Fig.2.13), the Port Jackson shark of pacific ocean is an example. The sharks of Jurassic period had their jaws shortened and adopted the hyostylic jaw suspension. The true sharks as they are called, the modern sharks (belonging to suborders Hexanchoidea, Galeoidea and Squaloidea) acquired sharp teeth and took to fast swimming. *Hexanchus* (Fig. 2.14a) and *Heptranchus* are long bodied and slow-moving sharks from warm waters. They are viviparous forms but lack a placenta. Nearly 75% of all sharks that occupy shallow tropical and warm temperature waters belong to the suborder Galeoidea.

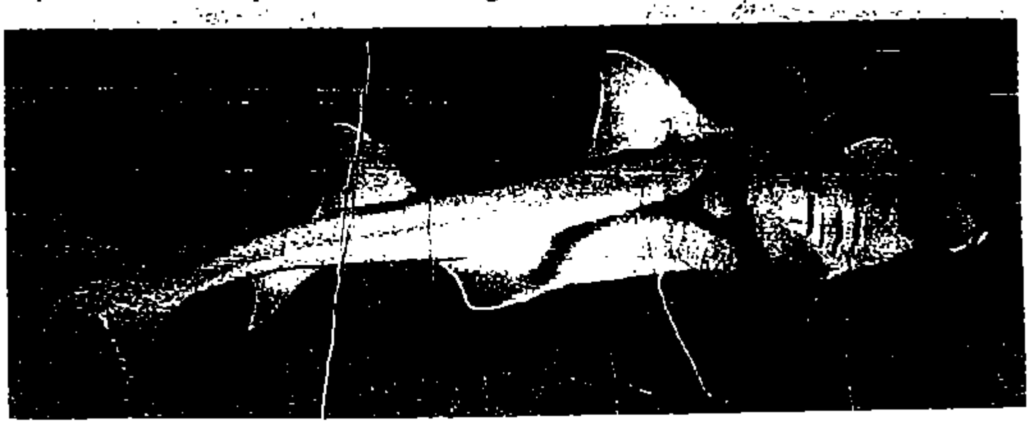


Fig.2.13: *Heterodontus*.

Scyliorhinus (cat shark) and *Mustelus* (Fig.2.14b), known as dogfish live in the bottom of oceans, feeding on crustaceans and molluscs. *Carcharinus* is an abundant species that measures upto 4m in length. It lives both in marine and fresh water, and is used for food, oil and leather. *Cetorhinus*, another member of Galeoidea, feeds by straining the plankton with comblike gills. The efficiency of this type of feeding can be seen in large size (of nearly 10.5m) attained by these sharks. The liver of these sharks also stores oil and the hydrocarbon squalene, all of which are adaptations to maintain a neutral buoyancy in waters.

Fig.2.14a): *Hexanchus, b) Mustelus.*

Another plankton feeder is the whale shark *Rhinodon* that attains a very large size. *Rhinodon* moves vertically up and down in water with its mouth kept open and sucks the plankton. The man eating shark. *Carcharodon* (Fig. 2.15) that is about 9m long is found in many seas of the world.

(a) (b)

Fig.2.15: *(a) Carcharodon* of tropical oceans (b) Front view.

Sharks that occur only in cold and deep water are included under the suborder Squaloidea. Saw toothed fishes *Pristiophorus*, spiny dogfish *Squalus* and monkfish *Squatina* (Fig. 2.16) belong to this suborder. The thresher shark *Alopias* has an interesting habit of food-capturing. Several sharks join together and drive small fishes such as mackeral into shoals by their whip-like tail and then seize them

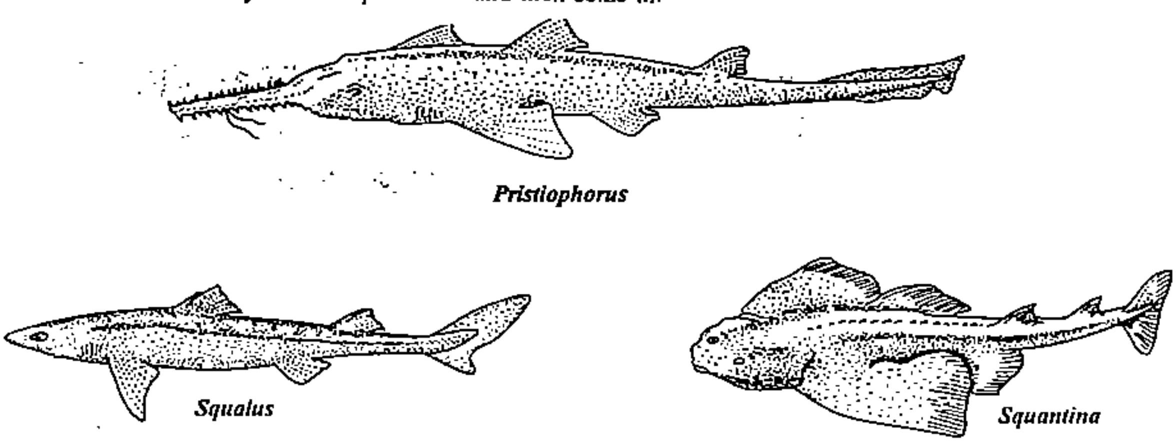


Fig. 2.16: Sharks of cold and deep waters.

Elasmobranchs also include skates, electric rays, sawfishes, stingrays, eaglerays and mantarays. Skates and rays are included under the suborder **Batoidea** that have flattened teeth specialsed for feeding on molluscs. Essentially skates and rays are flattened, bottom living creatures. Their locomotion is brought about by currents of water that pass backwards along the fins. Skates and rays have their pectoral fins greatly enlarged and fused to the head. Such a structure is used like a wing while swimming. The oldest of rays, the banjo ray, *Rhinobatis* that exists from Jurassic period has its pectoral fins enlarged but are distinct from the body. In the sawfish *Pristis* (Fig. 2.17), a form known to exist from cretaceous period, the head is drawn into a long rostrum armed with denticles. Some sawfishes live in fresh water as well.

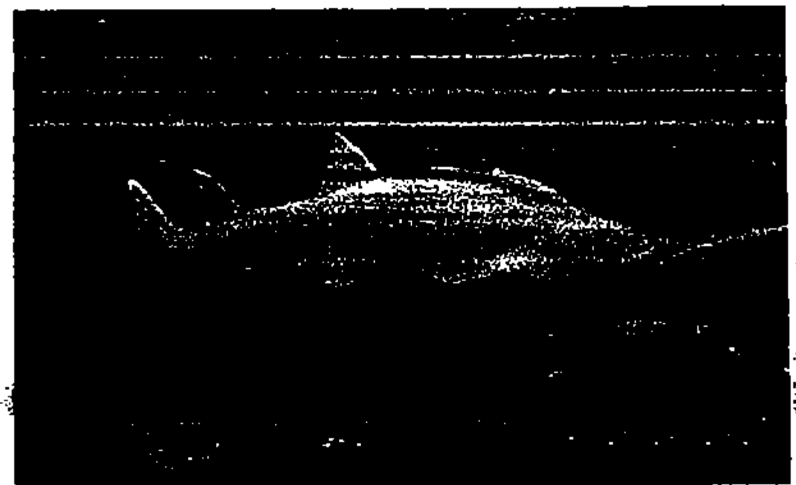


Fig.2.17: Sawfish, note the saw like denticles.

In the ray *Raja* (Fig.2.18), again known to occur from cretaceous times, the pectoral fins are attached to the sides of the body and median fins are small. In sting rays, (Fig. 2.19) the tail appears like a whip and the dorsal fin is modified into a poisonous spine. In eagle rays, eg. *Myliobatis,* the flattened teeth function like a mill, grinding the molluscan shell.

Fig.2.18: *Raja*.

In electric rays, *e.g., Torpedo* the pectoral fins extend forward and the front of the animal has a rounded appearance.

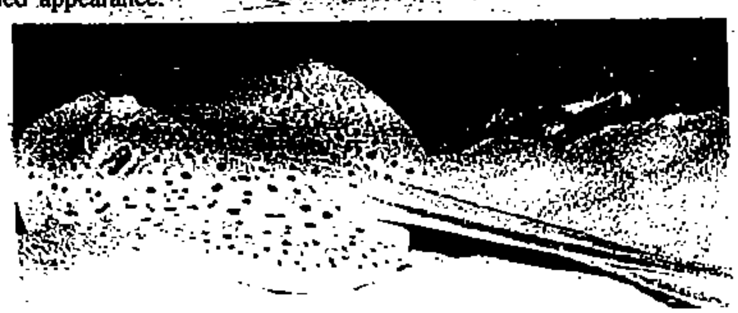


Fig.2.19 : Blue spotted sting ray.

The lateral plate muscles innervated by cranial nerves form a powerful electric organ (Fig. 2.20). Each organ is formed of numerous disc like cells that are connected in parallel, and on simulatancous discharge of all cells, a high amperage of current is produced that flows into surrounding water. The current thus produced stuns the prey and keeps the predators away. In forms which live in shallow and well illuminated water, the colour of the upper surface of skin is bright and that of bottom surface is white. The eyes protected by lids come to lie on the upper surface of the fish. Thus the sharks and rays have developed several adaptations that are useful for bottom living.

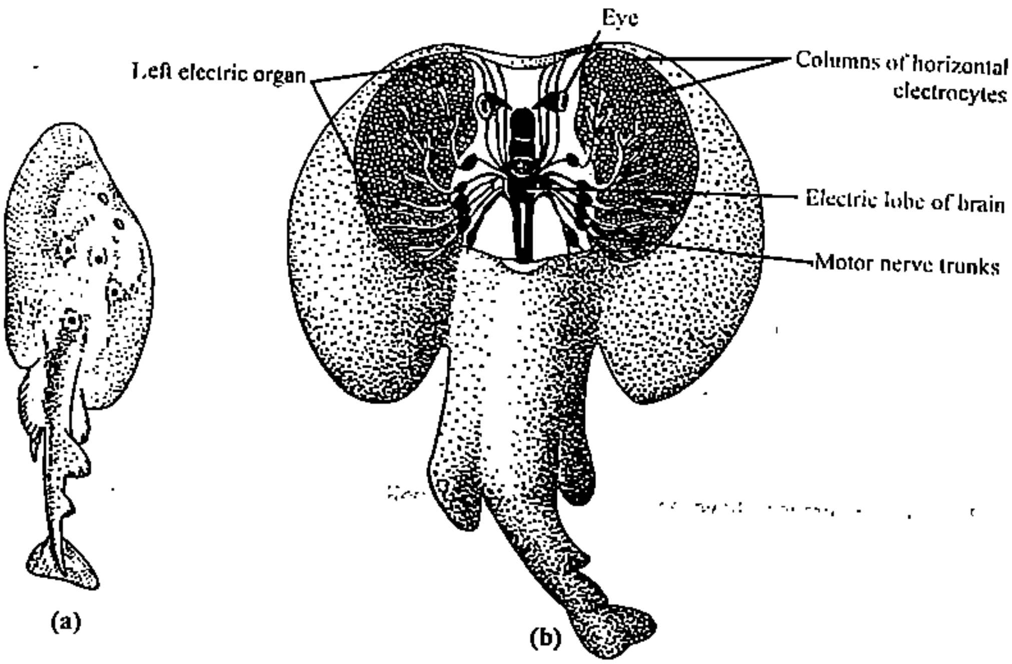


Fig.2.20: (a) Electric ray, (b) Electric organ of *Torpedo.*

2.3.3 Subclass : Holocephali

Bradyodonti or Holocephaii is the other subclass of class Chondrichthyes. The fishes first appeared during Devonian times. The subclass includes ratfishes, rabbitfishes and elephantfishes. These are also bottom living fishes feeding on molluscs and other invertebrates. The sweeping movements of pectoral fins aid in locomotion. In front of the dorsal fin there is an erectile spine which in some forms is poisonous. The tail is thin and long. The mouth appears as a small opening between the lips. The upper jaw is fused with the skull and the type of jaw suspension is known as **holostyly** as against the hyostylic jaw suspension seen in elasmobranchs. For this reason this group is known as Holocephali. The teeth appear as broad plates firmly attached to the jaws. The oesophagus leads directly into a broad spiral intestine, the stomach being absent. The intestine in turn leads into a rectum. The Holocephali have an opercular flap that is absent in elasmobrachs. Besides the pelvic claspers, as in elasmobranchs, male Holocephali have extra claspers in front of pelvic ones and an additional clasper in the head region—the cephalic clasper. The notochord does not show constrictions and vertebrae are reduced to separate nodules. The open lateral line canals are found more on the underside of the snout, probably to detect food. Cleavage is holoblastic.

Holocephali possess certain characters that resemble elasmobranchs such as the presence of conus arterious, separate urinary and spermatic ducts, urea in blood and the rectal gland. Since they have very large eyes, the brain has varied shape and the diencephalon is long and thin.

Earlier you have studied that Holocephali arose during Devonian period of the paleozoic era. *Chimaera* (Fig. 2.21), known as ratfish dates back to Cretaceous period of the Mesozoic era. But many extinct Holocephali were much older and could be traced to carboniferous period. The affinities of Holocephali are not known clearly. The snout and skull of Holocephali resemble those of the extinct group called placoderms. But such similarities are too meagre to place placoderms as ancestors of Holocephali.

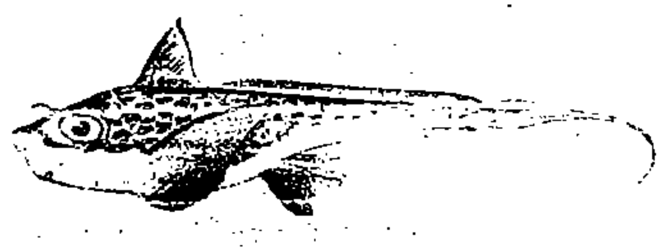


Fig.2.21 : *Chimaera.*

SAQ 2

I. Fill in the blanks with suitable words:-

1. ____________, ____________ and ____________ are three classes of fishes included under superclass Pisces.
2. ____________ and ____________ are the two subclasses included under class Chondrichthyes.
3. Elasmobranchs have an ____________ tail.
4. Elasmobranchs have ____________ scales in their skin.
5. Fishes have ____________ kidneys.
6. Osmoregulation in elasmobranchs is achieved by retaining the nitrogenous wastes ____________ and ____________ in blood.
7. In rays ____________ fins are greatly enlarged and fused with head.

II. Match the common names given under A with the generic names given under B.

A		B	
1)	catshark	a)	*Rhinodon*
2)	sawtoothed fish	b)	*Alopias*
3)	whale shark	c)	*Scyliorhinus*
4)	sawfish	d)	*Pristiophorus*
5)	thresher shark	e)	*Trygon*
6)	sting ray	f)	*Narcine*
7)	eagle ray	g)	*Pristis*
8)	electric ray	h)	*Myliobatis*

III. State which of the following statements relating to Holocephali are true:

a) Holocephali originated during Devonian times. (T/F)

b) Holocephali live in littoral waters feeding on molluscs and other invertebrates. (T/F)

c) The upper jaw of holocephalians is fused with the skull, and the jaw suspension is holostyly. (T/F)

d) The fishes have a poisonous erectile spine in front of dorsal fin. (T/F)

e) Holocephalians lack a stomach in their digestive system. (T/F)

f) As in elasmobranchs an opercular flap is absent in Holocephali also. (T/F)

g) Besides the pelvic clasper, Holocephali have a cephalic clasper. (T/F)

h) In the presence of separate urinary and genital ducts holocephalians resemble elasmobranchs. (T/F)

Class Osteichthyes, fishes with a bony skeleton, appear to have originated during the middle Paleozoic era. Bony fishes can be regarded as the most successful aquatic organisms in terms of mastering of the aquatic environment. From small streams to ocean depths they have occupied all possible niches in aquatic environment. With well developed eyes, ears and chemical receptors and complex behaviour patterns, their mastering of the aquatic environment is total and complete. Some of them live even in unfavourable and foul water conditions. A number of species can breathe air and live on land for a while. Majority of bony fishes are carnivorous but many of them feed on a variety of food ranging from plankton to sea weeds. Bony fishes have evolved complex reproductive mechanisms that include nest building and parental care. A pronounced social behaviour is observed when they move in shoals and recognise each other by exchange of sounds.

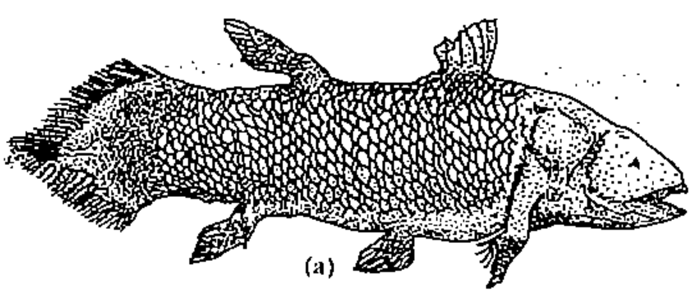
With this brief introduction of class Osteichthyes, you will now learn about the subclasses of bony fishes and their salient characters. The living forms of class Osteichthyes are included under two subclasses, the subclass Sarcopterygii — the fleshy-finned fishes, and subclass Actinopterygii, the ray finned fishes or modern bony fishes. Of the two subclasses, Actinopterygii can be regarded as the most dominant fish group of the present time.

In terms of numbers, Actinopterygii includes nearly 20,000 species as against only 575 species of elasmobranchs. The group includes most of the familiar fishes, perches, pikes, trouts, herrings and all other types of modern fish. The number of individuals in some of the species is almost an astronomical one. For instance ganoid fishes may have a population size of a million. The blue fish that live in the Atlantic coast of United States may have a population size of a thousand million. Such numbers are true of many other bony fishes as well. These examples speak of the tremendous productivity of the sea. Essentially bony fishes along with the elasmobranchs constitute a high proportion of total human food.

2.3.5 Subclass: Sarcopterygii

Sarcopterygii consists of two orders. **Crossopterygii** and **Dipnoi**. Crossopterygii or lobe finned fishes occupy an important position in the evolution of tetrapods — the amphibians. The fossils of crossopterygians first appeared during the Devonian times — a period that was marked by alternating drought and floods. The crossopterygians had nostrils which opened into the mouth, lungs as well as gills. They also had paired lobed fins. The presence of lungs to enable air breathing was quite useful during these times. It is believed that the lobed fins of crossopterygians functioned like legs to pull themselves onto sand bars and mud flats or crawl to a new pond or stream when the ones they were in, dried up.

The crossopterygians include two sub orders — the **Rhipidistia** and **Coelacanthiformes.** Rhipidistians originated during the Devonian period and were in abundance during late Plaeozoic era. Subsequently they became extinct and now, only certain fossil forms are found. The coelocanths also arose during Devonian period and flourished during Mesozoic era. Towards the end of mesozoic era, except for one surviving species *Latimeria chalumnae* (Fig. 2.22a) all have become extinct. The existence of the living species was known only in 1938 when the fish was brought to the museum in East London, South Africa. Subsequently many members of the species were caught in Comoro islands, off the coast of Madagascar, although most of them died a few hours after capture.


(a)


(b)

Fig.2.22: a: *Latimeria chalumnae.* b: Diphycercal tail.

Latimeria are large fishes weighing about 80 Kg and dull blue in [illegible] diphycercal tail (Fig. 2.22b) (see marginal remarks) and the body is covered with cosmoid scales. Notochord appears as massive structure without any constrictions and the teeth are not present on the margin of jaws but are confined to premaxilla, dentary and palate. *Latimeria* feeds on other fishes and the powerful oesophagus helps in the swallowing of fishes. There is a well developed spiral intestine. A swim bladder containing 95% fat helps in reducing specific gravity. Respiration is by gills. The heart has a linear arrangement of chambers. Blood contains urea as in elasmobranchs and the red cells are larger in size. The osmolarity of serum as well as sodium concetration are similar to that of sea water. Salt is excreted through salt glands. Brain occupies a small portion of cranium in the far back region and the rest of the cranium is filled with fat. Coelocanths have well developed eyes, internal ear and lateral line organ. Eggs are larger in size measuring some 9 cm in diameter and 330 g in weight. Development occurs in oviduct. *Latemeria* has remained more or less unchanged since it originated during Jurassic times (some 195 million year ago) and their numbers are very few. They could be regarded as living fossils.

A tail that tapers to a point in which the vertebral column does not upturn but extends to the tip. Eg, lungfishes is known as diphycercal tail.

Lung fishes

Dipnoi, otherwise known as lung fishes are air breathing forms and only three genera survive today. *Lepidosiren, Neoceratodus* and *Protopterus* (Fig. 2.23 a, b & c) are the surviving genera, of which the first two inhabit rivers and the third lives in large lakes. *Neoceratodus* lives in the rivers of Queensland (Australia), *Lepidosiren* in the rivers of tropical South America and *Protopterus* in the tropical S. Africa. These fishes do survive even when the water of their habitat dries up during summer. All the three genera have symmetrical diphycercal tail. There are no separate dorsal fins.

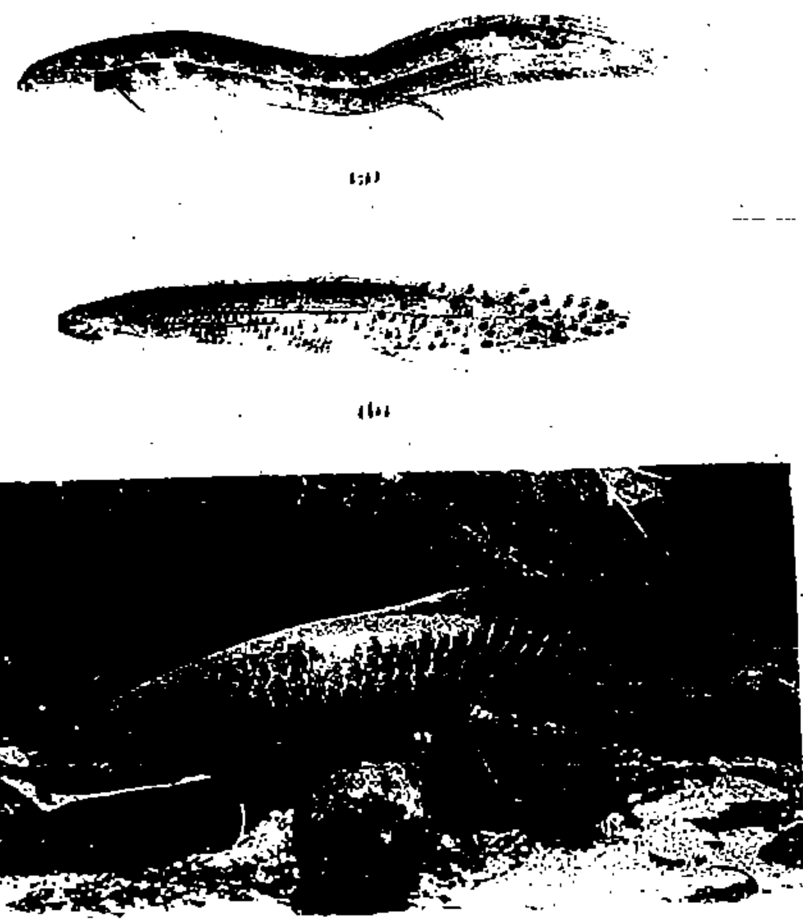


Fig.2.23: Lung fishes (a) *Lepidosiren* (b) *Protopterus* (c) *Neoceratodus*.

The scales are reduced to bony plates. The notochord as in Crossopeterygii is an unconstricted rod and the vertebrae are cartilaginous arches. There is reduced ossification in the skull. The jaw suspension is autostylic. Dipnoans feed voraciously on small invertebrates and decaying vegetable matter. They have a stomach and a ciliated intestine that is provided with a spiral valve. The external nostrils lying at the edge of the mouth lead to internal nostrils. In *Neoceratodus* the swim bladder is an unpaired structure but paired in other genera. When oxygen tension of water is very low, *Neoceratodus* is observed to come to surface to breath fresh air. It can also live in foul waters that usually kill other fishes, but it can not survive outside the waters. *Protopterus* and *Lepidosiren* obtain 98% of their oxygen from air. The cavity of swim bladder is subdivided into a number of pouches or alveoli — the sites of gas exchange. Lungs lie dorsally but open into oesophagus ventrally (Fig.2.24).

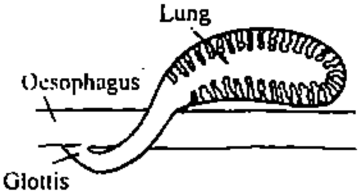


Fig.2.24: The openings of lungs into oesophagus in Dipnoi.

In *Neoceratodus* the lung is supplied with last branchial artery but in other genera the pulmonary artery arises from dorsal aorta. The blood is returned to the partly separated left side of sinus venosus of the heart by a pulmonary vein. Auricle is partly divided into two and the ventricle is almost completely divided in *Lepidosiren* and *Protopterus*. In *Neoceratodus* the ventricle is only partly divided. A renal portal system is present. The brain and the rest of nervous system resemble those of the amphibians (Fig. 2.25). Forebrain is evaginated into a well developed pair of cerebral hemispheres. Optic lobes are not well developed and cerebellum is very small. Inner ear is developed to form a special lobe called saccus endolymphaticus as is seen in amphibians.

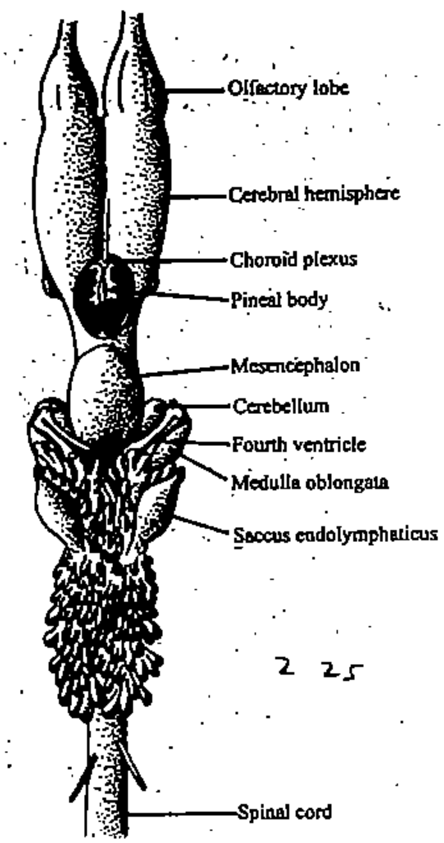


Fig. 2.25: Brain of *Protopterus* (dorsal view).

In *Protopterus*, adrenal glands are represented by two separate masses of perirenal tissues. The steroid tissue has a collection of functions — haematopoietic, phagocytic, storage, endocrine and pigmentary. Such a structure and functions are indicative of starting point of evolution of adrenal cortex. In males sperm produced from testes pass through vasa efferentia into the excretory portion of mesonephros. In females eggs are shed into the coelom from where they enter into Mullerian duct that opens to the outside.

Both *Protopterus* and *Lepidosiren*, that live in streams and rivers, during dry season burrow into the soil. They secrete a copious slime that is mixed with mud to form a hard cocoon in which they aestivate until the return of rains.

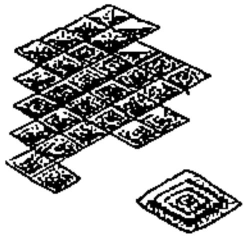


Fig.2.26: Ganoid scale.

2.3.6 Subclass: Actinopterygii

Actinopterygii or the ray-finned fishes are the most common of the bony fishes and include about 21,000 species. It is believed that these fishes have originated in fresh water lakes and streams during the Devonian period. The early ray-finned fishes known as Paleoniscidae were of small size with large eyes, extended mouth and a heterocercal tail. Also they had ganoid scales (Fig. 2.26), functional lungs and gills; and despite the fact that they shared the Devonian swamps and rivers with crossopterygians and dipnoans, they were distinctly different in their appearance.

Subclass Actinopterigii includes Infraclasses **Chondrostei**, and **Neopterygii**. Chondrostei are the more primitive of the two and include freshwater and marine sturgeons, paddle fins and the bichir-*Polypterus* (Fig.2.27) that lives in African rivers. The primitive neopterygians are often called holosteans.They flourished during Triassic and Jurassic periods but declined towards the end of Mesozoic era. There are only two surviving genera the bowfin—*Amia*, that lives in shallow and muddy waters of Great Lakes and Mississippi valley and the garpike *Lepisosteus* of north Amercian waters. The Modern neopterygians are placed in division. **Teleostei** — the modern bony fishes. Teleosts exhibit extensive diversity and variety in the body form. Eels, salmons, trouts, perches, minnows, carps, sculpins, mullets and mackerels are some of the many different types of teleosts. You will now briefly study about subclass Actinopterygii.

Fig.2.27 : *Polypterus*.

Infraclass Chondrostei

Chondrostei includes the most primitive of the Actinopterygii. It consists of two orders — order **Polypteriformes** and order **Acipenseriformes**. Excepting a few genera, most members of the order Polypteriformes have become extinct and only their fossils remain. The surviving genus *Polypterus* that lives in African rivers can be regarded as a representative of all the extinct forms. The body is long and eel like. *Polypterus* is carnivorous. It has many primitive characters such as the lining of the body with non-overlapping rhomoboid scales, the presence of a layer of denticles outside the scales, the presence of spiracle and in the arrangement of skull bones. The presence of a spiral valve in the intestine of *Polypterus* is again a crossopterygian and primitive actinopterygian character. The swim bladder resembles a lung. It is found as a pair of sacs lying ventrally below the intestine and opens into the pharynx by a median ventral 'glottis'. This arrangement seen in the fishes of Paleozoic times is found in lung fishes, as well as in tetrapods. Despite the functioning of swim bladder as a lung, *Polypterus* can only come to the surface to breath but cannot survive outside the water. In certain features, *Polypterus* resembles tertrapods. The tail does not appear to be markedly heterocercal, although there are certain signs of such a condition.

The Acipenseriformes that includes sturgeons and paddle fishes has also descended from Polypteriformes and are characterised by reduced ossification. *Acipenser* (Fig. 2.28) is an example of a modern sturgeon and *Polydon* is the paddle fish. The sturgeon probably originated around Jurassic period. *Acipenser* and other modern sturgeons live in sea but migrate to rivers to breed. Sturgeons attain very large size, some even reach up to 1000 kg. They stir the mud bottom with their long snout and feed on a variety of invertebrates. The mouth is small, the jaws are weak and teeth are absent. The jaws can be swung downwards and forward to suck up the prey from the bottom, and the prey

... crustaceans, insects and fishes. The skull and skeleton are almost cartilaginous. The notochord is unconstricted. There is a large swim bladder. Rhomboid scales are present in the skin. There is an open spiracle. The internal anatomy of sturgeons shows certain affinity to elasmobranch fishes such as the presence of spiral valve in the intestine and conus arteriosus in the heart. Sturgeons appear to be an early offshoot of actinopterygian line. They resemble teleosts in certain characters such as the presence of a thin roof on the cerebral hemisphere. The paddle fishes *Polydon* and *Psephourus* are related to sturgeons, although the relationship is not very close. Paddle fishes have flattened snout and a large mouth. Feeding is done by swallowing large amounts of water and filtering it by gill rakers of the pharynx.

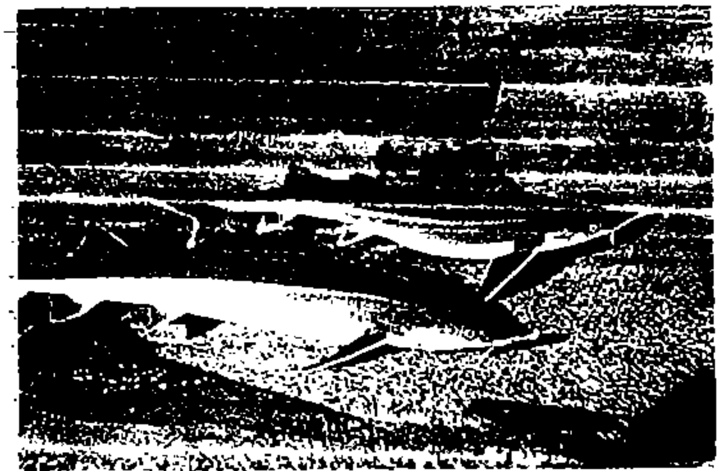


Fig.2.28: *Acipenser.*

The primitive Neopterygeans

These are also known as holosteans and include fishes that are less primitive than Chondrostei. Bow fins and garpikes are examples of Holosteans. These bony fishes first made their appearance during the Jurassic period. Their numbers began to dwindle around Cretaceous times and only two genera of holostean fishes survive today. *Lepisosteus*, the garpike and *Amia*, the bowfin (Fig. 2.29). But several fossil species are known. The two genera do not resemble each other much and the bowfin is more closely related to Teleostei. Both garpike and bowfin are fresh water forms, although Holosteans were mainly a marine group. *Lepisosteus* has several of the primitive characters and does appear to have evolved much from the time it originated during the Triassic period. It has an armour of thick scales on its body. The swim bladder opens into pharynx. Garpikes come to surface to gulp air. The tail is nearly symmetrical. Spiracle is absent. The fish is provided with long jaws with which it feeds on other fishes. The intestine is provided with a spiral value.

In bowfins scales are reduced to single bony cycloid scales as found in teleosts. The tail fin is completely symmetrical. But for its skeleton and the presence of small eggs that show holoblastic cleavage, the bowfin *Amia* more or less resembles teleosts.

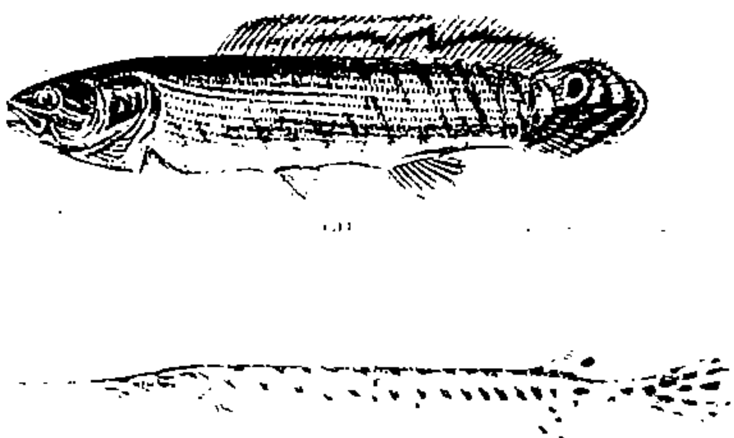


Fig.2.29: (a) Bowfin *Amia* and (b) Garpike *Lepisosteus.*

Division Teleostei

Teleostei, the modern bony fishes have completely replaced the other actinopterygians from all waters. They appear to have evolved from holosteans during late Triassic times and then branched into several lines of evolution. Today more than 20,000 species of bony fishes are found. They are included under nine orders. You will first learn about some of the general characters of Teleostei and then briefly study the classification.

The characters and organization of Teleostei that is presented here relates mostly to modern teleost fishes. Modern teleost fishes appear short and narrow in the lateral plane but are deep dorsoventrally, thus having a steamlined shape of their body (Fig.2.30). The tail of teleosts is symmetrical hence called homocercal tail (Fig.2.31). Besides the caudal, there are two dorsal and one ventral fin. The paired fins—the pectoral and pelvic fins—are small and supported by fin rays. The pelvic fins of bony fishes generally lie far forward. The skin of bony fishes consists of a thin epidermis and a thicker dermis.

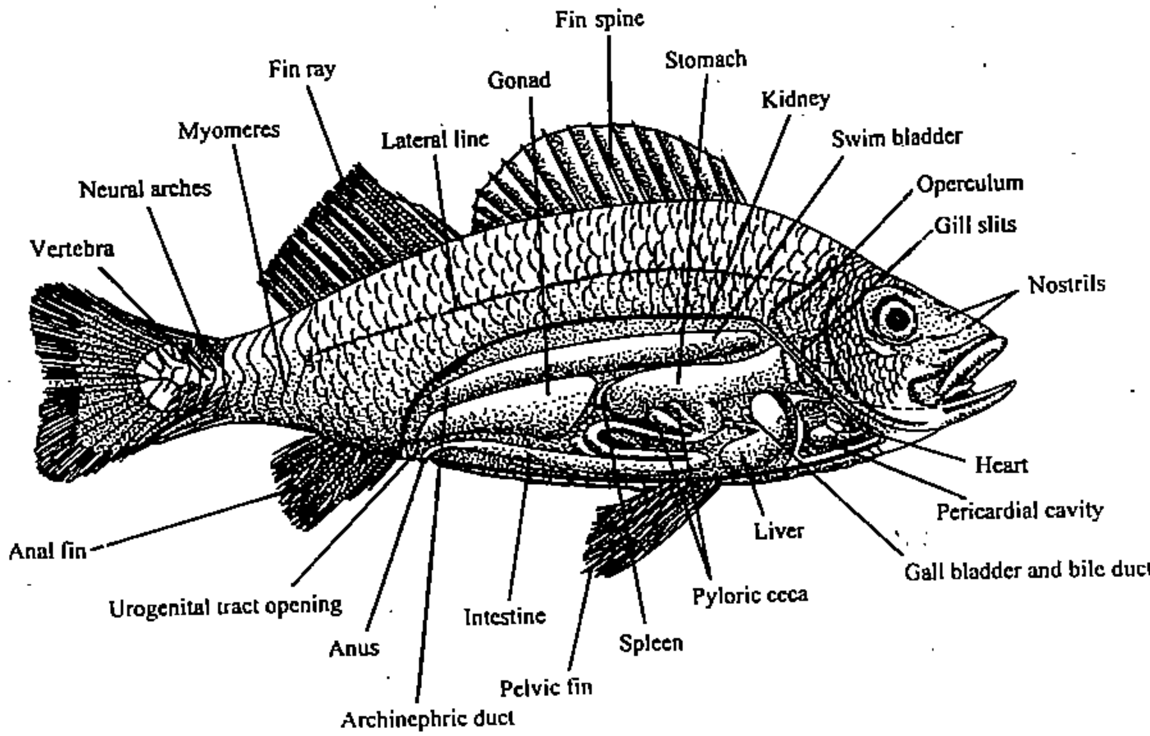


Fig.2.30: A teleost fish.

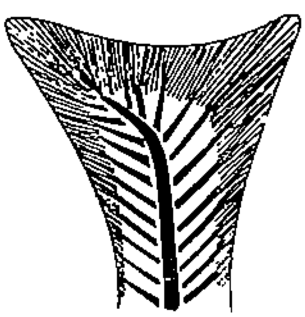


Fig.2.31: Homocercal tail.

Mucous glands are present in the skin. The scales on the skin are dermal derivatives. They appear as thin overlapping bony plates covered by skin. Pigment cells are present on the exposed part of the scale that control the colour of the animal. In the head there is a pair of nostrils. There is a large mouth, the sides of which are supported by movable bones. The tongue may carry teeth and taste buds. Behind the jaw there is operculum appearing as a flap that covers the gills and is supported by movable bones. During early stages of development the skeleton of the head appears as a set of cartilaginous boxes around the nasal and auditory capsules, brain and eyes and as a series of cartilaginous rods in gill arches. Bones are then added either as cartilaginous bones or dermal bones derived from a layer of scales on the skin. The vertebral column of bony fishes as in other vertebrates, helps in preventing the shortening of the body when the longitudinal muscles contract. The vertebral column is well ossified and is divided into a series of sections or vertebrae. The number of vertebrae correspond to the number of segments or somites in the body. The paired fins — pectoral and pelvic fins are supported by ossified radials that are covered by dermal fin rays. At the base, the radials of the fins are connected to the girdles.

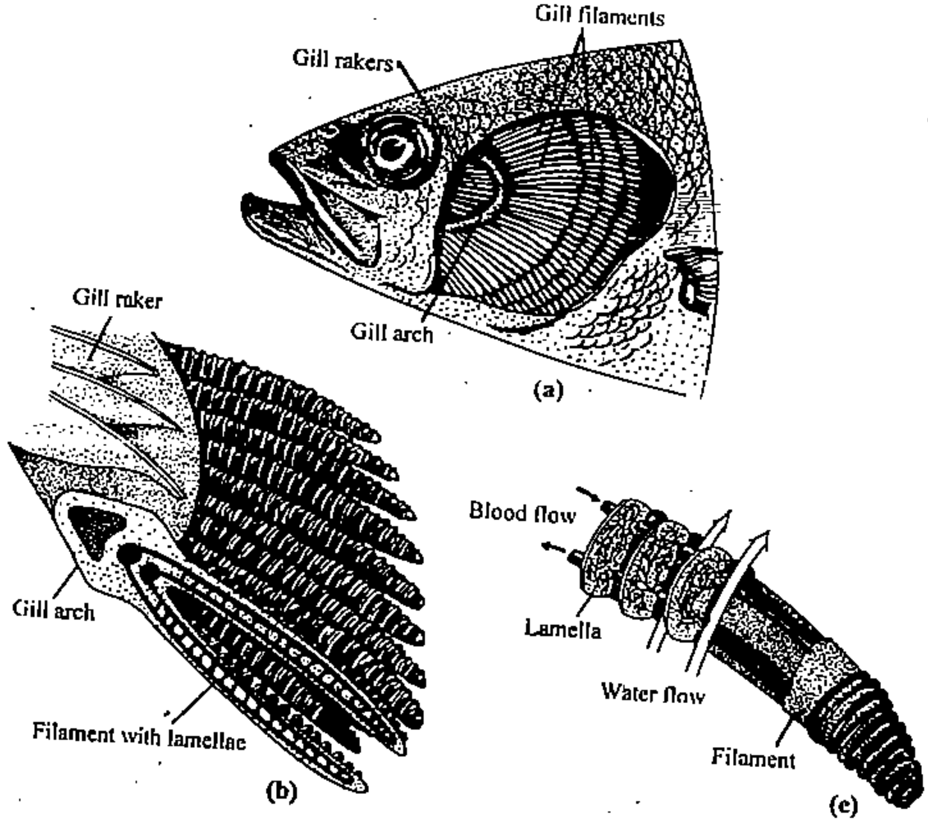


Fig.2.32: Gills of fish. (a) Branchial chamber showing gill raker and gill filaments after the removal of operculum (b) Gill raker and gill filaments (c) A single gill filament. (Large arrows indicate the direction of water flow and the small arrows the direction of blood flow).

Respiration is by gills. Water enters through the mouth and flows through the gill surface. Fish gills are made of thin filaments covered with a thin epidermal membrane (Fig. 2.32). The membrane is repeatedly folded to form plate like lamellae that are richly supplied with blood vessels. Gills are located outside the pharyngeal cavity. Gill lamellae appear as free flaps causing an increase in the surface available for respiration. The gill filaments and lamellae are arranged in such a way that they form a system of pores through which water flows (Fig. 2.32c). The exchange of gases is very efficient in gill respiration and when water leaves the gill in many cases it contains only one fifth of the oxygen initially present in it. The area of gills in different fishes varies depending on the activity of fishes. Essentially more active fishes have large gill areas. The rate of respiration is more in fishes that live in waters with low oxygen content. Fishes living in shallow, stagnant waters in tropical countries can breathe air. Fishes living near the surface of water can also gulp air. Fishes provided with air breathing organ such as *Anabas* the climbing perch (Fig.2.33) spend most of their time on land near the water's edge. Catifishes such as *Clarias* could be found on land at night hunting for food. Another catfish *Saccobranchus* (Fig. 2.34) aestivates by burrowing in mud when water dries up, and has large air sacs growing a long way down the body from the gill chambers.

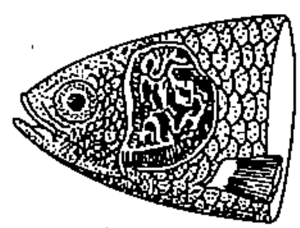


Fig.2.33: Head of *Anabas* showing air breathing organ.

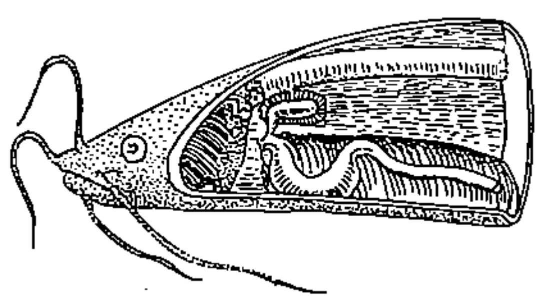


Fig.2.34: *Saccobranchus.*

Most fishes are carnivores and feed on a variety of animals varying from zooplankton to insect larvae to large vertebrates. Some deep sea fishes can feed on prey twice their own size. The prey is seized by the sharp, pointed teeth present in the jaws and on the roof of the mouth and swallowed as a whole. A few herbivorous fishes feed on flowering plants, algae and grasses. A third group of fishes are filter feeders, feeding on abundant microorganisms that are available in sea. Fish larvae, basking sharks, herrings belong to this category. Pelagic fishes strain both phyto- and zoo-plankton with their sieve like gill rakers. There are also omnivorous fishes that feed on both plant and animal food. Finally there are scavenger fishes that feed on organic debris and parasitic fishes that suck body fluids of other fishes.

Mouth is followed by a pharynx that leads into a short oesophagus. There is an oesophagal sphincter present at the opening of the stomach preventing the entry of water from the respiratory system. The intestine is long and coiled and has no spiral valve. Pyloric caeca may be present in the duodenal region that serve to increase intestinal surface.

All fishes are slightly heavier than water. This is because the skeleton and the tissues of fishes contain certain heavy elements that are present only in trace amounts in water. The bony fishes are aided in buoyancy in water by having a floatation device — a gas filled space — the swim bladder (Fig.2.35). Swim bladder is present in most pelagic fishes but is absent in fishes that live in abyssal waters and bottoms of the sea. The neutral buoyancy is achieved by adjusting the volume of the gas in swim bladder. Such an adjustment would enable the fish to remain suspended indefinitely at any depth with no muscular effort. Gas is added to the bladder when the fish descends to greater depth, and when it swims up, gas is removed from the bladder making the fish lighter.

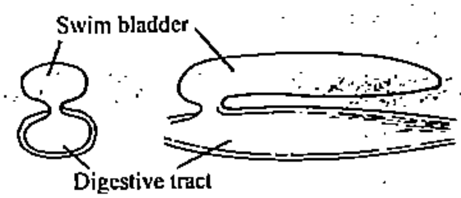


Fig.2.35: Swim bladder of a teleost.

The heart of teleosts contains a series of three chambers — sinus, auricle and ventricle. The muscular conus arteriosus found in elasmobranchs is absent, but there is a thin walled bulbous arteriosus present at the base of the short ventral aorta. Red blood cells are smaller in bony fishes, around 8 to 10 mm in diameter. Three main categories of leucocytes — granulocytes, monocytes and lymphocytes occur in bony fishes. Thrombocytes which are similar in function to the platelets of mammals are also present.

Adult teleosts have mesonepheric kidneys (Fig. 2.36). The ducts of the two kidneys join posteriorly and the common duct opens separately behind the anus. Elimination of the nitrogenous waste is carried out to a large extent by gills which excrete both ammonia and urea. Gills excrete six times more nitrogen than kidneys. The kidneys excrete creatinine, uric acid and trimethylamine oxide.

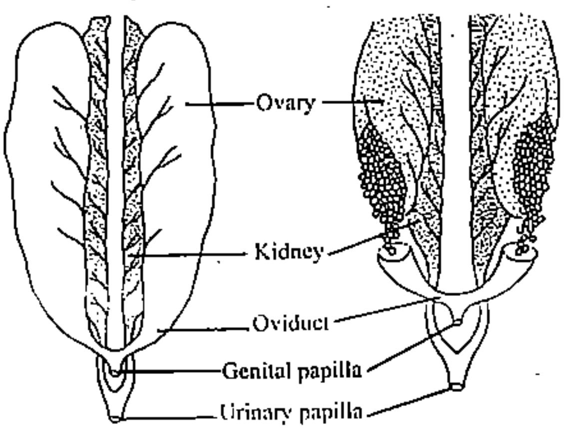


Fig.2.36: Urinogenital system of female teleosts (a) Typical teleost (b) trout.

Bony fishes that occur both in fresh and salt water face different problems with reference to regulation of water and salt content of the body. Fresh water fishes live in a medium of extremely low concentration of salts and face the danger of water entering into their body osmotically and salt being lost outward by diffusion.

water gain and salt loss primarily occur across the thin membrane of the gills. Fresh water fishes are hyperosmotic regulators. They pump the excess water by the mesophric kidney and discharge very dilute urine. The salt absorbing cells in the gill membrane actively transport sodium and chloride ions from the water to blood, thus replacing the salts lost by diffusion from the body (Fig. 2.37). The problems of marine fishes are totally different. Living in sea water with a high salt concentration around them, these fish tend to lose water from the body. Thus they lose water but gain salts. To prevent water loss from body, these hypoosmotic regulators drink sea water. Such a process also brings into the body a great amount of superfluous salt. The excess salt is disposed off by special salt secreting cells located in gills as well as from the intestine along with faeces. Some of these are also excreted by kidney by tubular secretion process. Since only very little filtrate is formed, the golmeruli have lost their importance and are altogether absent in some marine teleosts (Fig.2.37). Pipe fishes and goose fishes are examples of fishes with aglomerular kidneys.

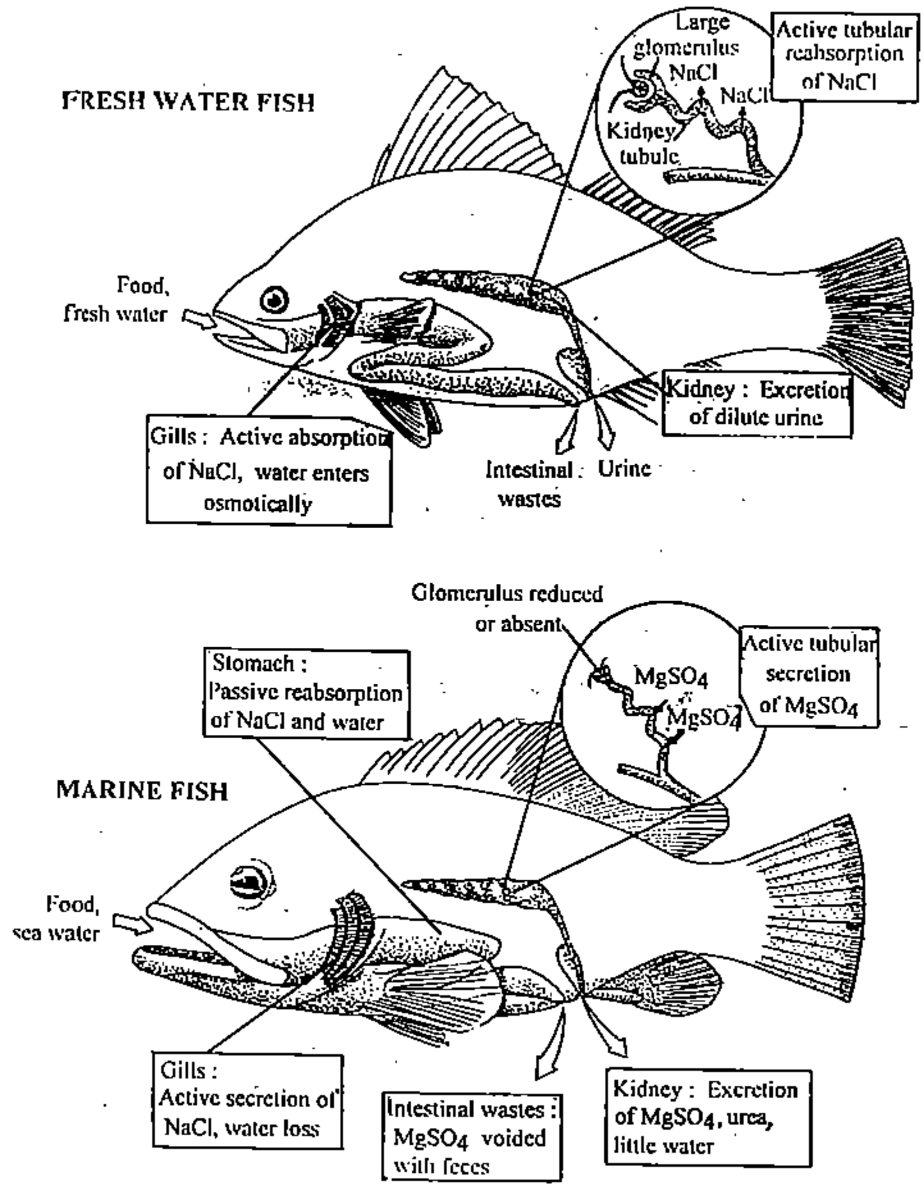


Fig.2.37: Osmoregulation in fishes.

Majority of teleosts are dioecious with external fertilization and external development of eggs and embryos. Most of them are oviparous but there are also ovoviviparous and viviparous forms. Many fishes, especially freshwater ones exhibit elaborate courtship behaviour. Unlike tetrapods, in bony fishes the excretory and genital systems are completely separated in both the sexes. Testes appear as a large pair of sacs opening into the base of urinary ducts. In general, ovaries are closed muscular sacs continuous with oviducts. But in certain fishes such as trouts, the ovaries are also elongated, eggs are shed free into the coelom (Fig. 2.36 b) and pass out through abdominal pores.

So far you have learnt about the general characters of bony fishes. In the next subsection, you will briefly study the classification of Teleostei.

Classfication of Division Teleostei

You have earlier learnt that there are around 20,000 species of teleost fishes included under nine different superorders. Of the nine, **Elopomorpha** includes the most primitive of living teleosts. *Elops* (ten pounder), *Megalops* (tarpon) and *Anguilla* (eel) (Fig. 2.38) are some of the examples. Superorder **Osteoglossomorpha** includes fresh water forms — the elephant snout fish *Mormyrus* and butterfly fish *Pantodon*. Superorder **Clupeomorpha** includes familiar herring *Clupea* (Fig. 2.39). Superorder **Ostariophysi** is a large group that includes over 5000 species, most of which are fresh water forms. In these fishes, the structures called **Weberian ossicles** connect the swim bladder to the ear. The Weberian ossicles are formed by the modification of anterior vertebrae. The group includes carps (*Cyprinus*) gold fish (Fig. 2.40) roach (*Rutilus*) and catfish (*Silurus*), barbs etc.

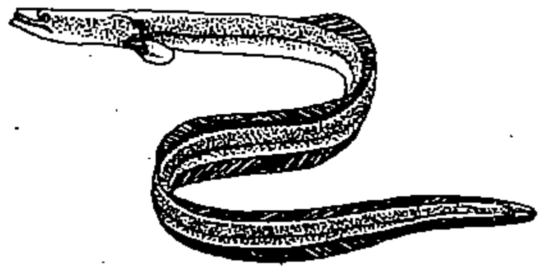


Fig.2.38: Fresh water eel *Anguilla*

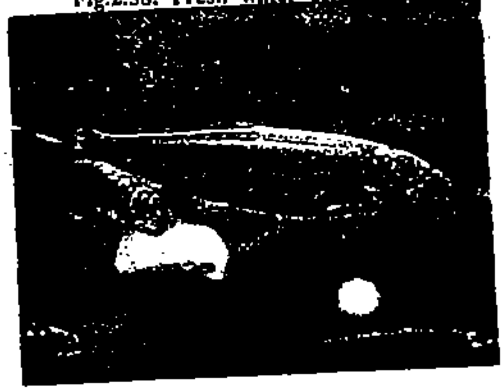


Fig.2.39 : The herring *Clupea*.

(a) (b)

Fig.2.40: a) *Cyprinus* the common carp (b) goldfish *Carassius*.

The fifth Superorder **Protacanthopterygii** includes fishes whose organization is intermediate between the more primitive forms and the modern spiny-finned teleosts. For this reason, these fishes are sometimes referred to as Mesichthyes. Examples of this group are trouts (*Salmo*) and pikes (*Esox*), (see Fig.2.41)

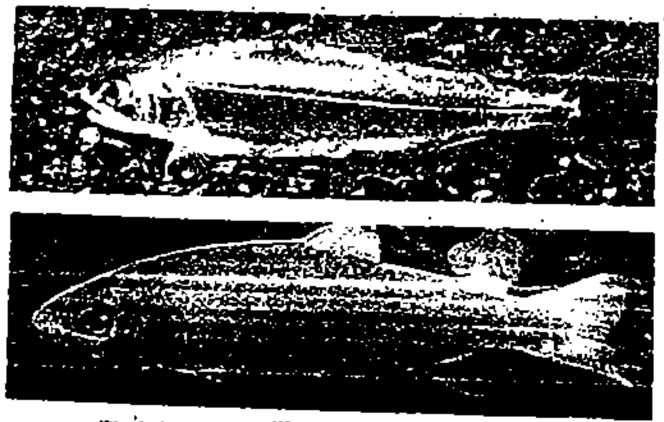


Fig.2.41: Rainbow trouts *Salmo.*

Superorder Stomiatiformes includes specialised teleosts like the light fish (*Gonostoma*); Superorder Scopelomorpha includes deep sea fishes like the lantern fish *Myctophus*. The Superorder Paracanthopterygii includes angler fish *Lophius*, deep sea angler *Photocorynus*, sucker fish *Echineis* (Fig. 2.42) and whiting fish *Gadus*. The Superorder Acanthopterygii that includes spiny finned fishes are the most abundant of all the actinopterygians.

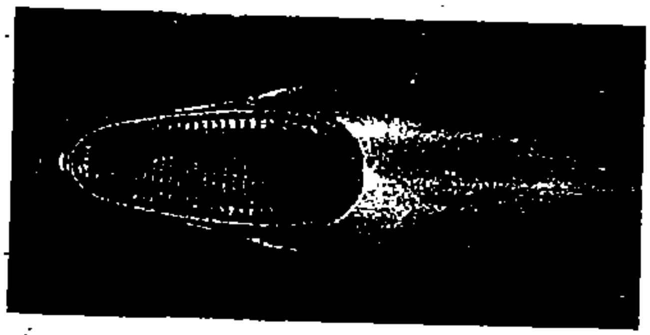
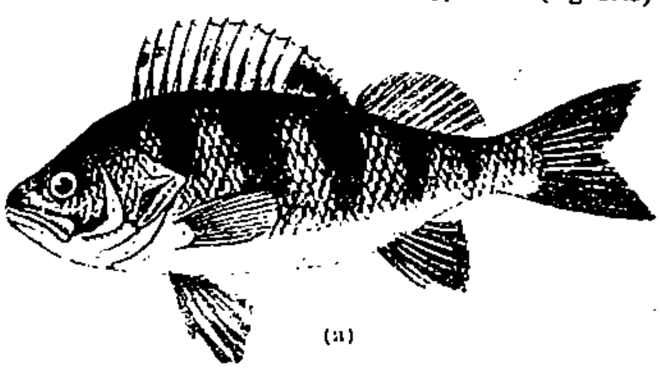


Fig.2.42: Sucker fish *Echineis.*

Also they are highly developed teleosts. These fishes are characterized by the presence of stiff spines at the front of the dorsal and anal fins, hence the name spiny finned fishes. Teeth are borne on the margins of premaxilla. The maxilla which lacks teeth functions as a lever to push the jaw forward to suck in the food. The duct of the swimbladder is closed, body is shortened and pelvic fins are moved far forward. The group includes a number of modern fishes such as perches (*Perca*) (Fig. 2.43a) mullet (*Mugil*) (Fig. 2.43b), flat fishes (*Pleuronectus*), sole (*Solea*) the stickle back *Gasterosteus*, pipe fish *Syngnathus*, sea horse *Hippocampus* (Fig.2.44) and a number of other species. This superorder also includes flying fishes *Exocoetus, Cypsilurus* (Fig. 2.45) and garpike *Belone*.



(a)

(b)

Fig.2.43: (a) Common perch *Perca* (b) The mullet *Mugil.*

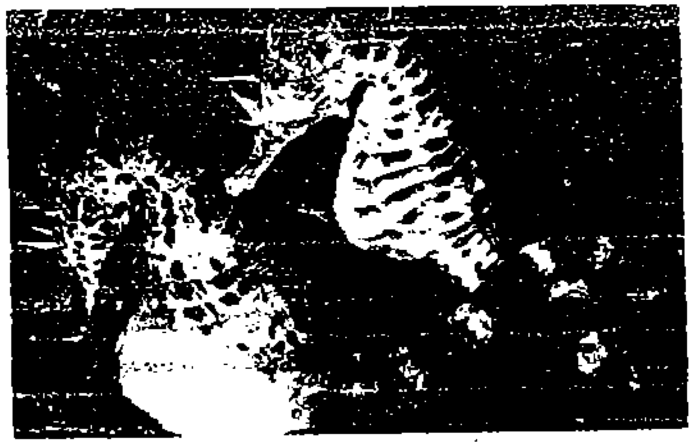


Fig. 2.44: Sea horse *Hippocampus*. Male and female. The male does all the parenting and carries the developing embryos in the pouch.

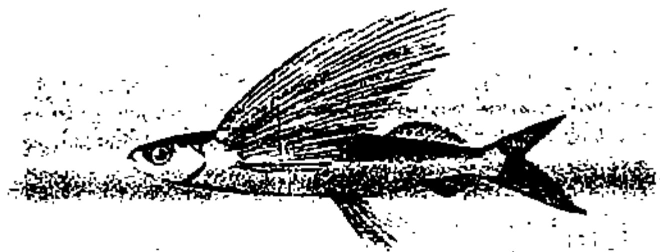


Fig. 2.45: Flying fish *Cypselurus*.

SAQ 3

In the following sentences strike out the inappropriate word form the alternatives provided :

a) Class Osteichthyes appears to have originated during the middle Paleozoic/Mesozoic era.

b) Majority of fishes are carnivorous/herbivorous.

c) Bonyfishes constitute a small/high proportion of human food.

d) Genus *Latimeria* belongs to the suborder Rhipidistia/Coelacanthiformes.

e) Crossopterygions have heterocercal/diphycercal tail.

f) *Latimeria* can be regarded as a fossil/living fossil.

g) Dipnoans have hyostylic/autostylic jaw suspension.

h) Genus *Neoceratodus* has unpaired/paired swim bladder.

i) Chondrostei include fishes that are primitive/advanced in organisation.

j) Sturgeons make anadromous/catadromous migration to breed.

k) The two living genera of Holosteans *Amia* and *Lepisosteus* are marine/fresh water forms.

l) Bow fins have cycloid/placoid scales in their skin.

m) Teleosts possess homocercal/diphycercal tail.

n) Fishes which live in waters of low oxygen content have a high/low rate of respiration.

o) Fish larvae are filter feeders/carnivorous.

p) Swimbladder is absent in pelagic/bottom living fishes.

q) The conus arteriosus of teleost fishes is muscular/thin walled.

r) Much of the nitrogenous excretion in teleosts is carried out by gills/kidney.

s) Fresh water teleosts pump excess/less water through mesonephric kidneys and discharge very dilute/concentrated urine.

t) In marine telosts a well developed glomerulus is present/absent.

u) In teleosts the excretory and genital systems are integrated/separated.

2.3.7 Some Common Fresh Water Fishes of India

The major river systems of India support a rich fish fauna. The physico-chemical and the hydrobiological factors of these systems are quite condusive for the life of fishes and their reproduction. The river systems also support a variety of other organisms including phyto- and zooplankton which form the feed organisms of fishes. The major river systems of India are: (1) the Ganga river system which includes rivers Ganga, Yamuna, and Gandhak; (2) the Brahmaputra river system; (3) East coast river system which includes rivers Godavari, Krishna and Cauvery; and (4) West coast river system that includes rivers Narmada and Tapti.

Fishes found in Ganga river system are carps such as *Labeo rohita* (Rohu, see cover page of the block), *Cirrhinus mrigala* (mrigal) (Fig. 2.46a), *Catla catla* (catla) (Fig. 2.46b), *Labeo calbasu* (Calbasa) (Fig. 2.46c) and the clupeid *Hilsa* (Fig. 2.46d). Other miscellaneous species such as *Pangasius*, *Silonia silondia*, *Setipinna phasa*. *Rita rita*, *Cirrhinus reba*, *Bagarius bagarius* are also present. The Brahmaputra river system supports nearly 126 species of fish fauna belonging to 126 families of which 41 species are of commercial importance. Catfishes, major and minor carps and hilsa constitute prominent species of this region. *Wallago* among catfishes and *L.rohita* are the dominant catches of the river system.

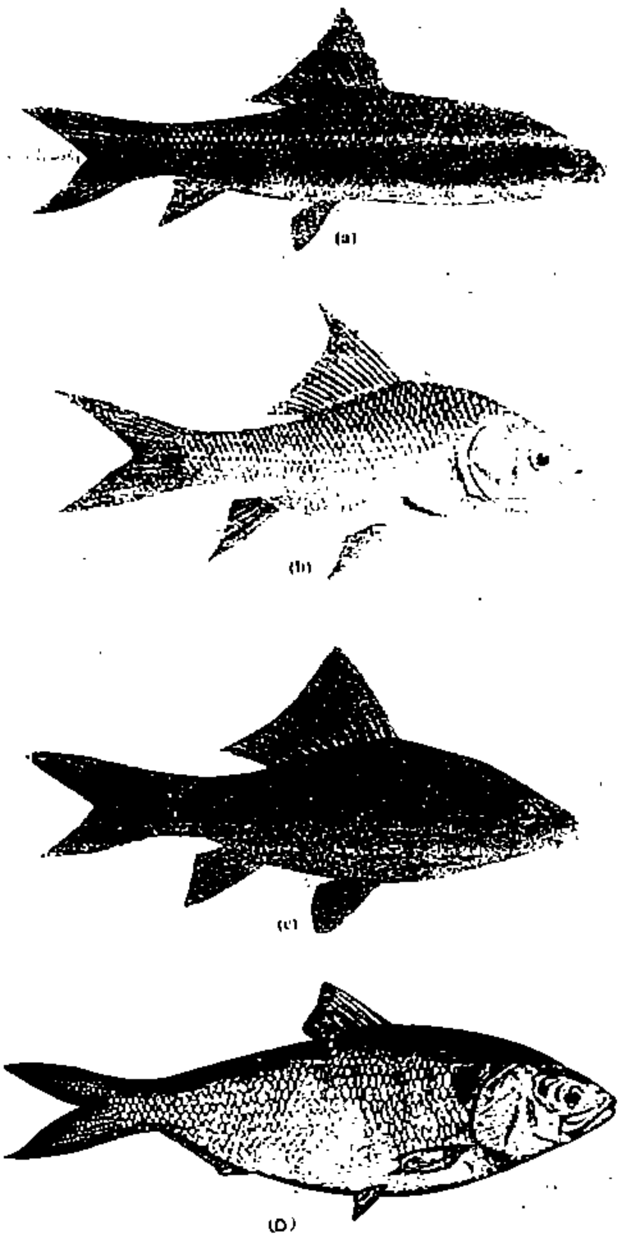


Fig. 2.46: Freshwater fishes of Ganga River System
a) *Cirrhinus mrigala* b) *Catla catla* c) *Labeo calbasu* d) *Hilsa ilisha.*

Among the rivers of the East coast systems, Godavari supports (1) carps *L.fimbriatus. C.mrigala, L.calbasu* and *C.catla* (2) catfishes *Mystus seenghala, Mustus aor, Silonia.childreni, W.attu P.pangasius* and *B.bagarius* and (3) *H.ilisha*. In river Cauvery about eighty species of fishes belonging to 23 fmilies are reported to be present. Among carps, *Acrossocheilus hexogonolepis, Tor pulitora, Barbus cardius, B.dubius, L.ariza* and *C. cirrhosa* are some important species. Imported catfishes *Glyptothorax madagaskariensis, Mustus aor, M.seenghala, P.pargasiens, W.attu* and *S.silondia* are also found in river Cauvery. Murrels such as *Channa marulius* and feather backs such as *Notopterus notopoterus* are also found in Cauvery. Gangetic species *Catla catla, L.rohita, C.mrigala*, and exotic species *Cyprinus carpio* and *Osphronemus gorany* are also introduced in River Cauvery.

River Narmada of West coast river system supports carps *Tor tor, L. fimbriatus, L.calbasu* and *C.mrigala*, catfishes *Ritu parimentata, M.seenghala, W.attu* and *M.aor*. More or less similar species are found in river Tapti also.

2.4 AMPHIBIA

One of the most significant events to have occurred during the course of animal evolution is the movement of animals from water to land. The shift from aquatic to terrestrial environment required varied structural, functional and behavioural modifications in the organisms. In fact such changes required alterations in almost every system of the body. This also explains the basic similarities in the fundamental structural and functional pattern of all vertebrates. Although among the vertebrates, amphibians were the first one to make the transition to land, among the invertebrates insects had done it much earlier and plants were the earliest. But among all the organisms that made transition to land, amphibians can be regarded as an important group as their descendents are the most advanced animals on land. The organisational modifications that were required for switching over to life on land were (i) the ability of the organism to support its weight (ii) resist drying and rapid temperature changes and (iii) extract oxygen from air. In the Devonian period, some 400 million years ago, the climate was characterised by alternating droughts and floods. The drought resulted in the drying up of fresh water bodies and those fishes that could not use atmospheric oxygen for respiration could not survive drought since their gills were unusable in such conditions. But many lobe finned and ray finned bony fishes did survive the drought periods because they had a lung developed as an outpocket of pharynx. With increased vascularisation and rich capillary network and a supply of arterial blood from the last pair of aortic arches, lungs became the primary organs of gas exchange in tetrapods. A pulmonary vein returned the blood to the heart that completed the pulmonary circuit. Thus the phenomenon of double circulation came to be established, with the systemic circulation serving the body and the pulmonary circulation supplying the lungs.

The evolution of pentadactyl limbs occurred during the Devonian period. The drying up of ponds and pools forced the fishes to move to neighbouring pools that still contained water. The crossopterygians used their lobed fins as paddles to lever their way across the land in search of water. Essentially, therefore, the limbs did not develop for purposes of colonisation of land but rather to live like a fish. But both lung and limb development were the adaptations that were required for a successful life on land. Most amphibians have to return to water (become temporarily aquatic) for purpose of reproduction. This means that these organisms still maintain their connection with the aquatic environment; hence the name Amphibia.

We shall now breifly look into some of the salient features of class Amphibia before describing their general organisation.

2.4.1 Salient Features of Amphibia

Frogs, toads, salamanders and blind worms are examples of Amphibia. Ampibia lack an exoskeleton. The endoskeleton is bony. The number of vertebrae differ in different groups. Some forms have ribs while others do not. A notochord is absent.

Body it may have an elongate trunk with a distinct head, neck and tail or it could be a depressed body with fused head and trunk and with no intervening neck. Skin appears smooth with many glands including some poison glands (Fig. 2.47), skin also contains pigment cells or chromatophores of different types. Generally scales are absent but in some, dermal scales may be present.

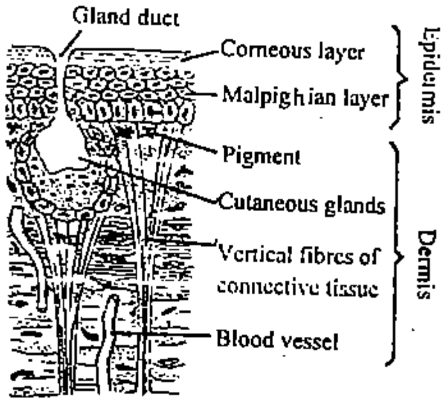


Fig.2.47: A section through frog skin.

Most of the amphibians have four limbs, while some have secondarily lost the limbs. In some forms forelimbs are shorter than hindlimbs and in some others all limbs may be very small and inadequate to be used for locomotion. Many forms have web in their feet as an adaptation to aquatic life. Nails and claws are often absent.

Amphibians possess large mouth with small teeth present both in upper and lower jaws. A pair of nostrils located in the snout region open into the anterior part of the buccal cavity. Skin, buccal cavity and lungs are the routes of oxygen entry for respiration. Salamanders lack lungs. Larvae show external gills (Fig. 2.48). They are also present in adults of some amphibians.

Fig.2.48 : Larva of salamander with feather like external gills.

Heart is a three chambered structure consisting of two atria and one ventricle and there is a double circulation through the heart (Refer to Unit 8 of this course). Skin is richly supplied with blood vessels and is always kept moist by mucous glands. Paired mesonephric kidneys are present. Amphibians excrete urea. Ten pairs of cranial nerves are present. Sexes are separate. Fertilization is external in frogs and toads but internal in salamanders and blind worms. Amphibians are predominantly oviparous. A few ovoviviparous and viviparous forms are present. Larvae undergo metamorphic changes before becoming adults. Eggs are mesolecithal (moderately yolked eggs) with jelly like membrane covering. The above mentioned features can be regarded as characteristic of amphibians. You will now study the general organization of amphibians and subsequently briefly about the classification of the group. Essentially Amphibia includes three living order; order Anura includes frogs and toads; order Urodela includes newts and salamanders; and order Apoda includes blindworms.

2.4.2 General Organization of Amphibia

Among the amphibians frogs and toads can be regarded as the most successful organisms. Therefore, our study of the organization of Amphibia will mostly centre around this group. Amphibians generally have a smooth and moist skin. Local thickenings of epidermis often occur in Amphibia. For instance, in the skin of toads that is often dry, epidermal thickenings appear as warts (Fig. 2.49). Frogs have various forms of claws and pads on the feet. Such feet may be used for digging insects from the mud as is done by the clawed aquatic toad *Xenopus*.

Fig.2.49: A toad showing warts on its skin.

In *Leptodactylus* they may be used for burrowing. The horny teeth found in many amphibian larvae are also epidermal thickenings. The glands in the skin are of two types the mucous and poisonous glands. Mucous serves to keep the skin moist. Skin is a respiratory organ and therefore the surface needs to be kept moist for exchange of gases. The secretions of the poison glands are alkaline in nature and may cause an irritation of the eye and nasal epithelium. Limbs and supporting girdles —pectoral and pelvic girdles are present. The basic pattern of structure of limbs and girdles found in amphibians are retained in all the higher tertrapods. For a more detailed description of skeleton of limbs and girdles, you may refer to the Unit 11 of the Block 3 of this course.

In anurans (frogs and toads) both skeletal and muscular systems are specialised for swimming and jumping modes of locomotion. Frogs and toads are also capable of walking on land. Urodela that includes newts and salamanders that have a fish like body exhibit two types of locomotion. One is, they wriggle along the belly on the ground and thus can move fast especially when they are frightened. The second is the normal locomotion, when the animal raises its body on its legs and then propels it along as movable levers. It is believed that the tetrapod limbs should have arisen from the lobed fins of the crossopterygians. The lobed fins were used as levers "to swim on the land". The contraction of the muscles of the limb would move the limbs forwards and backwards relative to the body and thus assist in locomotion. Slowly the elongation of limbs took place and subsequently they were turned away from the body. The limbs then showed distinct bends downwards at elbow and knee, and upwards at wrist and ankle. This enabled the tetrapods to have a firm application to the ground as well as to raise themselves off the ground. The transformation is completed by bringing the limbs to the side of the body by rotation so that the elbow is pointed backward and the knee forward (Fig. 2.50).

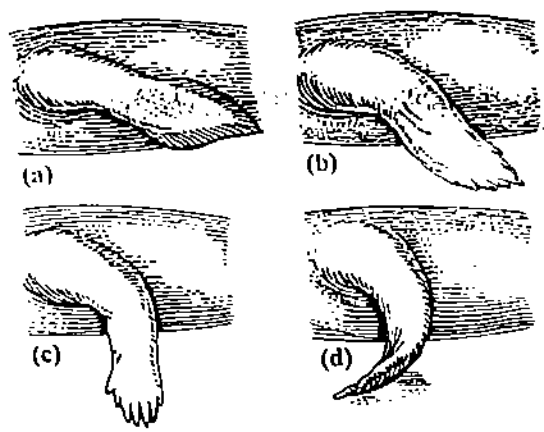


Fig.2.50: **Illustration showing the probable changes in position during the evolution of a tetrapod limb from a pelvic fin. (a) pelvic fin (b) double bends to give knee and ankle joints, and the foot directed backwards (c) and (d) rotation of tarsus and digits that turns the foot forward.**

Amphibians generally feed on invertebrates, mainly insects but may also eat worms, slugs, snails, spiders, centipedes and millipedes. The larval stage may be herbivorous or omnivorous. The tongue is an effective food capturing organ. In frogs and toads it is attached to the floor of the mouth anteriorly. The tongue is moist and sticky and is flicked outwards while catching the prey. Generally aquatic amphibians have a reduced tongue. In frogs and toads teeth are confined to upper jaw and they are useful in preventing the escape of the prey. Most urodeles have teeth in upper and lower jaws. The oesophangus of amphibians is short and the stomach is a simple tube. A pyloric sphincter is present between the stomach and intestine. (Fig.2.51) In adult amphibians intestine is a short tube and dilates into a large intestine that does the function of water absorption in terrsestrial animals. Liver and pancreas are the digestive glands.

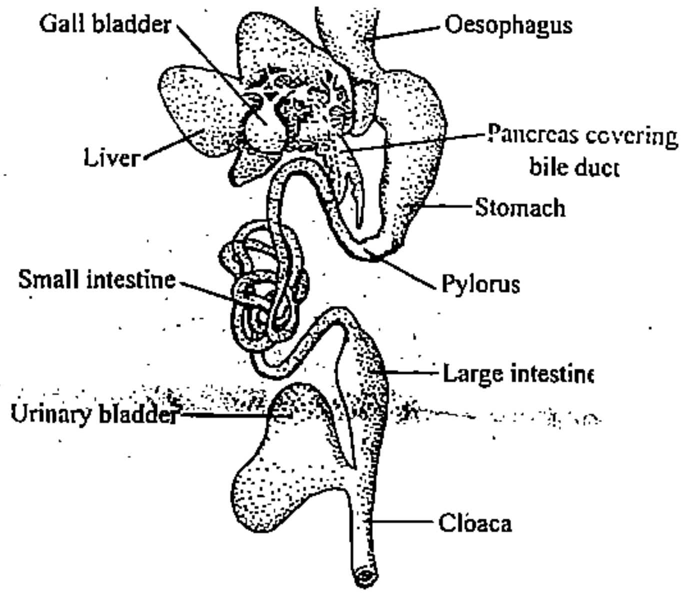


Fig.2.51: Digestive system of a frog.

Amphibians in general have varied means of respiration. Many amphibians, besides lungs use skin as an accessory respiratory organ. Lungs of frogs are paired sacs and open into a short laryngeal chamber. The laryngeal chambe. communicates, with the pharynx by a slit like opening, the glottis. For a detailed description of the structure and functioning of the respiratory system you may refer to Unit 7 Block 2. The richly vascularised skin as well as the buccal cavity play a significant part in exchange of gases.

In newts lungs have a hydrostatic function serving to lift the animal from water. For this purpose the inner surface of lungs is quite simple. In stream living forms, lung is entirely lost. In forms which live in cold waters, since the activity of the animals is much reduced the entire oxygen need of the organism is fully met by cutaneous (skin) respiration. In these forms skin is highly vascularised and lungs are much reduced. Gills are confined to amphibian larvae and neotenous adult urodeles.

In amphibians there is an incomplete separation of arterial and venous blood. In frogs, toads and salamanders the auricles are completely separated by an interauricular septum. The ventricle is a single chamber and is provided with spongy projection in the wall that prevents the mixing of oxygenated and deoxygenated blood to a large extent. The ventral aorta or the truncus arteriosus arises from the right side of the ventricle. From the truncus arteriosus three arches arise — the carotid arch that supplies blood to the anterior parts of the body, the systemic arch that supplies blood to the posterior parts of the body and the pulmonary artery that carries the blood to lungs. A more detailed study of aortic arches and their modification in different groups of vertebrates is provided in Unit-8 of Block 2 of this course.

The venous systems consists of a posterior vena cava that collects blood from the posterior organs of the body and drains into the sinus venosus. Most of the blood from hind limbs passes through the renal portal system before it enters the posterior vena cava. Also there is an alternate route in which the blood from hind limbs passes through the pelvic vein, and a median anterior abdominal vein that breaks into capillaries in the liver. The blood from forelimbs, skin and other organs of the anterior part of the body is drained into a pair of anterior vena cava which in turn empties it into sinus venosus (Fig.2.52)

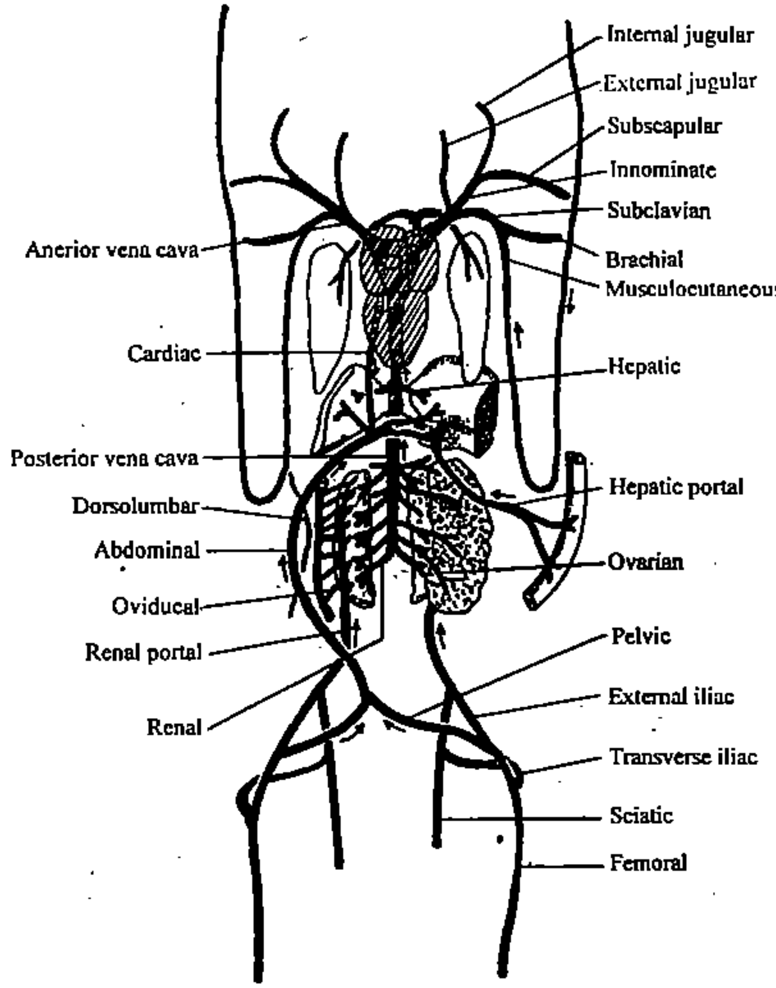


Fig.2.52: Venous system of frog.

Frogs also have a lymphatic system that consists of a set of spaces that communicate with tissue spaces around the capillaries. Lymph spaces in tissues join to form larger channels and great sinuses that lie below the loose skin of the frog. Lymph hearts that are sacs of endothelium covered by striated muscle fibers keep circulating the lymph fluid by rhythmic contractions. For a discussion on lymph and lymphatic system you may refer to Unit 8 of Block 2 of LSE-05 course.

RBCs of Amphibia are generally larger than 20 μm. Generally, red cells are formed in spleen and kidney although in some species bone marrow is the site of RBC production. Spleen is also the site of destruction of RBC; the life span of which is around 100 days. The haemoglobin of frogs has relatively less affinity for oxygen than is found in mammals. Lymphocytes, monocytes and polymorphogranulocytes are the three types of WBCs seen in blood. The polymorphogranulocytes may be neutrophils or acidophils or basophils. Thus there is a parallel between the mammalian leucocyte system and that of the amphibians. Frog's blood also carries platelets or thrombocytes that play a role in blood coagulation process.

Nervous system consists of a brain (Fig. 2.53) and spinal cord as found in Dipnoi fishes. Prosencephalon (forebrain) mesencephalon, (mid brain) and metencephalon (hindbrain) are the three regions of the brain. Olfactory lobes, large evaginated cerebral hemispherers and unpaired diencephlaon, shorter in frogs and larger in urodeles consitute the forebrain. Midbrain is dominated by well developed optic lobes. Hypothalamus and pituitary are located ventrally in the mid brain. The cerebellum is a simple and small structure. Amphibian brain is capable of regeneration after injury, more completely in urodeles than in anurans.

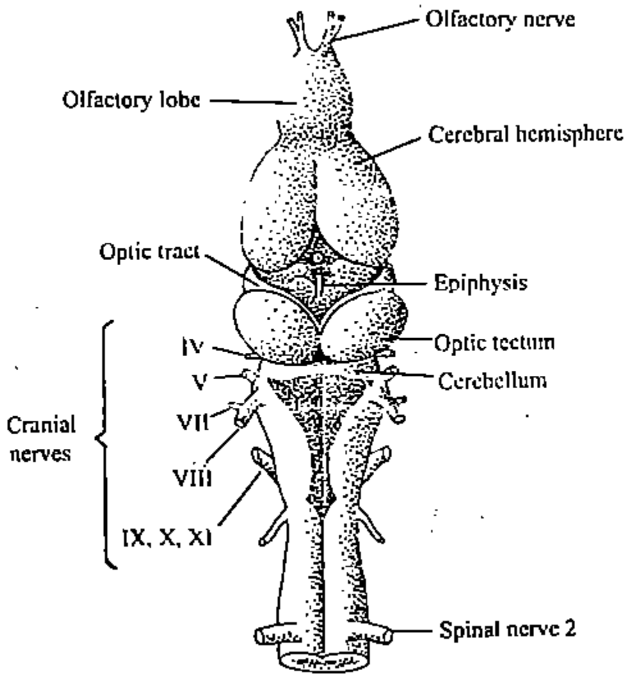


Fig.2.53: Brain of frog : dorsal view.

Amphibians possess various endocrine glands usually seen in mammals. The three divisions of the pituitary are clearly seen. Pituitary produces various tropic hormones (Refer to Unit 10 of Block 2 of LSE-O5 course). Paired thryroids and parathyroids that are derived from pharyngeal pouches are present. Ultimobranchial bodies that secrete calcitonin develop from the floor of last pharyngeal pouch. Adernal glands with ectodermal adrenaline secreting tissue and mesodermal steroid secreting tissues are developed for the first time in amphibians among vertebrates. In urodeles, adrenals are a spread out tissue whereas in frog they are compact orange masses lying over the kidneys. Pancreas contain islets of Langerhans with both a and b cells that secrete glucagon and insulin respectively.

Eyes are generally well developed in amphibians except in Gymnophiona and sight is the dominant sense in most species. To protect and to keep the eyes moist and free of particles, eye lids and lachrymal glands are well developed. A fixed upper eye lid, a movable lower eye lid and a nictitating membrane that can be pulled across the surface of the eye are the protective devices of amphibian eye. Amphibians like reptiles and birds lack an external ear. The tympanum is a round structure within the cavity of which lies a single middle ear bone the **columella auris**. The inner ear includes **sacculus, utriculus** and **lagena**, the **semicircular** canals and the two auditory structures — the basillar papilla and the amphibian papilla. The auditory structures of amphibians appear to be capable of discriminating various types of signals, such as mating calls, territorial calls, release calls, rain calls, distress calls and warning calls.

All aquatic larvae and some aquatic adults possess lateral line sense organs for maintenance of balance and equilibrium in the body. The organs are of simple type consisting of a group of cells in an open pit. The skin contains tactile sense organs and is also sensitive to chemical stimuli as well as to temperature changes. Taste buds in tongue appear to respond only to two types of taste, namely salt and sour. The olfactory function is carried out by the olfactory epithelia lining the internal nostril. A diverticulum of olfactory chamber — the Jacobson's organ — serves to test the 'smell' of the food in the mouth. The organ is absent in aquatic amphibians. The sense of smell is most developed in Apoda, as these organisms are blind.

Anuran amphibians have vocal organs that enable them to make noise. Both sexes have vocal organs and those of males are larger. Male frogs use them for making calls to attract females. Certain urodeles also make noise: some by means of larynx and others by lips during inspiration.

Amphibians have mesospheric kidney. Frogs and toads have relatively compact kidneys whereas those of urodeles are elongated. Ureter generally arises from the anterior margin of kidney. Frogs with their moist skin face the threat of being flooded with water osmotically while in the aquatic habitat and being desiccated while on land. The water content of the body is regulated by a complex control system located in the hypothalamus. While in water, flooding is prevented by the efficiently pumping glomerulus as they can filter water 1/3 of the weight of the body per day. While on land, a larger urinary bladder does the resorption of water as the resorbing segment in Henle's loop of nephric tubule is very short. Certain desert forms have no glomeruli altogether in order to conserve water.

The genital system consists of paired testes in males (Fig. 2.54) and sperm are discharged into the mesorephros by vasa efferentia. This is in contrast to what is seen in modern fishes which have acquired separate urinary and genital ducts. In the genus *Alytes* sperm do not pass through the kidney. Ovaries are sac like structures formed from peritoneal folds. Eggs are surrounded by follicle cells that appear to produce ovarian hormones. The nucleus of eggs of urodeles have large chromosomes with high DNA content and are known as lamp-brush chromosomes. Eggs leave the ovary and find their way to the mouth of oviducts — the Mullerian ducts, the walls of which are muscular and glandular, and secrete albumen. The oviducts are dilated at the lower end forming ovisacs in which eggs are stored until they are released.

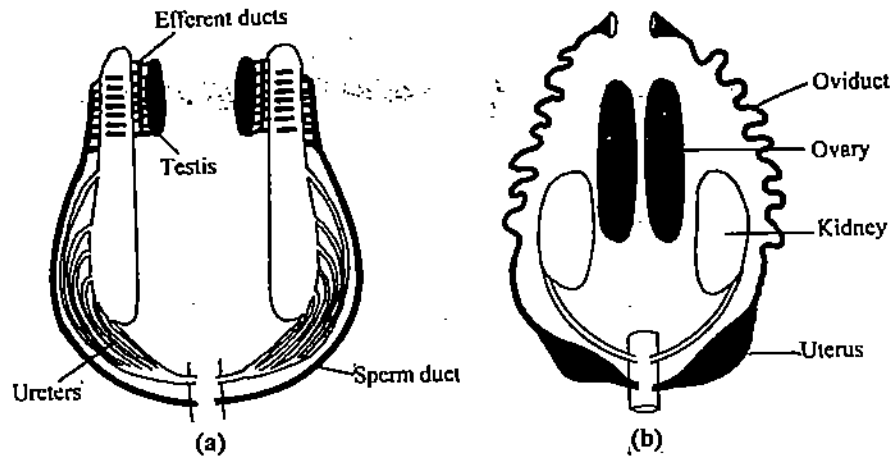


Fig.2.54: Urinogenital system of frog (a) male (b) female.

Fig.2.55 : Forelimb of male frog with nupital pad.

Since many of the amphibians are not completely adapted to life on land, they return to water each year to breed. Some frogs migrate several kilometers to the breeding site and prefer to visit the same pond each year. Pronounced sexual dimorphism is seen in many amphibians. Male frogs attract females by making mating calls. The louder and larger calls are more attractive to females and more inhibitory to other males. In toads sexual activity and the calls alternate with each other. Rainfall is one of the influences that initiates mating calls in frogs. During copulation, male clings to the back of the female with the 'nuptial pad' developed as an extra digit in the forelimbs (Fig.2.55). Newts exhibit elaborate courtship behaviour before the actual mating. In newts sperms are bundled into spermatophores before they are transferred to females.

Thus far you have studied structure and organisation of amphibians. You shall now study three major groups of living amphibia — the order Anura — the tailless Amphibians, order Caudata (Urodela) — the tailed Amphibians and order Gymnophiona (Apoda) — the limbless Amphibians. To date more than 3900 living amphibians have been described. The three orders of living amphibians are grouped into subclass Lissamphibia. We will begin the study with order Anura. But before you do so, attempt the following SAQ.

SAQ 4

I. Answer the following questions briefly.

i) What were the basic organizational modifications required when the vertebrates switched over from an aquatic environment to a terrestrial environment?

....

....

....

....

ii) What is meant by double circulation?

....

....

....

....

....

iii) List any five salient features of class Amphibia?

....

....

....

....

II. State whether the following statements are true or false:

a) The pattern of structure of limbs and girdles found in amphibians is different from those found in higher tetrapods. (T/F)

b) Skeletal and muscular systems of urodeles are specialised for swimming and jumping modes of locomotion. (T/F)

c) The larval stages of amphibians are herbivorous or omnivorous. (T/F)

d) In frogs and toads teeth are present in both upper and lower jaws. (T/F)

e) Many amphibians use skin besides lungs as an organ of gas exchange. (T/F)

f) Gills are used as respiratory organs in larvae of Anura and in adults of urodeles. (T/F)

g) The systemic arch that arises from truncus arteriosus supplies blood to the anterior parts of the body. (T/F)

h) The blood collected from the arterior and posterior venae cava are emptied into sinus venosus. (T/F)

i) The haemoglobin of amphibians has a higher affinity for oxygen than that found in mammals. (T/F)

j) In case of injury, the regenerative capacity of urodele brain is greater than that of anurans. (T/F)

k) Among vertebrates, amphibians are the first group to develop adrenaline secreting ectodermal tissue and steroid secreting mesodermal tissue in the adrenal gland. (T/F)

l) While living on land the resorption of water in frogs is carried out by urinary bladder. (T/F)

m) Absence of separate urinary and genital tracts and discharge of sperm into mesonephros through vasa efferntia are characteristic of male amphibians. (T/F)

2.4.3 Order Anura

Anurans are the most familiar and successful amphibians. There are more than 3400 species of frogs and toads known. The term Anura would mean lack of tail. And in anurans tail persists during development and in the larval stages only. Because of the leaping mode of locomotion, the order is also known as **Salientia**. Anurans are one of the oldest groups of amphibians and their fossil history dates back to Jurassic period, some 150 million years ago. In spite of certain inherent constraints anurans have come to occupy a great variety of habitats. Such constraints relate to the complusions of returning to water for breeding, and ectothermy that bars them from occupying polar and subarctic habitats. Some of the salient features of anurans are absence of a visible neck, fusion of the caudal vertebrae into a structure called urostyle (coccyx), absence of ribs in most species and enlarged hind limbs for leaping locomotion.

Frogs and toads are divided into 21 families. The most common genera are *Bufo, Rana, Hylas*, *Pipa* and *Xenopus* (Fig.2.56). Genus *Rana* includes 260 species and is one of the most abundant and successful group of frogs that has a cosmopolitan distribution spread over temperate and tropical regions of the world. *Rana* is not found in New Zealand, in oceanic islands and southern South America. *R. hexadactyla. R. tigrina, R.cyanophlictes* are some of the common species found in damp forest floors not far away from water.

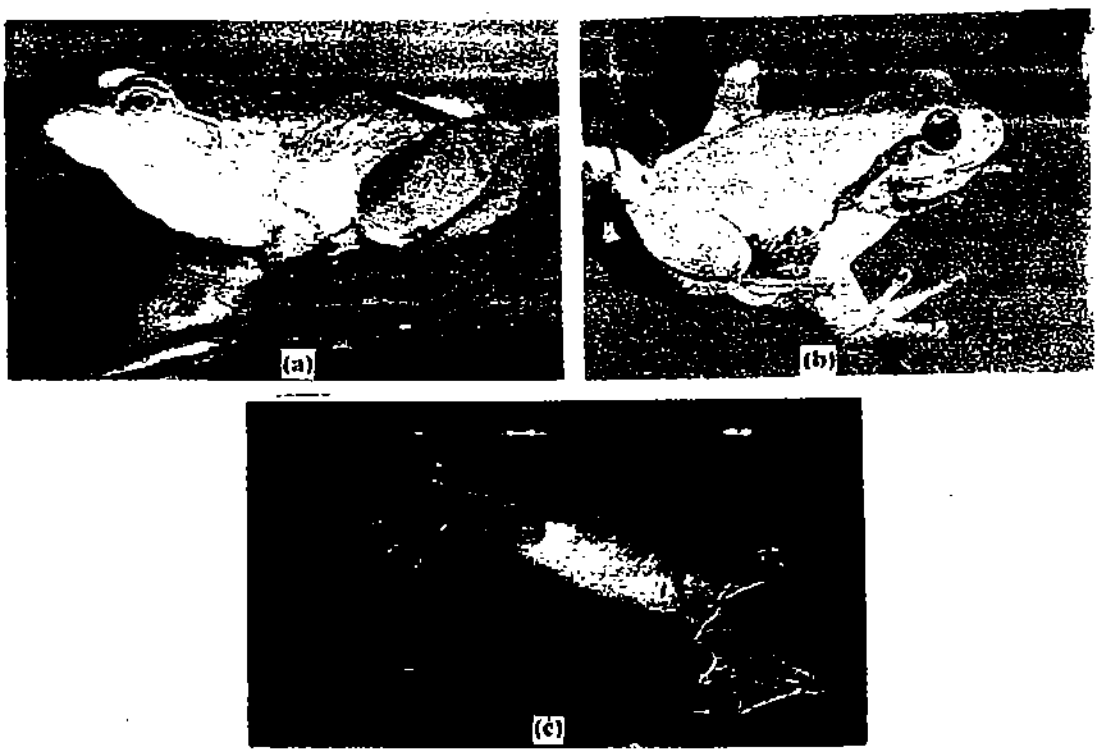


Fig.2.56: Some common anurans (a) *Rana* (b) *Hyla* (c) *Xenopus*.

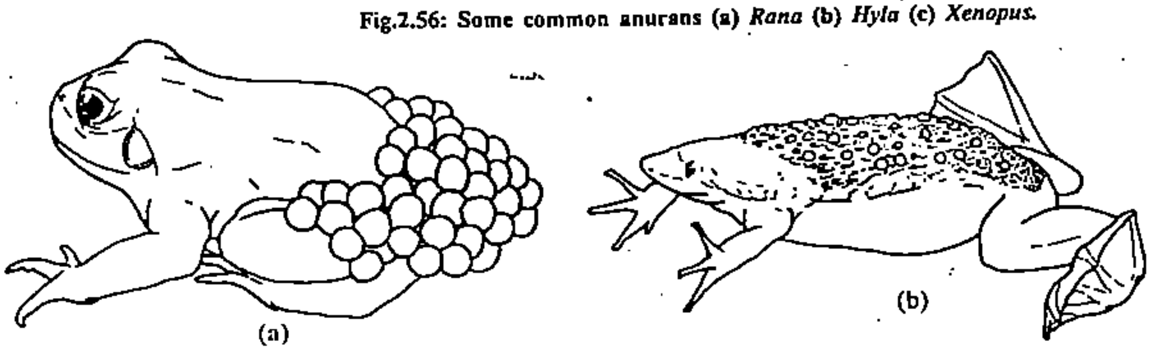


**Fig. 2.57: (a) *Alytes* midwife toad with eggs around his legs.
(b) *Pipa* female with eggs embedded in dorsum.**

The bull frog *R. catesbiana* and the green frog *R. clamitans* are found near permanent waters or swampy regions. *R.pipiens* lives in a wide variety of habitats and is the most widespread in America. Among toads, the bufonid toads are the most successful group. They are well adapted to terrestrial mode of life, but return to waters to breed. *Bufo* is a common genus that has worldwide distribution except in Australia and Madagascar and is known for parental care. In *Alytes* (Fig. 2.57a), the midwife toad of Europe, eggs are carried by the male wrapped around its legs. *Pipa* the South American aquatic frog has no tongue and has an elaborate arrangement by which the eggs are carried on the pits on the back (Fig. 2.57b). *Xenopus* is the African toad related to *Pipa* but does not exhibit parental care. Viviparity is not common among frogs and toads. A West African toad *Nectophrynoides* is the only genus to exhibit viviparity. Many frogs are tree living and well adapted to arboreal life. *Hyla* is a common tree living genus. The tree living frogs have developed pads in their toes. *Cacopus* and *Breviceps* are burrowing frogs which have a modified snout for burrowing purposes.

2.4.4 Order Gymnophiona

Gymnophiona are limbless amphibians, also known as caecilians or blind worms. The order is also known as Apoda. Nearly 160 species of Apoda are known. They have a long slender body with no limbs. Small scales may be present in the skin of some species. The animals have long ribs and many vertebrae. Their eyes are very small and reduced, and in some cases, totally blind. The subterrenean burrowing mode of living apodans explains the absence of eyes in these forms. The organisms are however provided with special sensory tentacles in the snout. They feed on subsoil insects and other small invertebrates. The skull is bony and solidly built to enable the organisms to burrow in soil. Fertilisation is internal and males have a copulatory organ Eggs are large and yolky. Cleavage is meroblastic. The eggs are laid on land and embryos have long plumed gills. *Ichthyophis* (Fig. 2.58) is a tropical apodan. *Typhlonectes* is a viviparous form.

Fig.2.58: ***Ichthyophis.***

2.4.5 Order Caudata

Order Caudata or Urodela includes tailed amphibians, the salamanders (Fig.2.59) and newts. They have a worldwide distribution but most species occur in north America. Most of the salamanders are small measuring around 15 cm in length, although some aquatic forms are considerably larger. A Japanese giant salamander measures 1.5m in length. Generally organisation and habitat occupation of urodeles are less specialized than that of the anurans. Adult urodeles do not differ much from the larval forms and the adults are well adapted to lead an aquatic life. In urodeles adaptations in different species range from life suited exclusively to terrestrial environments to a fully aquatic life. The European salamander *Salamandra maculosa* is a terrestrial form that exhibits vivlparity. The mud puppy of North America *Necturus* is a fully aquatic form.

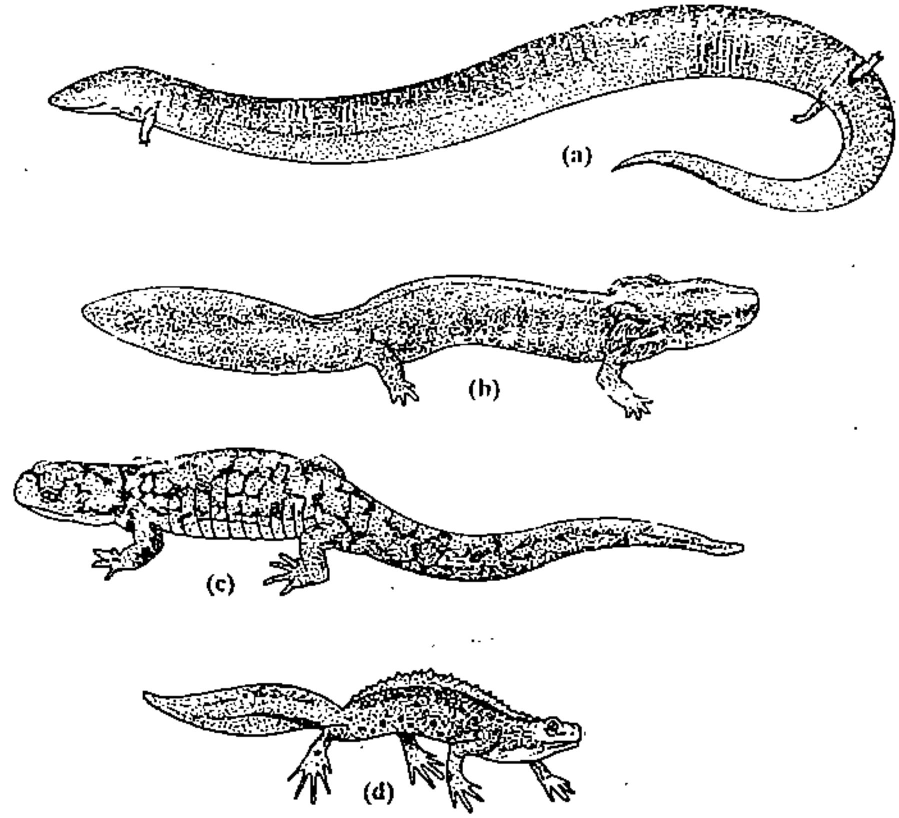


Fig.2.59: Newts and Salamanders (a) *Amphiuma* (salamander)
(b) *Necturus* (salamander) (c) *Triturus* (newt)
(d) *Ambystoma* (salamander)

Limbs of salamander are quite primitive, are of equal size and lie at angles to the body. Most of them feed on moving objects. They are all carnivorous, preying on worms, small arthropods and molluscs.

The young ones that emerge from eggs have gills. Gills are usually lost during metamorphosis except in aquatic forms and in those that fail to undergo complete metamorphosis. Many forms do not possess lungs and in some lungs are much reduced. In all of them, skin is richly vascularised and serves as an organ of gas exchange. Cutaneous respiration is supplemented by pumping air in and out of mouth, across the vascularised membrane of the buccal cavity.

Fertilization in most salamanders is internal and sperm transfer is via spermatophores. Aquatic species lay eggs in clutches in water and terrestrial forms deposit them in small grape like clusters under logs or below the soft earth. Parental care of eggs is quite common among salamanders which are observed to guard the eggs. Larvae that hatch out of the eggs resemble their parents and undergo metamorphosis in the course of development.

An interesting aspect of urodele development is neoteny. Neoteny essentially refers to the attainment of sexual maturity in larval condition. Further there is a retention of larval characters in the adulthood. Some neotenous forms remain permanently as larvae and their developing tissues fail to respond to thyroxine hormone that induces metamorphic events. This is a genetically imposed condition and known as **obligate neoteny.** *Necturus* It is an example of obligate neoteny. The mud puppy lives in the bottom of ponds and lakes and retains external gills throughout life. Another genus *Amphiuma* is also an obligate neotenous form and has non-functional rudimentary legs. Some species of salamanders become sexually mature and breed as larvae but have the potential to metamorphose into adults if there are changes in environmental conditions. Such neoteny is called facultative neoteny. Genera *Ambystoma* and *Triturus* are examples of urodeles showing facultative neoteny. *A.tigrinum* as an axolotl larval form is aquatic, possesses gills and is reproductively active. But with drying up of water, the organism metamorphoses into an adult, develops legs and becomes a typical adult salamander. Facultative neotenous forms can be induced to metamorphose by treatment with thyroxine.

SAQ 5

Match the subclasses of Amphibia given under A with their characters given under B.

A		B	
1	Anura	(a)	tailed amphibians
		(b)	Absence of visible neck
		(c)	Presence of fused caudal vertebrae - coccyx.
2.	Urodela	(d)	limbless amphibians
3.	Apoda	(e)	presence of long ribs
		(f)	absence of eyes
		(g)	viviparity is common
		(h)	primitive limbs
		(i)	absence of tail
		(j)	presence of sensory tentacles in the snout
		(k)	occurrence of neoteny
		(l)	bony skull to enable burrowing in soil
		(m)	absence of ribs.

2.5 SUMMARY

In this unit you have learnt:

- Agnatha - the jawless fishes are the earliest vertebrates and are ancestors of fishes. Two groups of jawless fishes — the hagfishes and lampreys are known. The body of agnathans are eel like, rounded and raked. Paired appendages are present. Disc like mouth adapted for sucking or biting is found. Heart with an atrium and a ventricle and aortic arches in the gill region are present. Five to sixteen pairs of gills in hagfishes and seven pairs of gills in lampreys are present. In hagfishes anteriorly the pronephric kidneys and posteriorly the mesonephric kidneys are present. In lampreys only mesonephric kidneys are seen. Dorsal nerve cord with differentiated brain is present. Eyes are degenerate in hagfishes but well developed in lampreys. A larval stage, the ammocoete larva intervenes in the life cycle of lampreys.

- Fishes are poikilothermic gill breathing aquatic vertebrates. Chondrichthyes — the cartilaginous fishes and Osteichthyes — the bony fishes are two classes included under the superclass Pisces. Chondrichthyes includes rays, skates, sharks and chimeras. All of them have a cartilaginous skeleton, paired fins, well developed sense organs and a characteristic predaceous habit. Generally fishes have a fusiform body, ventral mouth, placoid scales and mucous glands in the skin. Endoskeleton is entirely cartilaginous. Intestine is provided with a spiral valve. High urea and trimethylamine oxide in blood aid in osmo- and ionic regulation. Mesonephric kidney is present. Oviparity, ovoviviparity and viviparity are observed. Fertilisation is internal.

- Osteichthyes - The bony fishes have successfully mastered and occupied all possible niches in the aquatic environment. Crossopterygii, Dipnoi and Actinopterygii are the three subclasses included under Osteichthyes. The living crossopterygian—a coelacanth fish *Latimeria chalumnae*, a 20th century discovery, is a large fish with gills as respiratory organs and is provided with a swimbladder as well. *Latimeria* is a living fossil. Dipnoans are represented by three genera. *Neoceratodus* has an unpaired swim bladder. *Lepidosiren* and *Protopterus* with paired swim bladders obtain nearly 98% of oxygen from the atmosphere as the swim bladder is modified for gas exchange. Actinopterygii, besides the modern bony fishes Teleostei, also includes two groups of primitive bony fishes Chondrostei and Holostei. Chondrostei represented by bichir, sturgeon and paddle fishes have primitive characters such as the presence of rhomboid scales, presence of a layer of denticles outside the scale and the presence of spiracles. The swim bladder resembles lungs. Chondrosteans are either fresh water or marine and if marine they migrate to fresh water to breed. Holostei includes bow fins and garpikes that are less primitive than Chondrostei. The living genera *Lepisosteus* and *Amia* are both fresh water forms. Bow fins which are more advanced than garpikes have a completely symmetrical tail, no spiracle, and scales reduced to single bony cycloid type.

- Modern bony fishes included under Teleostei are the most advanced of the bony fishes. With the help of the gas filled swim bladder they have achieved neutral buoyancy in water. The gills of teleosts with an efficient counter current flow between water and blood facilitate high rates of gas exchange. Kidneys and gills play significant roles in osmo and ionic regulation of ammonia and urea. Most of them are oviparous. The excretory and genital systems are completely separated in both sexes. Teleostei includes 35 orders, 488 families and 21,000 species.

- Amphibians are poikilothermic tetrapod vertebrates and use glandular skin, gills and lungs for respiratory exchange of gases Anura. The living, modern amphibians include three groups — Anura — the frogs and toads, Apoda — limbless, blind amphibians and Urodela — the tailed newts and salamanders. Of these three groups; frog and toads are largest group of amphibians having adapted to jumping mode of locomotion. As the name implies amphibians have a biphasic life cycle in which aquatic larva undergoes metamorphosis to produce a terrestrial adult that returns to water to lay eggs. A few frogs, salamanders, caecilians have omitted an aquatic larval stage and undergo direct development. Some apodans have evolved viviparity. A few salamanders have acquired a permanent larval morphology and do not venture into the terrestrial enviroment. These forms are neotenous. Life on land has led to the development of (i) tetrapod limb and the associated pectoral and pelvic girdles. (ii) respiratory structures that utilise atmospheric oxygen and (iii) sensory structures that facilitate sensory perception on land.

2.6 TERMINAL QUESTIONS

1. List any three characters each of cyclostomes that are primitive, specialized and degenerated.

   ....

   ....

   ....

   ....

   ....

   ....

   ....

   ....

2. List any six of the salient features of elasmobranchs.

   ....

   ....

   ....

   ....

   ....

   ....

   ....

   ....

[illegible] been responsible for the success of bony fishes in mastering the aquatic environment?

4. Briefly write on the origin of tetrapod limbs and terrestrial respiration.

5. Briefly explain the following terms.

(a) holostyly (b) diphycercal tail (c) swim bladder
(d) living fossils (e) neoteny

2.7 ANSWERS

Self Assessment Questions

1. 1. T 2.F 3.F 4.F 5.T 6.F 7.T 8.T 9.T 10.F

2. I 1.Placodermi, Chondrichthyes and Osteichthyes
2.Elasmobranchi and Holocephali 3. heterocercal 4. placoid
5.mesonephric 6. urea, trimethylamine 7. pectoral

II 1-c; 2-d; 3-a ; 4-g; 5-b ; 6-e; 7-h; 8-f.

III a) -T; b) -F; c) -T; d) -T; e) -T; f) -F; g) -T; h) -T

3. The following are the appropriate words to be retained.
a) Paleozoic; b) carnivorous; c) high; d) Coelacanthiformes; e) diphycercal; f) living fossil; g) autostylic; h) unpaired; i) primitive; j) catadromous; k) fresh water; l) cycloid; m) homocercal; n) high; o) filter feeders; p) bottom living; q) thin walled; r) gills; s) excess, dilute; t) absent; u) integrated.

4. I (i) (a) Ability of the organism to support its weight on land
(b) Ability to resist drying and rapid temperature changes
(c) Ability to extract oxygen from air.

(ii) In double circulation, the systemic circulation is concerned with the supply of oxygenated blood from the heart to different organs and organ systems of the body, and the collection of deoxygenated blood from the organs and organ systems to the heart. In the second circulation, the pulmonary circulation the deoxygenated blood reaches lungs for oxygenation and is then returned to the heart for supply to various parts of the body. The two circulations are isolated from each other, but the blood for any one circulation is provided by the other.

(iii)(1) Lack of an exoskeleton (2) Adapted to live both on land and water (3) Skin, buccal cavity and lungs are the respiratoty organs

(4) Predpominantly oviparous forms (5) Larvae undergo metamorphosis before becoming adults.

II a)-F; b) -F; c) -T; d) -F; e) T; f) T; g) -F; h) -T; i) -F; j) -T; k)-T; l)-T; m) -F.

5. 1) b,c,i,m; 2) a,e,h,k; 3) d,f,g,j,i,l.

Terminal Questions

1 (a) Primitive characters
(1) Absence of jaws and paired limbs
(2) Presence of diphycercal caudal fin
(3) Vertebrae either absent or poorly developed

(b) Specialised characters
(1) Sac like gill pouches
(2) Well developed external eyes and inner ear.
(3) Presence of pro and mesonephric kidneys

(c) Degenerate characters
(1) Lack of an exoskeleton
(2) Lack of ossification and endoskeleton
(3) Reduced liver and lack of gall bladder in adult lampreys

2 (1) Fusiform body, heterocercal tail, paired pectoral and pelvic fins, two dorsal median fins, pelvic fins in males modified as claspers.
(2) Skin with mucous glands and placoid scales
(3) Entirely cartilaginous endoskeleton
(4) Intestine with a spiral valve
(5) Circulatory system with seven pairs of aortic arches and respiration with five to seven pairs of gills.
(6) Mesonephric kidney, high concentrations of urea and triethylamine oxide in blood for the purpose of osmoregulation.

3 (1) Streamlined body, either eel-shaped or spindle shaped, that facilitates movement through water causing almost no turbulance.
(2) The presence of a gas filled swim bladder that enables to achieve neutral buoyancy and float in water.
(3) Gills designed as thin filaments covered with thin epidermal membrane that is folded repeatedly into plate like lamellae and richly supplied with blood vessels.

(4) Fresh water fishes are hyperosmotic regulators. They pump excess water through mesonephric kidney and thus form very dilute urine. The salt absorbing cells in the gill epithelium actively transport sodium and chloride from water to blood. Marine fishes are hypoosmotic regulators, their problem is the loss of water from the body and entry of excess salt into the body. The problems are solved by (i) drinking sea water (ii) removal of excess sodium and chloride from the body by salt-secreting cells located in the gills (iii) removal of divalent cations along with faeces (iv) removal of 10 to 40% of divalent cations through the kidney (v) highly reduced glomerular or aglomerular kidneys and very concentrated and hypertonic urine.

(5) The evolution of jaws has enabled the fishes to adapt to predatory mode of life. Thus many fishes are carnivores, several are herbivores and filter feeders that browse on microorganisms. Finally there are omnivorous fishes as well as scavengers and parasites. Fishes feed in a variety of ways.

(6) Migration for feeding and breeding and development is seen is fishes. Fresh water eels migrate to sea for spawning and sea living salmons migrate to fresh water for the same purpose.

4 (a) Origin of tetrapod limbs: The evolution of tetrapod limbs occurred during the Devonian period. The fishes had to move from the drying pools and ponds to the ones that still contained water. The crossopterygians used their lobed fins as paddles to lever their way across the land in search of water. The contraction of muscles of the lobes would move them backwards and forwards relative to the body and thus assist in locomotion. Slowly limbs elongated and were turned away from the body. This is followed by distinct bends in the limbs, downwards at elbow and knee, and upwards at wrist and ankle. This allowed tetrapods to have a firm application to the ground as well as to raise themselves off the ground. The transformation is completed by bringing the limbs to the side of the body by rotation. This resulted in the elbow being pointed backward and the knee forward (Refer to Fig.2.50).

(b) Origin of terrestrial respiration: Terrestrial respiration also appears to have originated during Devonian times, at a time when the climate altered between droughts and floods. The drought resulted in the drying up of fresh water bodies. Many lobe finned and ray finned bony fishes had a lung developed as outpocket of pharynx. With increased vascularisation and rich capillary network as well as a supply of arterial blood from last aortic arches, lungs became primary organs of gas exchange in tetrapods. A pulmonary vein returned the blood to heart to complete the pulmonary circuit. Thus a double circulation came to be established.

5 (a) Holostyly: Is a type of jaw suspension found in Holocephali. Here the upper jaw is fused with the skull and the lower jaw is suspended from it.

(b) Diphycercal tail: This type of tail occurs in hagfishes. The tail tapers to a point and the vertebral column extends to tip without upturning.

(c) Swim bladder: Swim bladder is a diverticulam from the pharynx or oesophagus in many fishes. Originally it was lateral in position but subsequently assumed a dorsal position. It may be a single lobe or it could be paired. In crossopsterygians and dipnoi it arises from the ventral wall of pharynx and the structure resembles lungs of vertebrates. Swim bladder is present in pelagic fishes but is absent in bottom living fishes. In pelagic forms, the ventral buoyancy is achieved by adjusting the volume of gas in the swin bladder. The adjustment enables the fish to remain indefinitely at any depth with no muscular effort. Gas is added to the bladder when the fish descends to greater depth, and when the fish swims up, the gas is removed from the bladder making the fish lighter.

(d) Living fossils: Living fossils are those organisms which have not undergone much change since their origin and hence retain all the primitive characters. The coelacanth fish *Latimeria chalumnae* originated during Devonian period and persisted unchanged for nearly 100 million years. Living fossil provides clues to orgin and evolution of specific groups of organisms.

(c) Neoteny: Neoteny is a developmental phemonemon in which a organism may attain sexual maturity during larval stage. The retention of larval characters in adulthood can also be called neoteny. The phenomenon is widly seen in certain urodele amphibians. *Nectures* and *Ambystoma* are examples of neotenous forms.

UNIT 3 REPTILES AND BIRDS

Structure

3.1 INTRODUCTION

You have already read in the previous unit (Unit 2, Block 1 of the LSE-10 course) about the class Pisces, members of which are completely dependent on water, throughout their life. You have also studied the amphibians, some of which may be able to live on land but have to go back to water to breed, indicating that they are not totally adapted to a terrestrial mode of life. In this unit and the next unit you will learn about those vertebrates like reptiles, birds and mammals which are totally land animals, and do not need to go back to water to lay eggs or to produce young ones.

In the present unit, you will study reptiles and birds. In reptiles which belong to the class Reptilia you will learn about the characteristics, classification, evolution, and the salient features of the four extant orders: Rhynchocephalia Chelonia, Crocodilia and Squamata and their adaptation to terrestrial life. In birds which belong to the class Aves, you will study in brief their characteristics, classification, evolution and adaptations to flight.

Objectives

After studying this unit you should be able to:

- describe briefly the evolution and affinities of reptiles (Class Reptilia) and birds (Class Aves),
- describe the adaptations of reptiles to terrestrial life,
- list and describe the characteristics of reptiles,
- outline the classification of the four extant orders of reptiles,
- describe the salient features of the four extant orders: Rhynchocephalia, Chelonia, Crocodilia and Squamata,
- distinguish between poisonous and non-poisonous snakes,
- list and describe the characteristics of birds,
- outline the classification of extant birds upto the level of order,
- explain and describe the adaptations of birds particularly in relations to flight,
- describe the social behaviour of birds.

3.2 ANAMNIOTES AND AMNIOTES

The adaptations of reptiles, birds and mammals to life on land were made possible by evolving a reproductive pattern that freed them completely from dependence on external water sources. This was achieved by adopting essentially a mechanism, of internal fertilization (fertilisation of the egg within the body of the mother) and most importantly by developing a harder egg that could be laid on land. Such an egg that is surrounded by an air rather than an aquatic medium evolved the following features (Fig. 3.1) : a tough protective yet permeable horny or occasionally calcareous outer shell and a series of embryonic membranes that form a complete set of life support system. Among the membranes, the yolk sac encloses enough yolk to provide nourishment to the embryo. The **chorion** membrane sheathes externally both the yolk and the embryo. The **allantois** allows for gas exchange and stores excreted metabolites in the allantoic cavity. The **amnion** encloses the developing embryo in a liquid filled-space — a replica of the ancestral pond.

As a result of the evolution of such an egg, also called **cleidoic egg**, the vulnerable aquatic larval stage, so characteristic of fishes and amphibians, was suppressed and the embryo developed within the safety of the hard egg which was laid outside the body of the mother, or within the mother's body. These three animal groups, the reptiles, birds and mammals are called amniotes **(Amniota)** because they all share the presence of the amnion. Fishes and amphibians lack such extra embryonic membranes including the amnion and so are called **Anamniotes (Anamniota).**

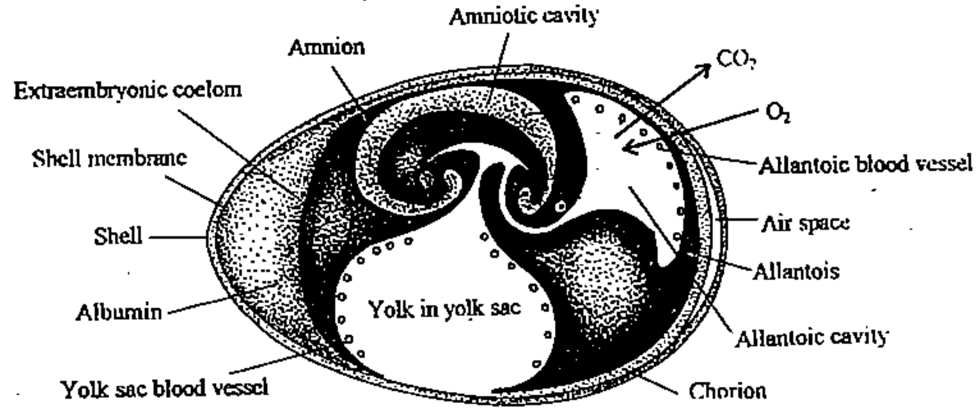


Fig.3.1 : Cross section of a bird embryo within the shelled egg, showing the four membranes of the amniote egg which surround and protect the embryo and its food supply. The shell permits gases to pass between the egg and the outside environment.

3.3 REPTILES

The study of reptiles is called herpetology (Gr-herpeton: reptiles)

Reptiles belong to the class Reptilia (rep-til'ea—L. repto, to creep) and were the first truly terrestrial vertebrates. They continued the colonization of land begun by the crossopterygian fishes and amphibians and became well adapted for existence on land.

3.3.1 Origin and Adaptive Radiation of Reptiles

Evolutionary biologists, in general, agree that a group of amphibian like tetrapods the labyrinthodonts, which evolved a reproduction strategy that freed them completely from dependence on external water sources gave rise to a monophyletic group of terrestrial amniote sometimes during the early Carboniferous period of the Paleozoic era (Fig. 3.2). This group separated into three lineages by the late Carboniferous that gave rise to vertebrates — the reptiles, birds and mammals. This as you have read in section 3.2 was made possible by the evolution of the cleidoic egg. Fig. 3.3 shows the evolution of the amniotes.

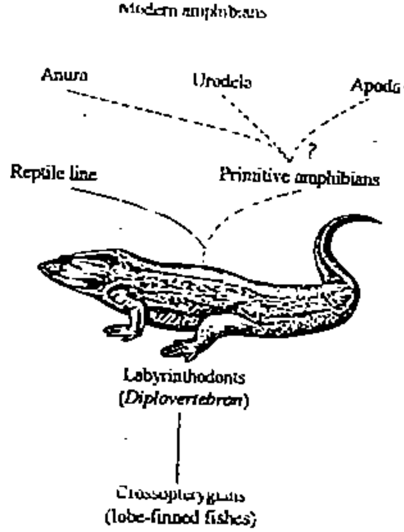


Fig.3.2 : **The labyrinthodont (*Diplovertebron*) shown here may have been the primitive amphibian from which both the reptiles and amphibians arose, although the lineage remains obscure.**

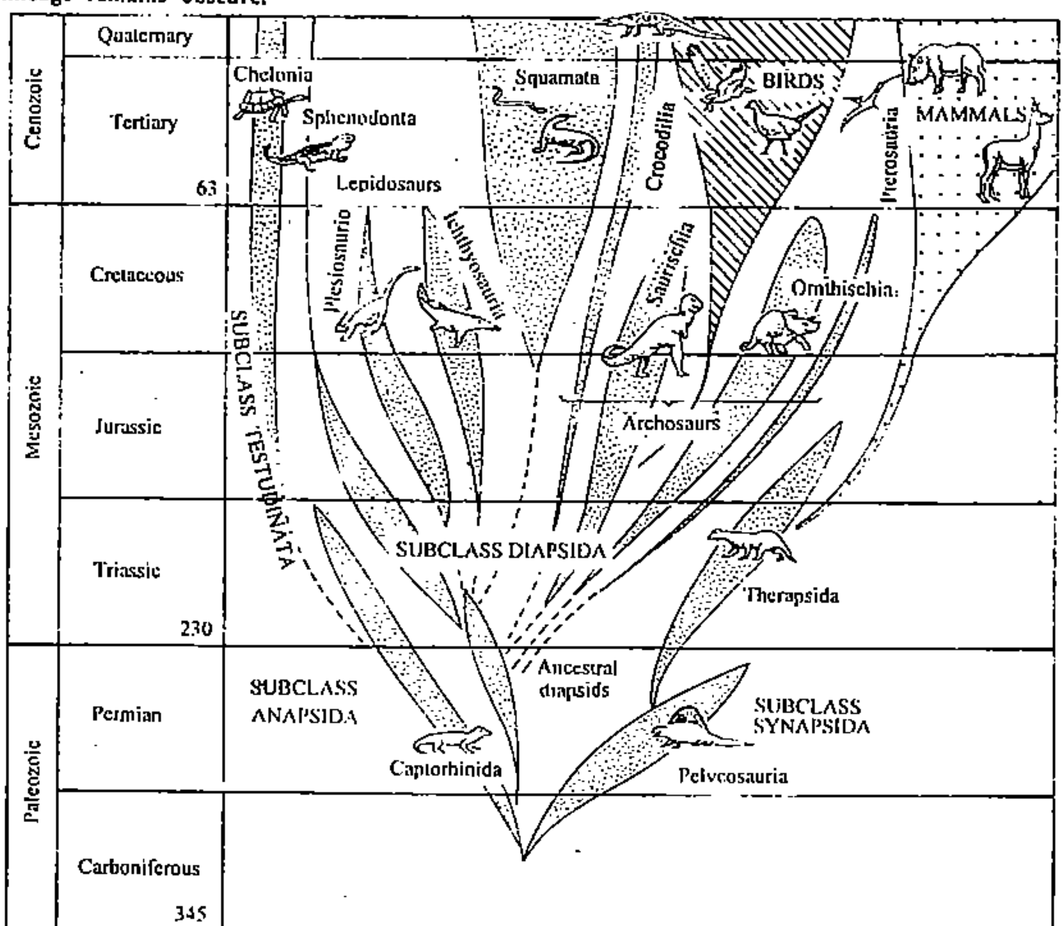


Fig.3.3 : **The phylogeny, geological distribution and evolution of the amniotic reptiles. The transition from certain labyrinthodont amphibian ancestor to earliest amnitoes was made due to the development of an amniotic (cleidoic) egg, which made land existence possible although this egg may well have developed before the earliest amniotes had attempted to move far on land. The amniotic assemblage, which includes the reptiles, birds and mammals, evolved from a lineage of small, lizard-like forms known as captorhinids, which retained the skull pattern of the amphibians. This was the anapsid lineage that led to the turtles. The first to diverge from the primitive stock were the mammal-like reptiles, characterized by a skull pattern termed the synapsid condition. All other amniotes including bird and all living reptiles except turtles, have a skull pattern called diapsid. The great Mesozoic radiation of reptiles may have been partially due to the increased variety of ecological habitats into which they could move. Note that reptiles are not a monophyletic group, as they encompass parts of three distinct evolutionary lines. Groups commonly assigned to the class Reptilia are those amniotes that are not birds or mammals.**

The remains of the early stem reptiles have been found in the fossilized stumps of primitive trees, dating back to the middle Carboniferus about 320 million years ago. The best known of the cotylosaurs is the Seymouria which so closely resembled the labyrinthodont amphibian that it has not been easy for paleontologists to set the two groups apart.

Reptiles diverged phylogenetically from the labyrinthodont amphibians during the late Paleozoic era, some 300 million years ago. The oldest stem reptiles from which the reptiles evolved are believed to be the captorhinomorphs or captorhinids (Fig. 3.4) which are placed in the Order Cotylosauria . These creatures resembled lizards superficially. Their skeleton was more thoroughly ossified than that of labyrinthodonts living at that time, and their limbs suggest that they were more agile. They probably fed upon small terrestrial arthropods that were becoming abundant at about the same time and were undergoing adaptive radiation of their own.

Reptiles being the first vertebrates that could penetrate terrestrial environment far beyond the shores of bodies of fresh-water, encountered few competitors upon land. They multiplied rapidly, spread into terrestrial niches available to them and specialized accordingly. Much of their adaptive radiation involved different methods of locomotion and feeding. Varied feeding patterns involved, among other things, modification of jaw muscles which in turn affected the structure of the temporal region of the skull from which the muscles originate. Skull morphology, therefore provides a convenient way to sort out the various lines of reptile evolution (Fig. 3.5). The skull of the captorhinids had a solid roof of dermal bone covering the jaw muscles dorsally and laterally (Fig. 3.5 a). This type of skull is called **anapsid** condition, for there are no temporal openings behind the orbits in the temporal roof bounded by bony arches. In other words the skull behind the orbits is completely roofed over with dermal bones. Captorhinids and their close relatives are placed in the subclass Anapsida. This group is represented today only by the turtles. Their morphology is an odd mix of primitive and specialized characters that has scarcely changed at all since the turtles first appeared in the fossil record in Triassic. As feeding patterns and jaw muscles underwent transformation, various types of fenestrae or openings evolved in the temporal roof overlying the jaw muscles. Some parts of the dermal roof were apparently not stressed and bone did not develop in such areas. Muscles can attach more firmly to the edges of openings and to bony ridges than they can to flat surfaces and they can bulge through the openings when they contract.

Fig.3.4: Captorhinid skeleton (fossil) from the Permian, about 285 million years ago. This specimen was about 25cm long.

The amniotes that evolved from the Captorhinids thus diverged by the late Carboniferous into three well defined line of evolution (Fig. 3.3) as given below :

1. **Anapsida:** as you know are represented today by turtles, in which the ancestral anapsid skull is retained.

2. Synapsida: include the mammals-like reptiles. Synapsid skull has a single pair of laterally placed temporal openings which originally lay ventral to the postorbital and squamosal bones. These openings are located low on the cheeks and bordered by a bony arch (Fig.3.5 b). Synapsids were the first amniote group to diversify, giving rise to pelycosaurs, later to therapsids which were mammal like reptile and considered to be ancestors of mammals and finally to mammals (Fig. 3.3).

3. **Diapsida:** The third lineage gave rise to all other reptilian groups and led on to birds (Fig. 3.3). The diapsid is characterized by the presence of two temporal vacuoties: one above and one below the post orbital squamosal bar. Thus one pair is located low on the cheeks as in synapsids, and a second pair is positioned above the lower pair and separated from them by a bony arch (Fig. 3.5 c). Three sub-groups of diapsids appeared. (1) The Lepidosaurs that include extinct marine

Some diapsids as they evolved jaw mechanisms that enabled them to open their mouths very widely secondarily lost one or both of the bars of bone bounding the temporal openings.

crocodiles. (2) The more advanced Archosaurs that comprised dinosaurs and their relatives and the living crocodiles and birds. (3) A third, relatively smaller line, the **Sauropterygians,** that included several extinct aquatic groups, the most conspicuous of which were the large, long-necked plesiosaurs.

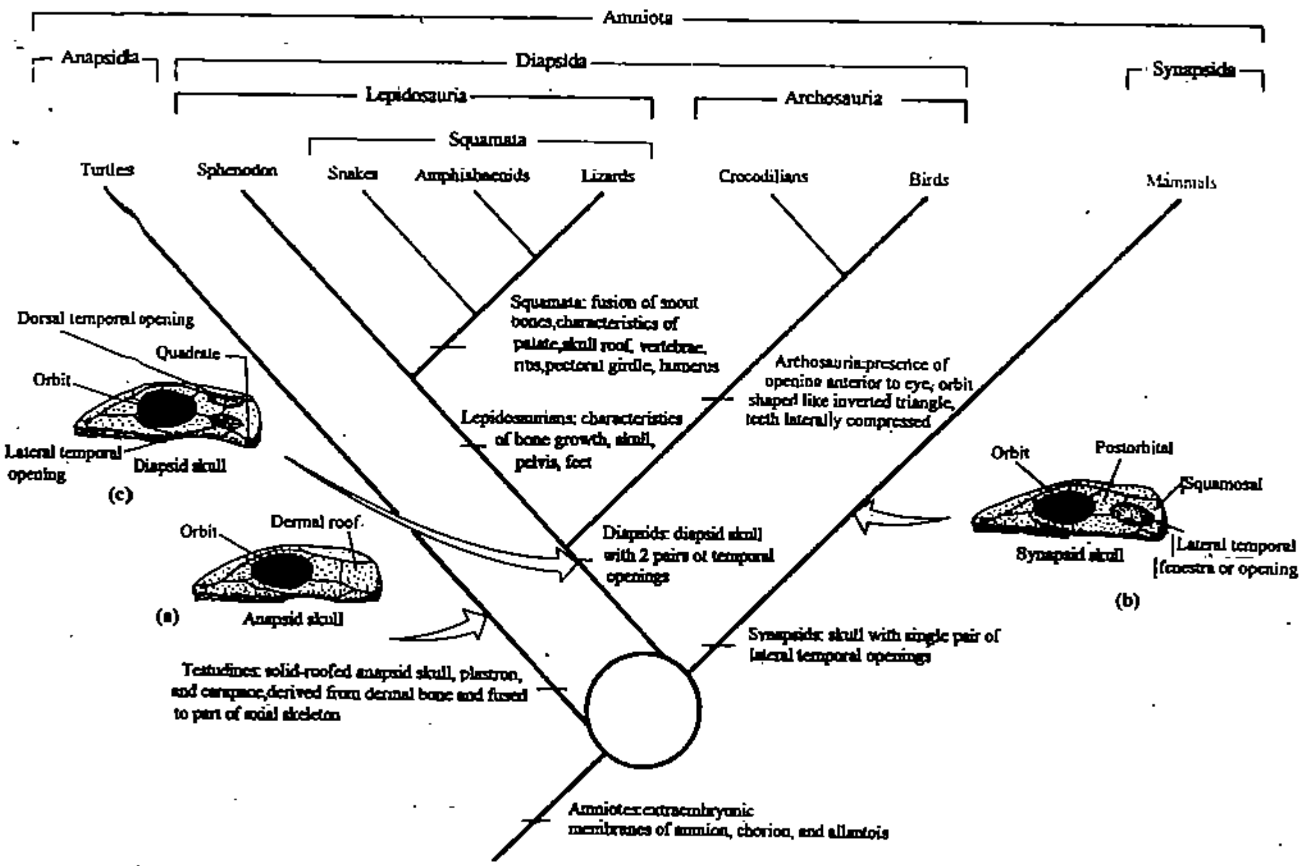


Fig.3.5: Cladogram of the Amniota. The relationship among the anapsids, diapsids, and synapsids is uncertain as indicated by the circle. Some of the shared derived characters (synapomorphies) that are diagnostic for the lineages are given. The skulls represent the ancestral condition of the three groups. The anapsid skull occurs in cotylosaurs and their modern descendants of turtles and tortoises. Two major groups, the diapsids and synapsids independently evolved from the anapsids. The skulls of modern diapsids and synapsids are often highly modified by loss or fusion of skull bones that obscures the ancestral condition. *Sphenodon* and crocodilians retain the primitive diapsid skull, but it has been modified in diapsid derivatives such as snakes, lizards and birds. a) The anapsid skull of a captorhinid; b) The synapsid skull of a mammal like reptile; c) the diapsid skull of a Sphenodontid.

The adaptive radiation of the class Reptilia, was specially pronounced in the Triassic period (which followed the Permian period) and corresponded to the appearance of new ecological habitats. The periods of Jurassic and Cretaceous seem to have been favourable to reptiles. Giant reptiles, the dinosaurs appeared during this period. *Brontosaurus* was a giant dinosaur measuring 20 meters in length and weighing almost 20 metric tons. It is said to be the largest animal to have ever walked the earth. During this time the following types of dinosaurs flourished: Pterosauria the flying reptiles (eg *Pterodactyles*), Ichythosauria the aquatic reptiles eg (*Ichthyosauria*), bipedal carnivorous Theropods, (eg *Tyranosaurus*), herbivorous Sauropods (eg amphibious *Diplodocus*) and a host of other reptiles. From the Archosaur dinosaurs arose crocodiles and birds. Reptile fossils are found in all continents except Antarctica. But the richest deposit of reptile fossils is found in North America.

The classical view of dinosaurs and other Mesozoic reptiles as witless, cold blooded beasts with inferior adaptability has been changing recently. Many biologists believe that dinosaurs were alert creatures, exhibiting behaviour, similar to that of today's lizards and crocodiles. Speculations that dinosaurs were fully endothermic (warm blooded) have generally been discounted, although because of their large size the dinosaurs probably benefitted from elevated and fairly stable body temperatures.

Fossils of dinosaurs eggs have been discovered in late Cretaceous deposits in Mongolia, China, India, France and United States. Most of these fossils are fragments of egg shells, but intact eggs containing embryos have also been found. These findings are believed to be of Sauropod dinosaurs and indicate that these animals had well-defined nesting grounds. Till recently all fossil dinosaur egg found were believed to be of herbivorous dinosaurs. However the skeleton of *Oviraptor*, a carnivore theropod dinosaur was found buried atop a nest of its own eggs in 1995 in Mongolia. This finding added new significance to a 1923 (70 years ago) discovery in the Gobi desert of a similar dinosaur attending a nest of eggs. At that time it was believed that the carnivorous dinosaur was an egg stealer. But with this recent find a group of scientists now believe that dinosaurs brood their eggs in a manner similar to birds, and that the fossil dinosaurs found were also brooding their eggs. However, there exists a controversy regarding this hypothesis as another group of scientists on the basis of studies of pelvic structure and ossification of bones of dinosaurs believe that the dinosaurs had a nesting pattern similar to crocodiles and not to birds.

Lizards appeared in Jurassic, snakes in Cretaceous, turtles in Triassic and crocodiles in late Triassic. Only members of these four reptile groups continue to exist today. The great reptiles i.e. the dinosaurs which achieved immense size, and ruled the earth for more than 60 million years during the Mesozoic era, drammatically disappeared and became extinct by the late Cretaceous approximately 65 to 85 million years ago. The factors responsible for their extinction are still a matter of conjecture.

3.3.2 Changes in Traditional Classification of Reptiles

The traditional classification of reptiles has recently undergone important changes due to the use of cladistic methodology in zoology and the insistence on hierarchical arrangement of monophyletic groups. Despite the fact that all the reptiles have a common ancestry, the class Reptilia is no longer recognized by cladists as a valid taxon since it is not monophyletic. **Usually the class Reptilia is defined as those amniotes which are neither birds nor mammals—that share common ancestry with reptiles. The class Reptilia is thus a paraphyletic group since it does not include all descendent of their common ancestor.** This is clearly seen in Fig. 3.2 which depicts the phylogenetic tree of amniotes. An example of this problem is the shared ancestry of birds and crocodiles. Based solely on shared derived characteristics, crocodilians and birds are sister groups and most closely related than with any other living animal group. They are recent descendants from a common ancestor and belong to a monophyletic group, apart from other reptiles. According to cladistic rules thus, birds and reptiles should be assigned to a clade that separates them from the remaining reptiles. This clade is recognized as Archosaruria (Fig. 3.3., Fig. 3.5), a grouping that also includes the extinct dinosaurs. Therefore, birds according to cladists should be classified as reptiles, specifically as saurischian dinosaurs, the reptilian group to which birds are most closely related. However, evolutionary taxonomists disagree and think that the birds represent a novel adaptative zone and grade of organization while crocodilians remain within the general reptilian adaptive zone and grade. In their view the morphological and ecological novelty of birds should be recognized by maintaining the traditional classification that puts crocodilians in the class Reptilia and birds in the class Aves. Such conflicting opinions between two major schools of taxonomy; the cladistics and evoutionary, have forced zoologists to re-evaluate their views of anmiote genealogy as to how vertebrate classification should be made to represent both genealogy and degree of divergence.

In the present unit we have retained the class Reptilia as followed by evolutionary taxonomists since this is the standard taxonomic classification. However we want you to be aware that this is subject to considerable revision.

3.3.3 Classification of Extant Reptiles

The earth at present does not harbour as many reptiles as it once did in the Mesozoic era. Out of the dozen or more main lines of reptiles that have been known to exist in reptile history, biologist have classified 16 orders of which 12 are extinct.

The four extant (surviving) orders comprise of about 7000 species and are clearly a successful group of reptiles, occupying a large variety of terrestrial and aquatic habitat. The most successful among these are lizards and snakes. The four extant orders are :

1. Testudines (Chelonia).
2. Sphenodonta (Rhyncoephalia)
3. Squamata
4. Crocodilia.

The classification of the living reptiles upto order is given here. The Linnaean classification is adapted from Carroll (1988). It agrees with the genealogical relationships of living reptiles shown in Fig. 3.2.

A. **SUBCLASS ANAPSIDA** (Literal meaning of the word an = without; apsida = arch). Anapsids. Primitive amniotes having a skull with no temporal opening.

a. **ORDER TESTUDINES (CHELONIA) : turtles** (330 species). Body in a bony case of dermal plates, consisting of a dorsal carapace and a ventral plastron; jaws with horny beaks instead of teeth; vertebrae and ribs fused to overlying carapace; tongue not extensible; neck usually retractable; quadrate immovable and anus in the form of a longitudinal slit.
Examples: tortoises and turtles.

B. **SUBCLASS DIAPSIDA :** (Di = two; apsida = arch) : **Diapsids**. Amniotes having a skull with two temporal openings. Two super orders (a) **Lepidosauria** represented by lizards, snakes, worm lizards and *Sphenodon* (b) **Archosauria** represented by the crocodilians.

(a) **SUPERORDER LEPIDOSAURIA :** Diapsid lineage appearing in the Permian; characterized by sprawling posture no bipedal specializations; diapsid skull often modified by loss of one or both temporal arches. The 2 orders of superorder Lepidosauria are as follows :

a.i **ORDER SPHENODONTA (RHYNCHOCEPHALIA): Tuatara.** Primitive diapsid skull; vertebrae biconcave; quadrate immovable; median, parietal eye present; transverse anal opening. *Sphenodon punctatus* is the only extant species.

a.ii **ORDER SQUAMATA : snakes** (2300 species), **lizards** (3300 species), **amphisbaenians** (135 species). Skin of horny epidermal scales or plates which is shed; teeth attached to jaws; freely movable quadrate; skull kinetic (except in amphisbaenians); vertebrae usually concave in front; anus in the form of a transverse slit, paired copulatory organs. The 3 suborders of the order Squamata are as follows :

1. **Suborder Lacertilia (Sauria) :** Lizards. Body slender, usually with four limbs; rami of lower jaw fused; usually movable eyelids; external ear present; paired copulatory organs.
2. **Suborder Serpentes (Ophidia) :** Snakes. Body elongate; limbs, external ear and middle ear absent; internal ear present; both pectoral and pelvic girdles absent (the latter persists as vestiges in boas and pythons), vertebrae of vertebral column numerous and shorter and wider than those of tetrapods, permitting quick lateral undulations through grass and over rough terrian; ribs present, increasing rigidity of vertebral column and providing more resistance to lateral stresses; neural spine of vertebrae elevated enabling the numerous muscles more leverage; mandibles joined anteriorly by ligaments; eyes capable of only little movement and are lidless since eyelids are fused into transparent cup or spectacle; tongue forked (bifid) and protrusible; conical teeth present on jaws and roof of mouth; left lung reduced or absent.
3. **Suborder Amphisbaenia (Worm-lizards):** Amphisbaenians. Body elongate and of nearly uniform diameter; no legs (except for one genus with short front legs); skull bones interlocked for burrowing (not kinetic); limb girdles vestigial; eyes hidden beneath skin; only one lung.

(b) **SUPERORDER ARCHOSAURIA:** Advanced diapsids, mostly terrestrial, but some specialized for flight. The order of superorder Archosauria is as follows :

b.i **ORDER CROCODILIA :** Crocodilians (25 species). Skull elongate and massive; nares terminal; secondary palate present; four-chambered heart; vertebrae usually concave in front (procoelous); forelimbs usually of five digits; hindlimbs of four digits; quadrate immovable; longitudinal anal opening; advanced social behaviour;
Example : alligators, gavials (gharials), caimans and crocodiles.

SAQ 1

a. State whether the following statements are true or false.

(i) The stem reptiles evolved from the labryrinthodont amphibians. True/False

(ii) The oldest stem reptiles were the therapsids. True/False

(iii) The archosaurs gave rise to the snakes. True/False

(iv) Fishes and amphibians are called amniotes. True/False

(v) Birds and crocodiles belong to a monophyletic group. True/False

(vi) All anamniotes lay their eggs or produce young ones on land. True/False

(vii) Skull morphology of reptiles provides a convenient way of sorting out lines of their evolution. True/False

(viii) The synapsids gave rise to the pelycosaurs. True/False

b. Fill in the blanks with appropriate words

(i) Lizards are placed in the suborder________________.

(ii) Snakes are placed in the suborder________________.

(iii) Worm-lizards are placed in the suborder____________.

c. Match the name of the animal given on the left in Column A with its order on the right in Columb B.

Animal (A)	Order (B)
i) Turtle	a. Crocodilia
ii) Lizard	b. Squamata
iii) Tuatara	c. Testudines
iv) Caiman	d. Sphenodonta.

3.3.4 Main Characteristics of Reptiles

In reptiles, water loss is minimized by the dry skin consisting of protective scales and few mucous secreting glands. This dry scaly skin however lacks elasticity and must be shed periodically as the animal grows.

1. Reptiles are amniotes that have evolved a cleidoic egg.
2. Shape of body may be compact in some and elongated in others.
3. Body covered with an exoskeleton of dry, horny, cornified skin or integument (not slimy) usually with epidermal scales or scutes on the surface. Bony dermal plates present in some. Skin has few glands.
4. Limbs paired usually with five digits or toes, each ending in a horny claw. Limbs suited for crawling, running or climbing or in marine turtles for swimming. They are reduced in some lizards and are absent in a few other lizards and in all snakes (vestiges are seen in certain boas).
5. Endoskeleton well ossified. Skull monocondylar (only one occipital condyle is present to articulate with the first vertebrae). Teeth homodont (all of the same type). Ribs with sternum (sternum absent in snakes) forming a complete thoracic basket. Two sacral vertebrae support the pelvic girdle.
6. In most reptiles the heart is either three chambered or imperfectly four chambered. The auricle is divided into two chambers the right and the left and the ventricle is only partially divided. Crocodiles, as a result of complete separation of ventricle have four chambered heart. In reptiles, there is separation of oxygenated (pure/arterial) and non-oxygenated (impure/venous) blood in the heart. Usually one pair of aortic arches is present. Red blood corpuscles are oval, biconvex and nucleated.
7. Cutaneous respiration is negligible. Reptiles respire mainly by lungs which are ventilated by changing body size. Gills are absent in reptiles. Pharyngeal and cloacal respiration is used in some aquatic turtles. In embryonic life, respiration is by branchial arches.
8. Reptiles are ectothermic (Heliothermic). However, they maintain a relatively high body temperature during their periods of activity by behaviourally controlling their exposure to sun. They are more active than amphibians.
9. Excretion by means of paired metanephric kidneys; uric acid is the main nitrogenous waste excreted.

10. Nervous system is provided with optic lobes on the dorsal side of the brain; and 12 pairs of cranial nerves in addition to nervous terminalis.
11. Paired tympanic ears have independently evolved in most reptiles from amphibians. They have been secondarily lost in some.
12. Sexes are separate, fertilization internal usually by copulatory organ found in males.
13. Eggs are large with much yolk and are covered by leathery or calcareous (limy) shells; usually laid and incubated outside but retained within the body for development by some lizards and snakes. Extra - embryonic membranes (amnion, chorion, yolk sac and allantois) present during development. Young ones on hatching (or on being born) resemble adults. Metamorphosis absent in reptiles.

SAQ 2

1. State whether the following statement are true or false.
   a) In reptiles endoskeleton is well ossified and the skull is monocondylar. T/F
   b) Reptiles are endothermic and maintain a relatively high body temperature. T/F
   c) Tympanic membrane has been lost in reptiles. T/F
   d) In reptiles, sexes are separate but copulatory organs are absent in males. T/F
   e) In reptiles, excretion is by means of metanephric kidneys and uric acid is the main nitrogenous waste product. T/F

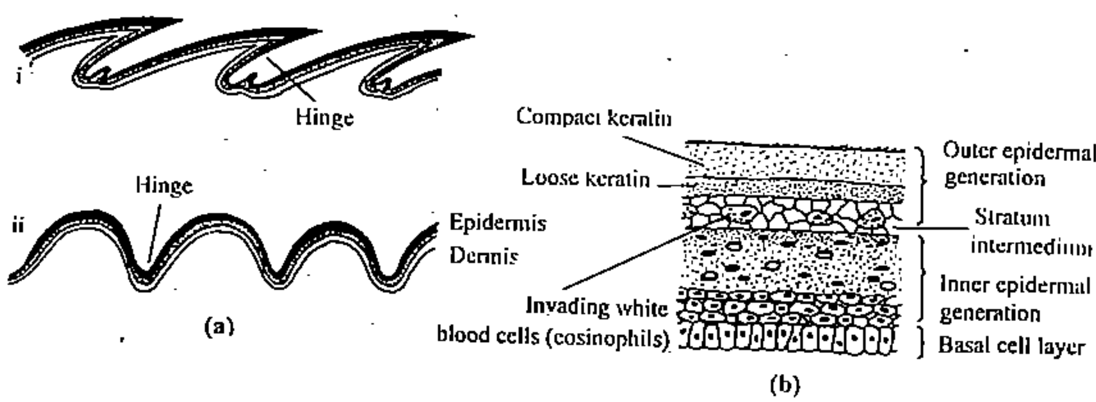
3.3.5 Distinguishing Features of Reptiles as Compared to Amphibians

Reptiles are well adapted to terrestrial life and are easily distinguished from amphibians by sever[illegible] ations which enable them to live in arid regions and in sea habitats that are inacc[illegible] :o the amphibians due to their reproductive requirements.

Let us stud[illegible] n detail the difference between reptiles and amphibians and the various adaptations [illegible]olved by reptiles in order to lead a completely terrestrial existence.

Integume[illegible]

The body of a reptile is covered by a tough, dry, leathery or scaly skin. Skin (Fig. 3.6) consists of (1) a thin epidermis, shed periodically and beneath it (2) a well developed, much thicker dermis. The epidermis is horny and contains a large amount of keratin, a water insoluble protein. The surface cells of the epidermis form the horny plates or scales which protect the body from harmful radiations, physical injury and dessication (by reducing the loss of body water).



6: **Reptilian skin : (a) Showing overlapping epidermal scales. Extent of projections and overlap of epidermal scales is variable among reptiles and even along the body of the same animal. Snake body scales (i) and tubercular scales of lizards (ii) are shown. Between the scales is a thin region of epidermis, a hinge allowing skin flexibility (b) Section of reptile skin prior to shedding: just before the old outer layer of epidermis is shed, the basal cells produce an inner epidermal generation. White blood cells, accumulate in the splitting off zone in order to promote separation of the new epidermis from older outer one.**

he newer or fresher cells develop deep within the epidermis and whenever or wherever ecessary replace surface epidermis. In some reptiles such as alligators, scales remain hroughout life growing gradually to replace wear. In them the skin is not shed in total.

The scales or plates of reptiles are not homologus to the fish scale which are bony dermal structures. Both the scales and claws of reptiles represent the exoskeleton.

In others such as snakes and some lizards, new scales grow beneath the old, which are then shed as a unit at intervals and replaced by the new skin. Turtles add new layers of keratin beneath the old layers of the platelike scutes, which are modified scales. The dermis of reptilian skin is provided with chromatophores, that give many snakes and lizards their colourful appearance and provides them protection from enemies.

Reptiles unlike fishes and amphibians have few glands in their skin. Some have scent glands that produce odiferous secretions, used by them for sexual and species recognition. Certian lizards and snakes have other glands which secrete sticky or irritating material in order to protect them to some extent from predators.

In some reptiles, bone may develop in dermis, beneath the horny scales as for example the bony plates in a turtle shell and the small nodules of bone in some crocodiles and lizards.

Skeleto-muscular System, and Locomotion

Reptiles have well ossified endoskeletons (Fig. 3.7) which are stronger than that of the amphibians. The skull is monocondylar. Teeth are homodont and fused to jaw bones. All reptiles except the limbless members have better body support than amphibians and more efficiently designed limbs for travel on land. During locomotion, the proximal segment of their front and hind leg moves back and forth close to the horizontal plane, as it does in the labyrinthodonts and salamaders. Many of the dinosaurs walked on powerful hind limbs alone. The thrust of hind legs is transferred to the vertebral column through two sacral vertebrae instead of a single one as found in amphibians. Feet have toes with claws which allow them to get a good grip upon the substratum. The muscular system is more complex in reptiles than in amphibians.

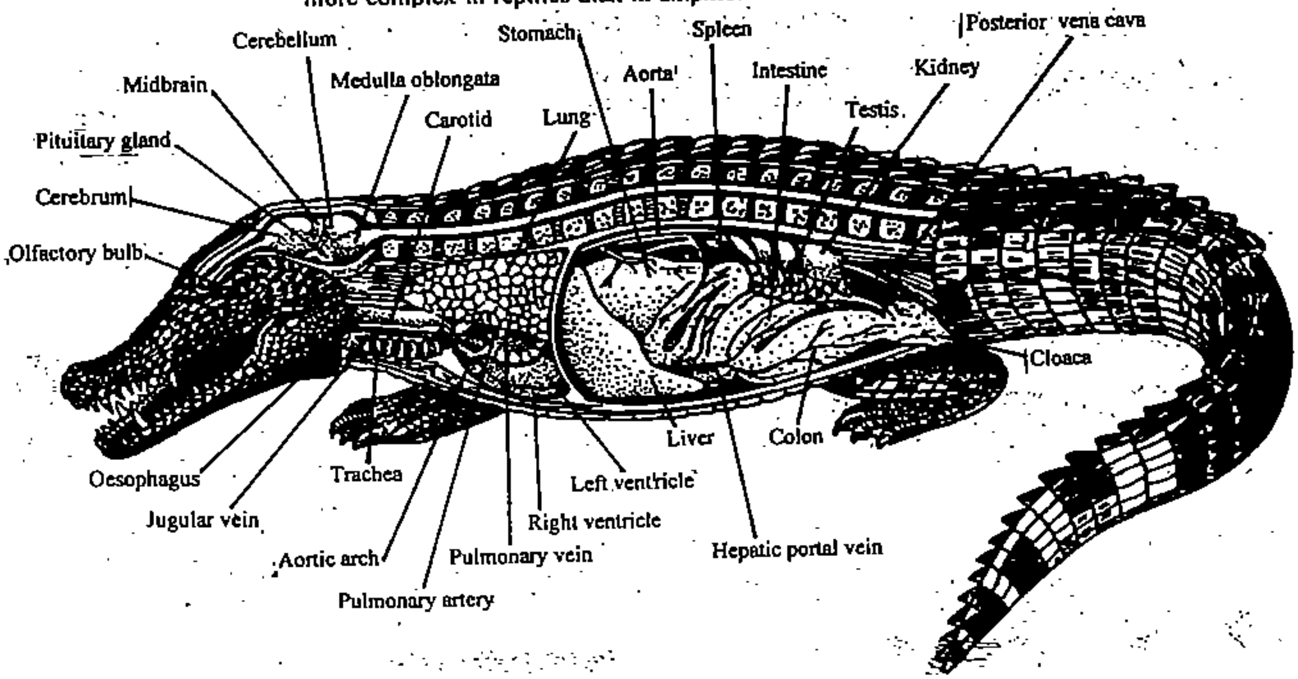


Fig.3.7: Internal structure of a male crocodile.

Jaws

Reptiles of temperate regions cannot maintain their temperature during extended cold periods and so similar to amphibians hibernate. Reptiles living in tropical climates have a thermally more favorable and uniform environment, thus they have little difficulty in regulating their temperature.

The reptilian jaws are more efficiently designed for using crushing force on the prey. Jaws of fish and amphibians are designed for fast jaw closure, but once the prey is caught, little static force can be used. In reptiles, however jaw muscles are longer, larger and arranged for more efficient mechanical advantage.

Metabolism

Reptiles as you know are ectothermic, gaining body heat from their surroundings. They are not endothermic like birds and mammals which generate their own heat by metabolic processes. Body temperature of reptiles living in temperate regions falls sharply at night, making them sluggish. On sunrise, they seek out sunny spots and warm up their bodies by solar radiation and by conduction of heat from sunwarmed rocks and soils on which they bask (Fig. 3.8). Absorption of solar energy is further enhanced early in the morning by the dispersal of pigment in the chormatophores of skin so that the skin darkens and absorbs more light energy and also by an increased blood flow through the skin. When it becomes too warm the skin lightens, cutaneous blood vessels get constricted and the animals move towards shade. A few species such as chuckwalla (*Sauromalus*) can also cool their body by eliminating heat through panting. Reptiles thus can maintain a high and relatively constant body temperature and remain active during daytime by **behavioral thermoregulation**, (adjusting their exposure to the sun). Some of the lizards in United States maintain, even when air temperature is considerably lower, temperatures of about 34°C (93°F) which is close to that of most mammals.

Reptiles are also called heliotherms (helios - sun) since they regulate their temperature by behaviourally regulating their exposure to the sun.

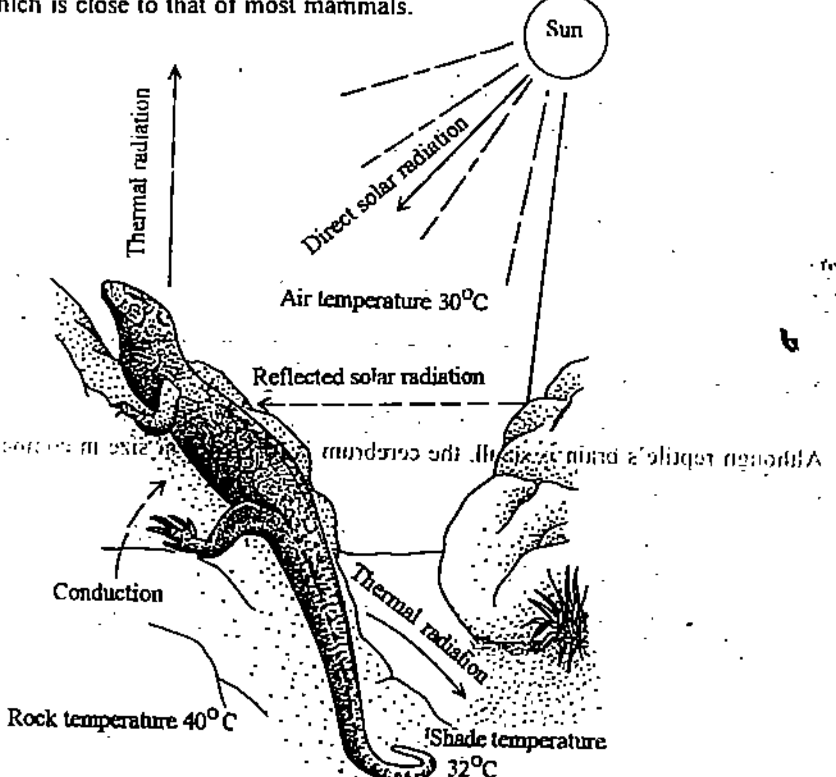


Fig.3.8: Reptiles during their period of activity normally maintain a body temperature close to 34°C by controlling, behaviourally the amount of heat they gain or lose to the environment.

Body temperature in reptiles, as in mammal, is regulated by a center in the hypothalamus of the brain. The amount of solar radiation being received, is monitored in many lizards by a well developed parietel eye on the top of the head. (Fig. 3.9)

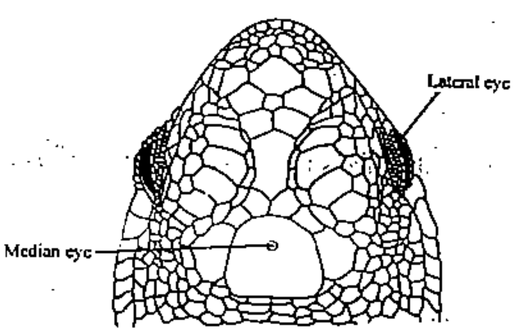


Fig.3.9: The parietal eye of a reptile and its relationship to the lateral eyes. The simplest and smallest vertebrate eye called median eye or parietal eye is a photo sensory organ located near the middle of the top of the heat. Many lizards monitor the amount of sunlight they receive by their parietal eye.

The tortoises and some lizards are herbivores. Their large intestine is usually longer than the small intestine and is divided by internal folds into compartments. Food passes slowly through the large intestine where a bacterial colony digests the cellulose.

Feeding and Digestion

Low food requirements allow reptiles to live in deserts and other habitats where there is not enough food to sustain high energy demands of many mammals. For example a frog or a mouse would be enough to provide a small snake the energy it needs for a week or more. Most reptiles except for tortoise and some lizards are carnivourous. Some have specialized ways of catching and swallowing food, but in a number of ways the structure of their digestive tract is very similar to that of amphibians (Fig. 3.6). However digestion in reptiles is more rapid than in amphibians, as most of the time reptiles maintain higher body temperature.

SAQ 3

1. Fill in the blanks with suitable words.
   a) In reptilian skin, epidermis is horny and contains a large quantity of_________, a water insoluble protein.
   b) Reptiles maintain a high and relatively constant body temperature by_________, _____________.
   c) In many lizards the amount of solar radiation is monitored by a well developed _____________ eye on the top the head.
   d) The structure of the digestive tract of both amphibians and reptiles is very _____________.

Nervous System

Reptilian nervous system is considerably more advanced than that of the amphibian. Although reptile's brain is small, the cerebrum is increased in size in comparison to the rest of the brain (Fig. 3.10).

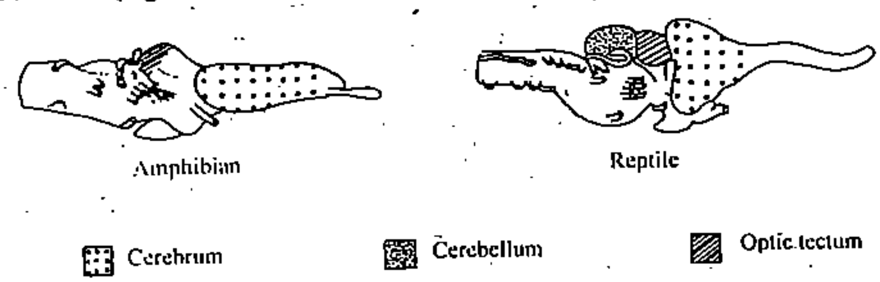


Fig.3.10: Brain of (a) amphibian (b) reptile. Note the enlargement of the cerebrum in the reptile.

Crocodiles have the first true cerebral cortex (neopallium). Central nervous system connections in reptiles are more advanced, allowing more complex types of behaviour than observed in amphibians. Sense organs are generally well developed. Sense of hearing in reptiles is poor. The external ear appears first in reptiles among some Lizards and crocodilians and consists of a short indented tube the external auditory meatus, that opens to the surface through the external orifice. The middle ear consists of three parts (i) a tympanum or tympanic membrane or ear drum which is a thin taut membrane at the body surface in a few reptiles but is usually recessed at the bottom of the external auditory meatus in most reptiles. (ii) a middle ear cavity or meatus which is connected to the pharynx by the auditory or eustachian tube. The middle ear also contain the middle ear ossicles of which the columella a small bone spans the distance from tympanic membrane to inner ear. The columella is tipped with a cartilaginous extension, the extra-columella. This cartilaginous structure rests on the under surface of the tympanic membrane. (iii) the inner ear that includes the vestibular apparatus and the surrounding perilymphatic spaces. The primary sound sensitive area within the inner ear is the slightly expanded lagena. The primary receptor is the auditory papilla which is stimulated by sound vibrations transmitted to the fluid of the inner ear (Fig. 3.11) In addition various supplemental auditory receptors are present in some species. All except the snakes possess a middle and an inner ear. In snakes the middle ear cavity (tympanic cavity) and tympanic membrane is missing. The tympanic membrane in other reptiles is often visible on the head and in some lizards is covered by scaly skin. The lateral line system is completely lost in reptiles. Jacobson's organ, a unique sense organ, is a separate part of the nasal sac and communicates with the mouth; it is especially well developed in lizards and snakes. It is innervated by a branch of the olfactory nerve and is used in smelling odours. This organ in some form is also found in other groups, including the amphibians.

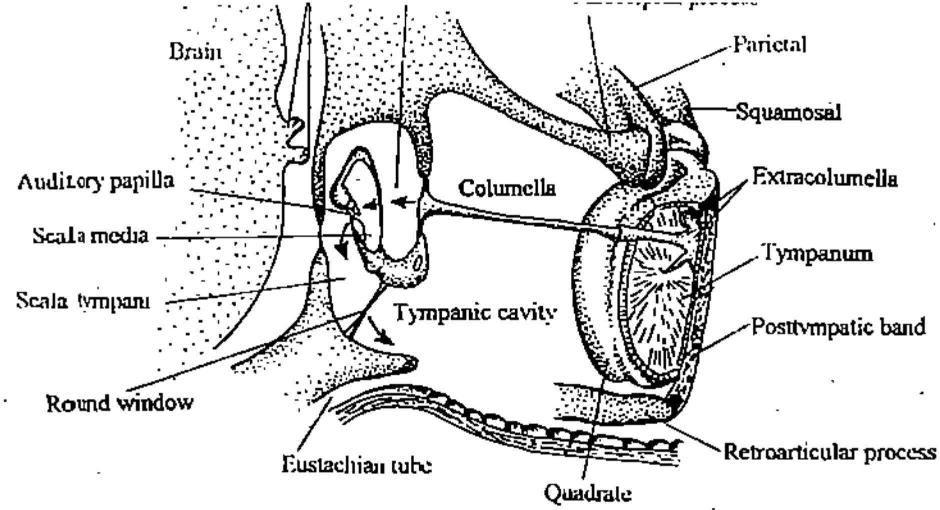


Fig.3.11: Hearing in reptiles. Cross section through the ear of reptilian head (iguana) showing the relationship of tympanum, extracolumella, columella and inner ear.

Respiration

In reptiles, dry scaly skin reduces cutaneous respiration to a negligible level. As a result reptiles depend almost exclusively on lungs for .. exchange, supplemented in some of the aquatic turtles by pharyngeal membrane respiration. Lungs of reptiles unlike the simple - sac like lungs of amphibians are composed of many small compartments and thus have a sponge like texture and a larger respiratory surface. This type of lung is needed because of the general increase in metabolic activity of reptiles. Lungs of reptiles similar to those of mammals are aspiratory (drawing in air) and so air is sucked into the lungs by changing the size and pressure within the body cavity that contain them, rather than forced in by the mouth muscles as in amphibians. Air is retained in lungs during a period of apnoea (cessation of breathing) and is then forced out of the lungs by contraction of trunk muscles and elastic recoil of the lung.

Circulation

Reptiles have a higher blood pressure and a more efficient circulatory system than the amphibians. Heart in reptiles is more fully divided than in amphibians (Fig. 3.12). In all reptiles the right atrium which receives unoxygenated blood from the body is completely partitioned off from the left atrium which receives oxygenated blood from the lung. The ventricles are either partially or as in crocodiles completely separated by the interventicular septum. Even in reptiles where there is incomplete separation of ventricles, the blood-flow-pattern within the heart prevent admixture of pulmonary (oxygenated) and systemic (unoxygenated) blood; all reptiles therefore have two functionally separate circulations.

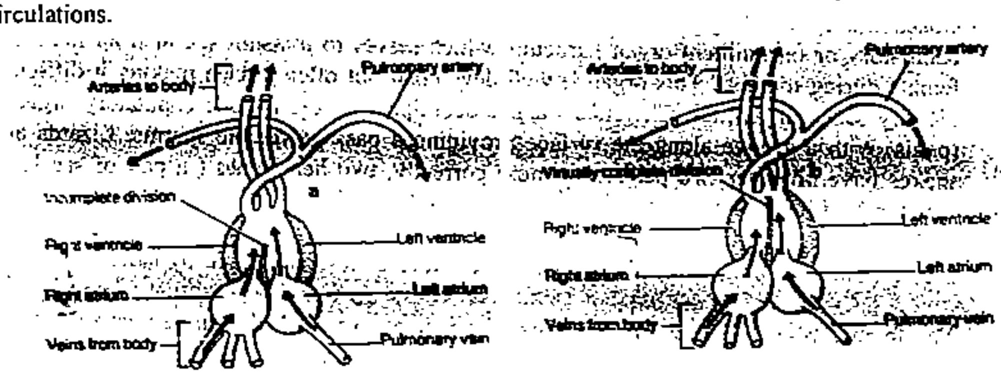


Fig.3.12: Reptilian hearts: (a) in most reptiles the two sides of the ventricles are not completely separated (b) In Crocodilians a separation exists. Even in the unseparated ventricle there is little mixing of arterial and venous blood.

Excretion and Water Conservation

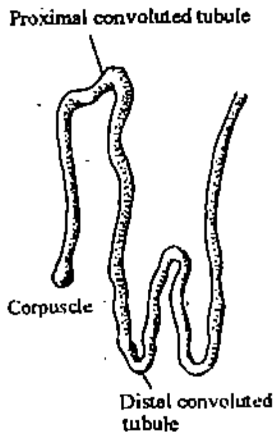


Fig.3.13: A renal tubule of a reptile showing the absence of Loop of Henle. Many renal corpuscles are found in each kidney.

Reptiles have evolved efficient strategies for water conservation. Although the paired kidney of reptiles are of advanced metanephros type, (Fig.3.13) each with its own passage way (ureter) leading to the cloaca, however they lack the loops of Henle of the more advanced mammalian metanephros and so are unable to produce a urine more concentrated than the body fluids. Instead, the nitrogenous wastes are excreted as uric acid rather than urea or ammonia. Reptiles need less water to remove nitrogenous wastes from the blood than the amphibians since the non-toxic solid crystals of uric acid have low solubility and precipitate out of solution readily, allowing water to be conserved. Much of the water that is removed from the blood is later reabsorbed by other parts of the kidney tubules, the urinary bladder and cloaca. Terrestrial and fresh water turtles as well as lizards generally have a urinary bladder while in snakes instead the ureter dilates in the posterior region, forming a urinary reservoir. The urine of many reptiles is a semi-solid suspension. A number of reptiles also remove excess salts by means of salt glands located near the nose or eyes (in the tongue of salt water crocodiles) which secrete a salty fluid that is strongly hyperosmotic to the body fluids. Fig. 3.14 shows the male and female urinogenital systems of reptile.

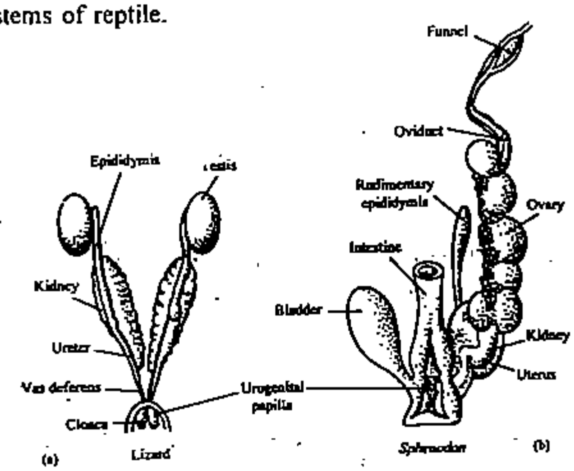


Fig.3.14: Urogenital systems of reptile (a) male organs of the lizard *Varanus* (b) female organs of *Sphenodon*. Bladder is not shown in a, while in b it is turned to one side. In b the organs of only the left side are shown.

Reproduction & Development

Sexes are separate. Most males have a copulatory organ or organs. Internal fertilization is obviously necessary for a shelled egg, since the sperm must reach the egg before it gets covered by a shell. Reptiles have a pair of elongated testes. (Fig. 3.14 a). Each testis is connected with an epididymis which continues backward to form the ureter and subsequently the vas deferens. Sperms from the paired testes are carried by vasa deferentia to the copulatory organ (in some cases organs) which is an evagination of the cloacal wall. All living male reptiles except the *Sphenodon* possess some form of copulatory or intromittent organ (structure which serves to transmit sperm from male to female during mating). This organ is well developed but often hidden making it difficult to identify sexes in reptiles. Chelonians and crocodilians have only one copulatory organ (penis) with a groove along the surface providing a passage for the sperms. Lizards and snakes have however two penises or more correctly, two hemipenes (a pair of sac like structure) which can be everted (turned inside out like fingers of a rubber glove). However, only one is used at a time depending on which side of the female the male is present, since mating in lizards and snakes is more or less from side by side.

Each hemipenis is connected to only one testis. The male prefer to alternate sides, using the hemipenis on the side with the larger store of sperm. Each penis is covered with backwardly directed barbs and hooks.

The female system (Fig. 3.14b) consists of a pair of ovaries and their respective oviducts. The glandular wall of the oviduct secretes albumen and shells over the large eggs.

Most reptiles are oviparous and lay cleiodoic eggs in sheltered locations. They bury their eggs in soil, sand or leaf mound, where heat from solar radiation or plant decomposition can incubate them. Some lizards and snakes retain their eggs in the uterus and embryos develop there, primarily using food stored in yolk. At birth the young ruptures the membranes and the thin walled shell. This type of development is sometimes referred to who have developed a placental relationship with the mother.

Reptiles lay fewer eggs than most fishes and amphibians because mortality is comparatively low due to the hard, shelled, cleidoic egg which protects the developing embryo, and due to the suppression of the larval stage as well as ability of the reptiles to conceal their eggs well after laying. A collard lizard lays only 4 to 25 eggs; a leopard frog from 2000 or more.

True viviparity means that the embryo establishes direct connection with the maternal body so that nutrients pass from mother to embryo without getting dissolved and absorbed in the uterine fluid. In all viviparous animals the embryonic development take place within the uterus of the mother since the eggs has minimum amount of yolk. In most viviparous invertebrates and vertebrates the connection between mother and embryo during development is established by means of the organ known as placenta. The placenta serves for exchange of nutrients and gases between the tissues of the mother and the embryo. Placenta is found in *Peripatus* (Onychophore), in tunicates (*Salpa*), in certain fishes, reptiles and placental mammals. However, the mode of origin in each case differ. The type of placenta that occurs in reptile is either formed by union of yolk sac and chorion or by fusion of allantois, chorion and uterine lining. Mammalian placenta however has double origin. It is developed by the apposition of the extra embryonic membranes (except amnion) and the endometrium of the uterus (not just uterine lining)

SAQ 4

State which of the following statements are true or false:

a) The crocodilians have the first true cerebral cortex. True/False

b) Young reptiles hatch as gill breathing juveniles. True/False

c) Lung structure of both amphibians and reptiles is very much like. True/False

d) In the reptilian heart, right atrium which receives unoxygenated blood from the body is completely partitioned off from the left atrium which receives oxygenated blood from the lungs. True/False

e) Reptiles lay more eggs than fishes and amphibians. True/False

f) The sense of hearing is poorly developed in reptiles as the middle and inner ear is lacking in them. True/False

g) The skin of some reptiles has scent glands that produce odoriferous secretions which is used by the reptile for sexual and species recognition. True/False

---

3.3.6 Characteristics of Extant Reptilian Orders

A. SUB CLASS ANAPSIDA:

ORDER TESTUDINES (CHELONIA) - EXAMPLE : TURTLES AND TORTOISES

Testudines are mostly semi-aquatic. They vary in size from a few centimeters to forms like the marine leatherback that may be 2 meters in length. There are both herbivorous and carnivorous forms. Turtles are slow moving and live for several years. Some are thought to have lived for more than 150 years. Their longevity is attributed to their low metabolism.

Modern turtles have changed very little in morphology during the last 200 million years. Jaws lack teeth and instead are covered by sharp horny plates for gripping and chewing food. Their short, broad trunk is enclosed in a protective shell, consisting of a dorsal convex **carapace** and a ventral flatter **plastron** (Fig. 3.15). The shell is an integral part of the animal, and is fused with the thoracic vertebrae and ribs. It is of two layers; an outer horny layer of keratin and below it, an inner layer of bony plates. The bony plates get ossified in the dermis of the skin and some are fused with the vertebrae and ribs. As the turtles grow and age, new layers of keratin are laid down beneath the old ones.

The terms "turtle", "tortoise" and "terrapin", are applied differently to different members of the order. The term tortoise is often used for land turtles, especially the large forms. British use of the term differs: tortoise is an inclusive term while turtle is used only for aquatic members. In North American usage, they are all correctly called turtles.

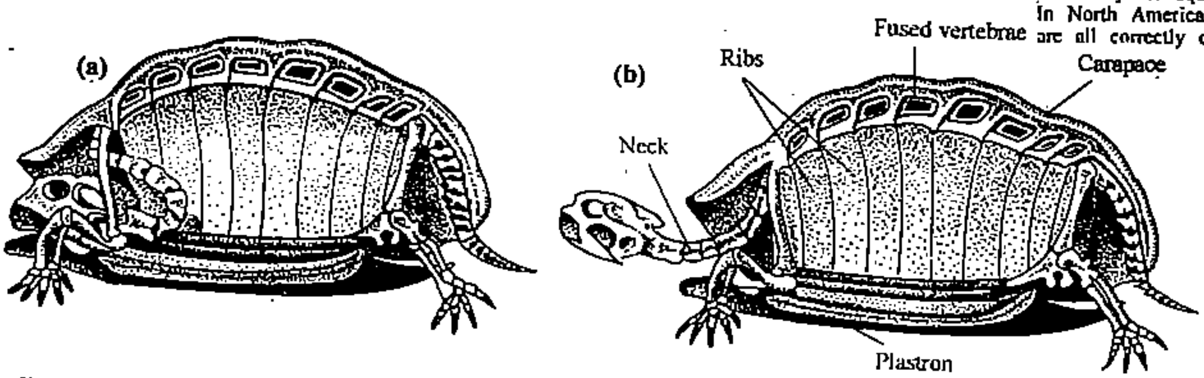


Fig. 3.15 : The skeleton and shell of a turtle (a) Most turtles withdraw their head into their shell by bending their neck in the vertical plane into an S-shaped loop. (b) showing the fusion of vertebrae and ribs with the carapace. The long and flexible neck allows a turtle to withdraw its head into shell for protection.

Many aquatic species gain oxygen supply through the vascular lining of their mouth and pharynx and through sacs that bud off from the cloaca. This allows them to remain submerged in the water for long periods when inactive. When active they need to breathe through the lung more frequently.

Box turtles or tortoise (*Terrapene carolina*) have a plastron hinged both anteriorly and posteriorly that can be pulled up against the carapace so tightly that one cannot force a knife blade between the shells. Some turtles such as the large eastern snapping turtle (*Chelydra serpentina*) have reduced plastron, making complete withdrawal for protection quite impossible. However, these turtles compensate for the inadequate protection by being very aggressive

Turtles due to their rigid shell with fused ribs cannot expand ... that lung ventilation by a change in diameter of the rib cage becomes impossible. They have overcome this problem by employing certain abdominal and pectoral muscles as 'diaphragm'. Air is drawin in by contracting limb flank muscles to make the body cavity larger. Exhalation is also active and is accomplished by drawing the shoulder girdle back into the shell, thus compressing the viscera and forcing air out of lungs.

Turtles also compensate for an inflexible trunk by having a long flexible neck that facilitates feeding. Ancestral turtles were unable to retract their heads but modern specie can withdraw theirs into the protective shell. Turtles when threatened can also withdraw their limbs into the shell.

Turtle brain is small and never exceeds 1% of body weight. The cerebrum, however, is larger than that of an amphibian, and turtles are able to learn a maze nearly as quickly as a rat. Turtles have a middle and an internal ear, but lack an external ear and their sound perception is poor. Therefore, turtles are virtually mute although many tortoises during mating utter grunting or roaring sounds. The poor hearing sense of turtles is compensated by a good sense of smell, sharp vision and colour perception which appears as good as that of humans.

The toes end in horny claws that are useful in crawling or digging. In terrestrial tortoises feet are stumpy while in marine forms front limbs are flipper like. Fig. 3.16 shows some turtles adapted for various modes of life.

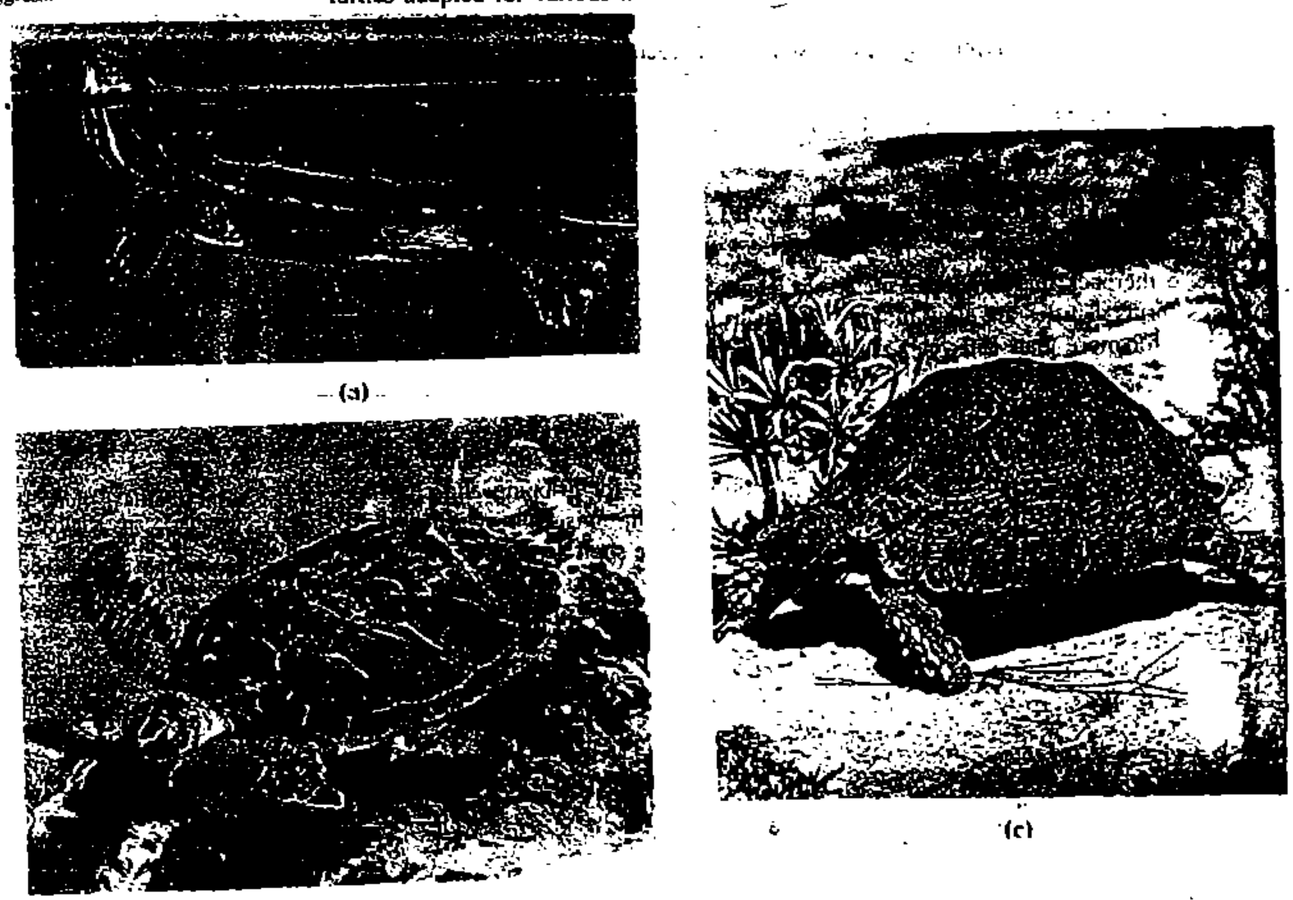
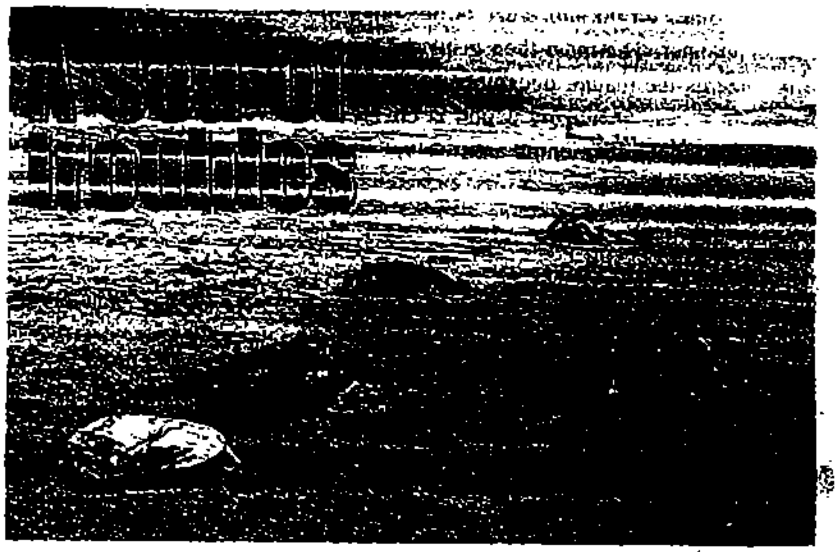


Fig.3.16: Some representative turtles. Some turtles are well adapted to life in fresh waters (a), others to sea water (b), while others to a terrestrial mode of life.

Most turtles have well developed, bilobed bladders which open into the cloaca. In turtles the ureters are connected to the bladder and do not open separately into the cloaca. In some turtles a pair of accessory urinary bladders are also connected with the cloaca. They function as accessory organs of respiration. In females they may be filled with water which is used to soften the ground when the nest is being prepared. The urine of turtles is fluid.

Turtles are oviparous and fertilization is internal and is accomplished by means of an erectile penis. All turtles, even the marine forms bury their shelled, amniotic eggs in the ground. Females come ashore to lay eggs and usually make nests. Once the eggs are laid they are covered by the female who after this deserts the eggs.

Turtles at present are also an endangered lot (Fig. 3.17) because of the edibility of their meat and eggs and use of their shells for ornaments, their life history, and change in their enviornment and destruction of their habitats.



Year 1999- Another 4,000 Sea turtles killed at the Gahirmatha rookery this year.

Fig.3.17: Turtles at present are also an endangered lot.

Conservation of sea turtles present problems for a variety of reasons-like their economic value as well as the risk involved due to their migratory habits, their long gestation periods and the effect of temperature on the sex of hatchling. Many of our own and goverment actions also endanger turtles. The unusually important nesting ground of the Olive Ridely turtle at Gahirmatha in Orissa is threatened by a fishing port and increased fishing activities in the immediate neighbourhood.

SAQ 5

State which of the following statements are true and which are false.

a) Turtles shed their shell thrice during their entire life time. True/False

b) Turtles are viviparous and their fertilization is internal. True/False

c) Ancestral turtles were unable to retract their head into the shell. True/False

d) Many aquatic species of turtles can remain under water for long periods as they have specialized gills. True/False

e) The cerebrum of turtles is larger than that of amphibians and so they are able to learn a maze as nearly as quickly as a rat. True/False

B. SUBCLASS DIAPSIDA: (a) Super Order Lepidosauria - (ai) Order Sphenodonta (aii) Order Squamata

(ai) ORDER SPHENODONTA (RHYNCHOCEPHALIA) - EXAMPLE : TUATARA

The order Sphehodonta is represented today by a single living species, the tuatara (*Sphenodon punctatus*). Once these animals were widespread on the North Island of New Zealand. They are now restricted to the islets of Cook strait and off the northern coast of North Island.

Sphenodon is the sole survivor of a group of primitive reptiles that were abundant in the early Mezoic and most became extinct about 100 million years ago. It is the most primitive of the surviving lepidosaurs (Fig. 3.18). It remains a quadruped. It has two pairs of well developed limbs, a strong tail and a scaly crest down the neck and the back which is more prominent in males. It is a lizard like form. Males achieve a length of 60 cm and weigh 1000 grams while female grow to a length of 50 cms and sometimes weigh as much as 500 gms. The tuatara are essentially nocturnal animals and live in burrows often shared with petrels (birds). The lateral undulations of the trunk and tail continue to be an important part of the locomotor pattern. It is a slow growing animal and has a long lifespan; one is recorded to have lived 77 years.

Sphenodon (Gr. Sphenos - wedge odontos+tooth) represents one of the slowest rates of evolution known among the reptiles as it has not changed greatly from species that were living 150 million years ago. It is thus sometimes described as a "surviving fossil"

Other features include a primitive, diapsid skull with a bony arch, low on the skull behind the eye that is not found in lizards but was present as in the early Permian reptiles that were ancestors to the modern lizards; A well developed median parietal eye, with cornea retina, pineal eye, lens and pineal nervous connections to the brain is present in these animals. Although covered with scales, this third eye or parietal eye is sensitive to light. A specialized feature are the teeth, which are fused wedgelike to the edge of the jaws instead of being set in sockets. A complete palate is present. Males lack copulatory organs and transfer sperms to the females by everting their cloaca. During mating the crest in male becomes turgid and erect as he stalks the female and approaches her in a slow and jerky manner. The male then grips the female over the shoulders with his fore limbs. Unlike lizards the tuatara does not use the jaw for grasping the female. The female lays 8-15 eggs in a nesting burrow which is covered by several centimeters of soil. Development takes about 13 months and the young emerge in early to mid summer.

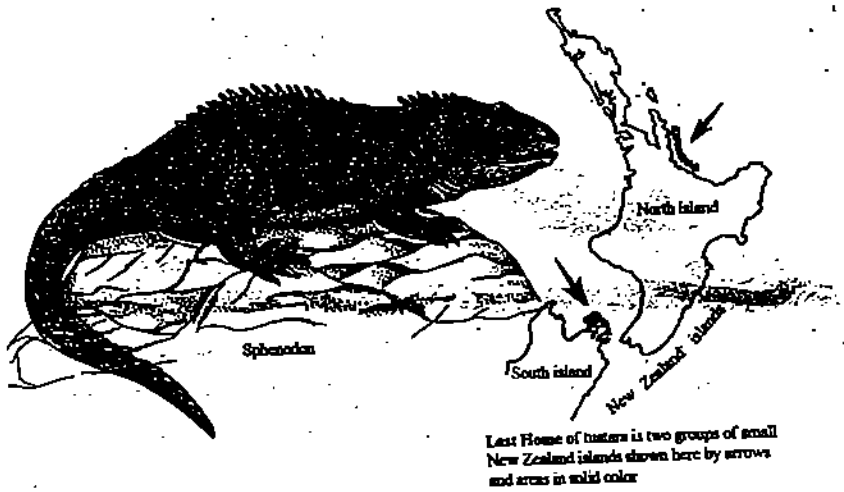


Fig.3.18: Tuatara, *Sphenodon punctatus* is the only living representative of Order Rhychocephalia and is found only in New Zealand. The living fossil has a well developed parietal eye on top of the head. This eye has retina and lens but it is covered with a scale. Function of parietal eye is unknown.

SAQ 6

Pick out the appropriate words from the alternatives provided in the following statements.

a) *Sphenodon* is the most primitive surviving archosaur/lepidosaur.

b) *Sphenodon* lives in burrows often shared with moles/petrels.

c) *Spenodon* has a skull which is of primitive diapsid/anapsid type.

d) In male *Sphenodon* a copulatory organ is present/absent.

e) In *Sphenodon* teeth are absent/present.

(aii) Order Squamata: (1) Suborder Lacertilia, (2) Suborder Serpentes, (3) Suborder Amphisbaenia.

ORDER SQUAMATA - EXAMPLES : LIZARDS, SNAKES AND WORM LIZARDS

Order squamata as you have studied is divided into the following three suborders (i) Lacertilia, (Sauria) the lizards (2) Serpentes (Ophida), the snakes; and (3) Amphisbaenia, the worm lizards.

The familiar lizards, snakes and worm lizards though superficially different are similar enough in basic structure to be placed in the single Order Squamata. The squamates are the most recent and diverse products of diapsid evolution, and make up approximately 95% of all known living reptiles.

The diapsid skull of squamates are uniquely modified from the ancestral diapsid condition. From sub section 3.3.1 and Fig. 3.4 of this unit you will recall that the diapsid skull has two temporal openings, one above and one below the post-orbital squamosal bar. In squamates the diapsid skull, during the course of evolution is secondarily modified by the loss of one or both bars that bound the temporal openings. This change in their jaw enables the squamates to open their mouth very wide. Thus, this has allowed the evolution of a mobile skull having movable joints. Such a skull is referred to as a kinetic skull and is clearly observed in lizards and snakes.

In lizards the quadrate, which in other reptiles is fused to the skull, has a joint at its dorsal end, as well as its usual articulation with the lower jaw. In addition there are joints in the palate and across the roof of the skull that allow the snout to be tilted up (Fig. 3.19). The specialized mobility of the skull enables lizards to seize and manipulate prey; it also increases the effective closing force of the jaw musculature. The skull of snakes as you will read further in this unit is even more kinetic than that of lizards. Such exceptional skull mobility is considered to be a major factor in the diversification of lizards and snakes.

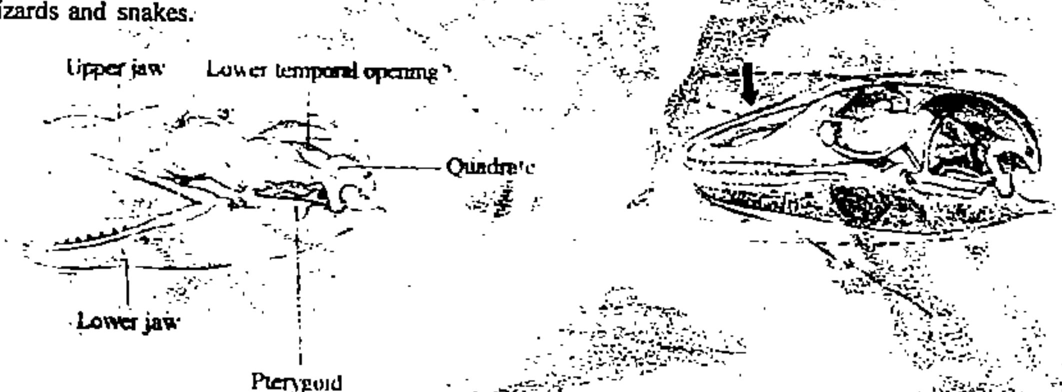


Fig.3.19: Kinetic diapsid skull of a modern lizards (monitor lizard) showing the joints (indicated by dots) that allow snout and upper jaw to move on the rest of the skull. The quadrate can move at its dorsal end and ventrally at both the lower jaw and the pterygoid. The front part of the braincase is also flexible allowing the snout to be raised. Observe that the lower temporal opening is very large with no lower border; this modification of the diapsid condition, common in modern lizards provides space for expansion of large jaw muscles. The upper temporal opening lies dorsal and medial to the post orbital - squamosal arch and is not visible in this figure.

SUBORDER LACERTILIA -EXAMPLE : LIZARDS

Body size and shape of lizards vary; many are slender, some are laterally compressed and others like the horned lizards, are dorsoventrally flattened. The great majority of lizards have four limbs, though in many, limbs may be reduced or lacking as in a large number of limbless lizards ("glass snake" - legless lizards). Limbs may be short or long, delicate or thick. Generally all limbless forms live in soil, through which they move by wriggling from side to side. In some fast running lizards tail is long and acts as a counterbalance but in sluggish forms it may be short and stumpy. Fig. 3.20 shows some lizards adapted for various modes of life.

The komodo dragons, now restricted to certain Indonesian islands are the largest living lizards; being 3 metres or more in lenght. They feed on small deer, wild pigs and goats. (Fig. 3.20)

Fig.3.20: Lizards show many adapatations to particular environments.

Many Lizards can regenerate their tail if it is cut. This is particularly seen in species like the skinks in which the tail vertebrae are incompletely ossified in a zone midway across the vertebra which functions as a breaking point (Fig. 3.21). If tail is seized the vertebrae separates (autotomizes) at one of these breaking points and the animal escapes. The tail is often conspicuously coloured and its muscle's anaerobic metabolism sustains tail thrashing for a considerable period, thus distracting the predator and increasing the time for the animal to escape. In time a new tail regenerates which however is supported by cartiligious rod and not by vertebrae which does not regenerate.

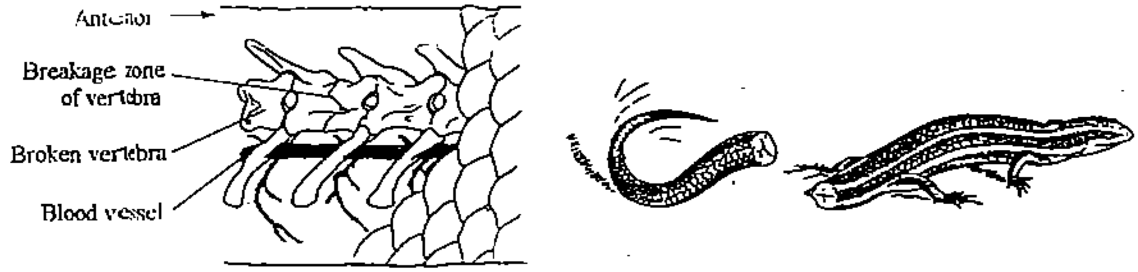


Fig.3.21: Side view of tail vertebrae of western skink, showing breakage zones. Amputated tail moves rapidly.

The lizard skin is flexible and is loosely attached to the body. It contains many scales, arranged in longitudinal, transverse or diagonal rows. In most lizards the scales of the back and sides overlap behind, like shingles in a roof. Individual scales may be variously smooth, pitted or have a longitudinal keel. The ventral surface is generally covered by small scales.

Most lizards possess movable upper and lower eyelids; many retain the parietal eye (Fig. 3.22). Lizards have sharp daylight vision (retinas rich in rods and cones), although, the nocturnal gecko of one group has pure rod retinas which enable it to see extremely well in the dark. Most lizards have an external ear that snakes lack and this has evolved independently from the turtles. The inner ear of lizards is variable in structure but as with other reptiles hearing does not play an important role in the life of most lizards.

Hearing plays an important role in geckos . The male geckos are strongly vocal in order to specify territory and discourage other males from approaching and so they must, of course hear their own vocalizations. Other species of lizards vocalize to indicate defensive behaviour.

Tongue may be only slightly mobile or freely extensible. In chameleons it can be shot several inches beyond the snout to capture insects on its sticky, mucous coated tip. Lizards despite their diversity, as a group bear a number of features that distinguish them from snakes. One is the lower jaw. Even in limbless forms the two halves are firmly united at the mandibular symphyasis. This limits the lizards, despite their kinetic skull from swallowing oversize meals as snakes which have floating jaw elements. The jaws of lizards are provided with teeth, usually short and alike but differentiated in some skinks, and old world Agamidae, in some teiids and skinks.

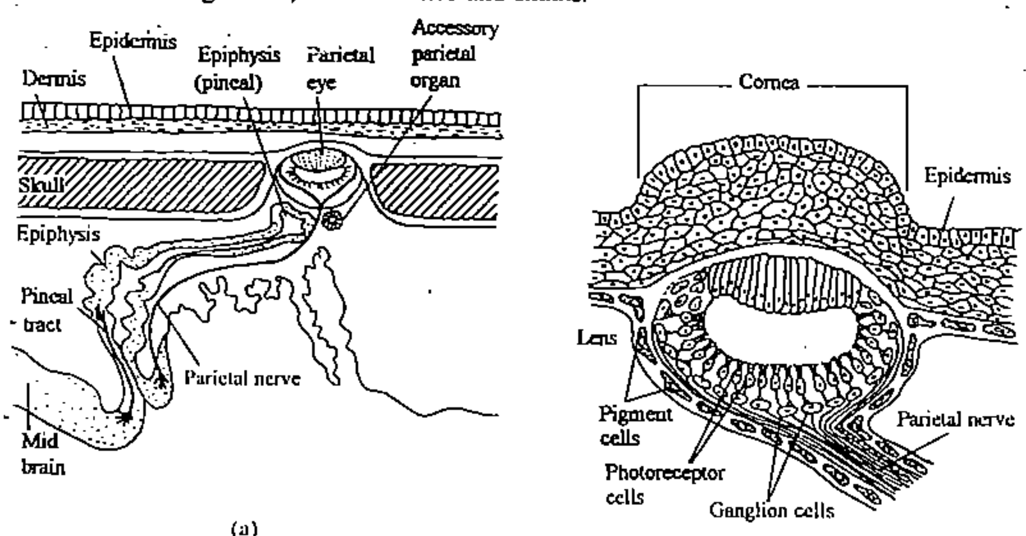


Fig.3.22: (a) a cross section of the pineal complex of a lizard showing also the parietal eye (b) saggital section of a generalized parietal eye.

One characteristic feature of lizards is their camouflage ability to change colour rapidly (metachrosis), so as to blend in with their background. Not all lizards however have this ability.

A bladder is present in lizards and uric acid is passed from the cloaca with faecal matter. Males have two hemipenes in the base of the tail. At copulation, one or both are everted but usually one is used. Seminal fluid passes in a groove on the hemipenis into the cloaca of the female. Snakes also have hemipenis, a characteristic uniting the two groups.

A large number of lizards are also found in India. Common lizards of India are house lizard (*Hemidactylus brooki*) and the garden lizard (*Calotes versicolor*) Apart from these, other interesting lizards found in India are the monitor lizard *(Varanus monitor)*, chameleon *(Chameleon calcaratus)*, the horned toad *(Phyrynosoma)*: (actually a lizard) and skink (*Mabuia carinata*). Some of these are interesting because of their peculiar adaptation.

Modern Lizards are an extremely diversified group, including terrestrial, burrowing, aquatic, and arboreal members and are found throughout the temperate and tropical regions of the world. Fig. 3.23 shows some of the lizards found in India.

Many lizards live in the hot and arid regions being suitably adapted for desert life. Their skin lacks glands, minimizing water loss and they produce a semisolid urine with a high content of crystalline uric acid.

Most lizards are carnivarous feeding on insects and other small prey. Some larger species such as monitors prey upon vertebrates. Iguanas and some skinks are among the few vegetarian lizards. Gila monster is the only poisonous lizards and has two species.

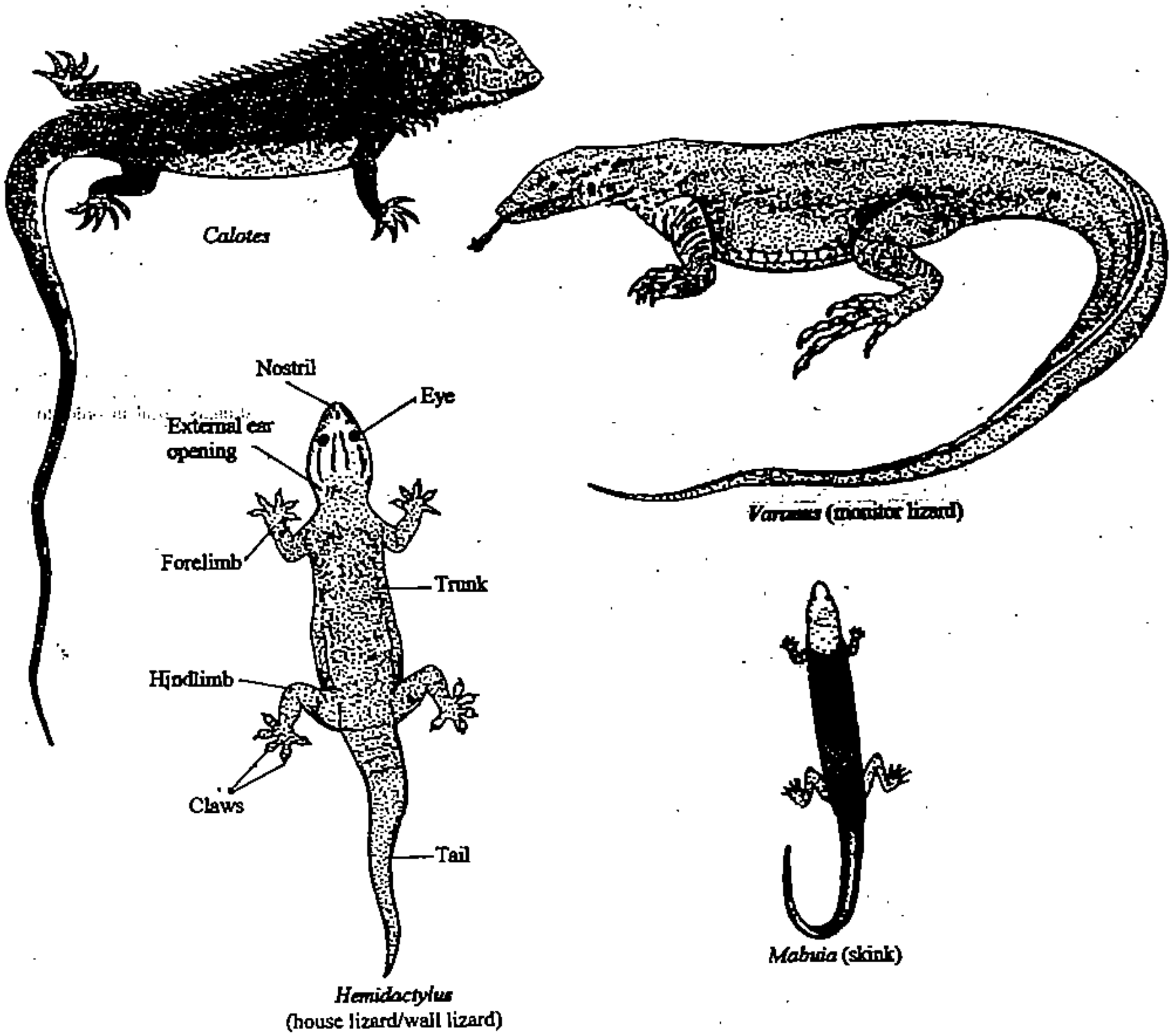


Fig.3.23: Some lizard types found in India.

SAQ 7

Pick out the suitable words from the alternatives provided in the parenthesis :

a) The zoological name of the house lizard found in India is *(Hemidactylus brooki/ Calotes versicolor)*.

b) In lizards cloaca is (absent/present).

c) Most lizards possess (moveable/immovable) eyelids.

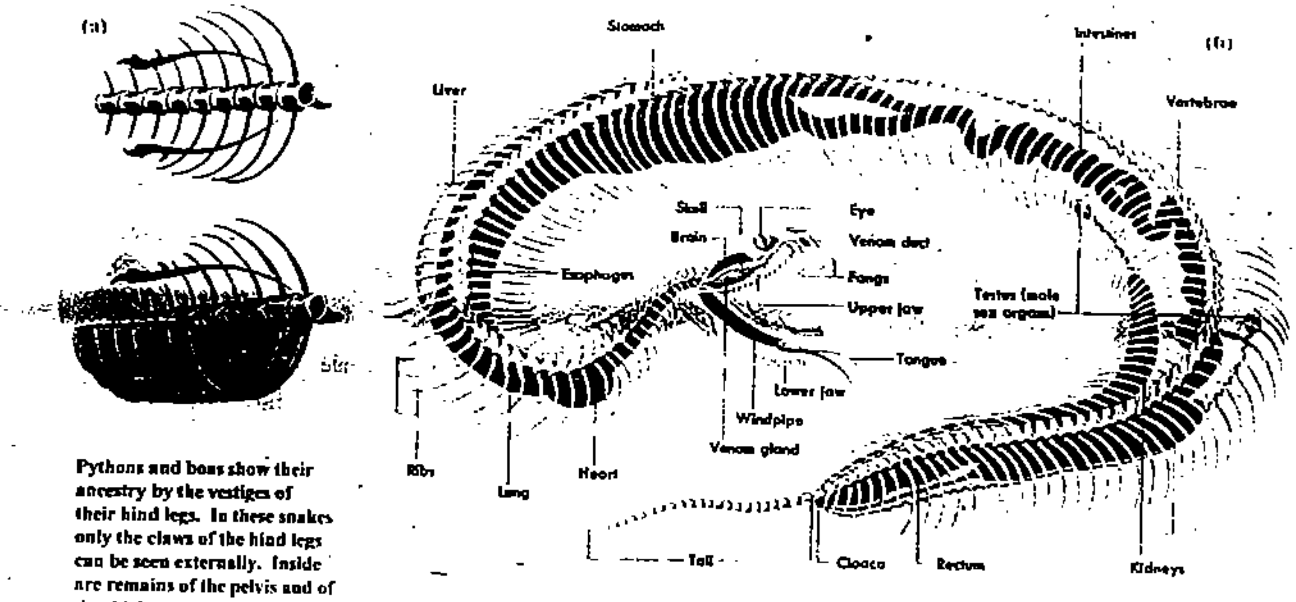
d) The largest living lizards are the (Komodo dragons/Gila monsters).

SUBORDER SERPENTES-EXAMPLE : SNAKES

Snakes are odd creatures, feared and loathed by many people but revered and worshipped in many cultures as symbols of power, healing and rejuvenation. Two specialization that characterize snakes are (i) extreme elongation of the body and the accompanying displacement and rearrangement of internal organs and (ii) specialization of eating larger sized prey.

Furthermore, apart from their elongate bodies most snakes are entirely limbless and lack both the pectoral and the pelvic girdles and sternum. However, boa constrictors and python (Fig. 3.24a) are exceptions which retain spur like rudiments of hind legs that are used in courtship. The numerous vertebrae of snakes are shorter and wider than those of tetrapods and so allow quick, lateral undulations of their exceptionally long trunk and tail that contain 200 or more vertebrae through grass and over rough terrain. The vertebrae in long snakes, number 200 to 400 (Fig. 3.24 b). The many segmental body muscles are slender, connecting vertebrae to vertebrae; vertebrae to ribs; ribs to ribs, ribs to skin; skin to skin. Many extend from one body segment to the next but other connect by tendons between segments far removed from one another. This arrangement makes possible the graceful sinous movement of a snake. The ribs increase rigidity of the vertebral column, providing more resistance to lateral stresses. The elevation of the neural spine gives the numerous muscles more leverage.

The medical profession as you may have noticed is symbolised by two snakes entwined around a staff called the caduceus (an Ancient, Greek or Roman herald's wand carried by the messenger god Hermes or Mercury).



Pythons and boas show their ancestry by the vestiges of their hind legs. In these snakes only the claws of the hind legs can be seen externally. Inside are remains of the pelvis and of the thigh bone or femur.

Fig.3.24: Skeleton of snakes (a) showing remain of pelvic girdle. (b) Internal structure of a snake with its skeleton. Each of a snake's several hundred vertebrae has its own pair of ribs attached. These ribs anchor the many muscles needed to manipulate the long, slender body.

The body of snakes, similar to those of lizards is covered entirely with a tough, impervious scaly skin. The scales may be smooth as in king cobra or keeled as in rattle snakes, garter snakes and others (Fig. 3.25). The skin of snakes is not elastic and so when it needs to stretch, as it must after an enormous lunch, it does so in an unusual manner. The hard scales are set together, sometimes overlapping like shingles on a roof, with the skin folded inward between scales. When the snakes swallow a large object, the skin folds are pulled out straight, leaving the scales separated like islands on the skin.

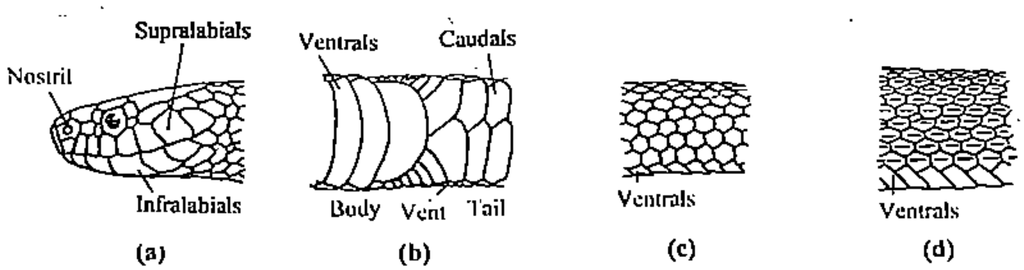


Fig.3.25: Scales of snakes: (a) Head of ringneck snake. (b) Lower surface of a snake in the vent (anal) region showing e enlarged ventral scales on body and tail. (c) Snake body with smooth scales. (d) Snake body with keeled scales.

Snakes neither chew nor tear food but swallow it entirely. They do so by means of a series of adaptive modifications (Fig. 3,26) which include (1) a delicate highly specialized kinetic skull with several bones that move upon one another and in which the two halves of the lower jaw (mandibles) are joined only by flexible tissue in the form of muscle and skin, allowing them to spread far apart; (2) The loose attachment of quadrate bone on either side to both skull and mandibles (3) Movement of bones of the palate; (4) Slender backward pointing teeth on the jaws and palate which prevent the food from slipping forward. once swallowing has begun; (5) Absence of a sternum (breast bone); and (6) Ribs. free of any bony articulation ventrally, so that the body wall may be dilated; (7) Presence of soft elastic skin between scales on the back and sides of body, allowing wide distention (8) thin and easily stretched walls of oesophagus and stomach (9) placement of glottis of the trachea far forward between the jaws and just beneath the sheath for the slender tongue which allows respiration during the swallowing of food. During swallowing the glottis may be projected forward to aid breathing and the flexible jaws are advanced alternately in a walking movement over the prey. (Fig.3.27).

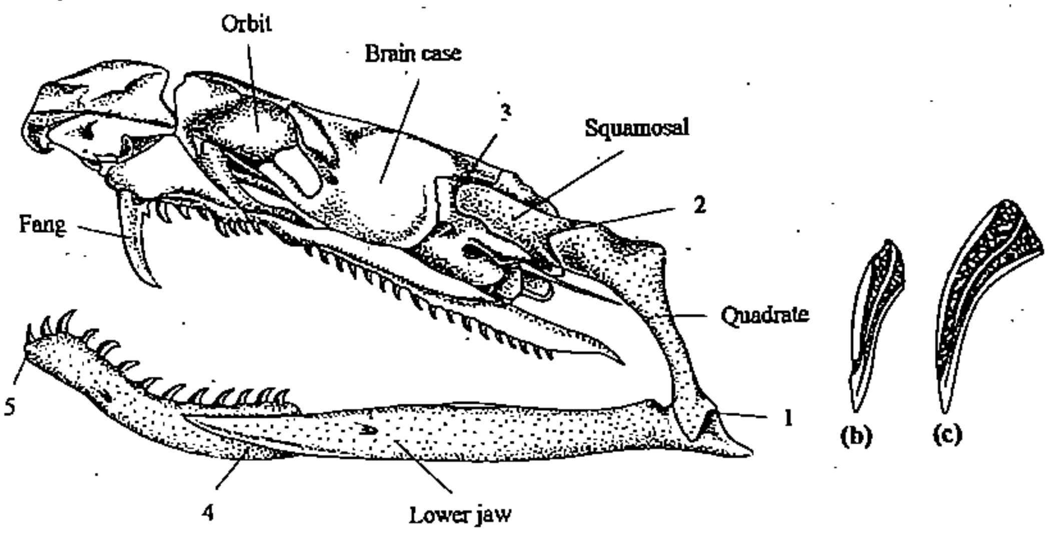


Fig.3.26: (a) Skull bones of a cobra. Bones that move during feeding have been stippled and areas of movement have been numbered (1) The usual jaw point between the lower jaw and quadrate (2) a joint between quadrate and squamosal (3) one between squamosal and brain case (4) one about halfway along the lower jaw and (5) at the chin as the two halves of the lower jaw are not firmly united at this point. b) The fangs of the cobra are at front of the jaws. Their fangs have forward directed orifices unlike c) the hypodermic fangs.

The eyelids of snakes are immovable. Cornea is permanently protected with a transparent membrane, (Fig. 3.28) which together with a lack of eye ball mobility, give snakes their cold, unblinking stare that most of us find so unnerving. Most snakes have relatively poor vision, with the exception of some of the arboreal snakes that have excellent binocular vision.

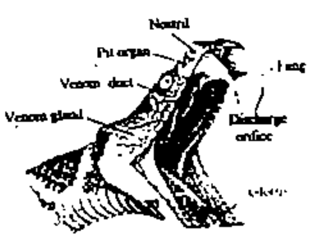


Fig. 3.27 : Head of a rattle snake showing the venom apparatus and the glottis projected forward. The venom gland which is a modified salivery gland is connected to the hollow fang by a duct.

Snakes lack external and middle ears but do have internal ears. They can detect ground vibrations within a limited range of low frequencies (100 to 700 Hz) through their skull bones. Most snakes, however, use chemical sense rather than vision and hearing to hunt their prey. For this, snakes possess in addition to the usual olfactory areas in the nose, (which are not well developed) a pair of pit-like chemosensory organs in the roof of the mouth called the **Jacobson's organ** each of which has ducts opening, far forward on the palate. These organs are lined with an olfactory epithelium and are richly innervated. The sensitive. forked tongue of the snake (and many lizards) picks up the odour particles from food, mates, predators and perhaps rivals and conveys these smells to the mouth. Tongue is then drawn past the Jacobson's organs or the tip of the forked tongue is directly inserted into the organs. Information is then transmitted to the brain where the scent is identified. The Jacobson's organ occurs in many other terrestrial verterbrates. It is particularly well developed in snakes, which need it to follow prey trails and for sex recognition.

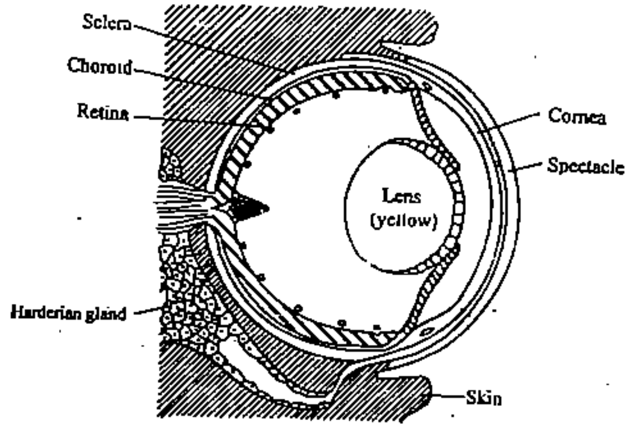


Fig.3.28: Eye of snake.

The snake tongue is narrow, flexible and ribbon like with a forked tip and can protude through a notch in the upper jaw when the mouth is closed.

In snakes the digestive tract is basically a straight tube from mouth to vent (anal opening). Virtually all other internal organs are elongated and the left lung is usually vestigial (Fig. 3.24). Hemipenes as in lizards are present in males.

Locomotion for snakes is an obvious problem, since they are limbless. It is accomplished in two ways by sideward muscular undulations of the body and by movement of transverse ventral scales. You will study their mechanism of movements in Unit 16 of this course.

Most snakes are oviparous and lay shelled, elliptical eggs under rocks, beneath rotten logs, or in holes dug in the ground. However, a number of them, including all the American pit-vipers (except the tropical bush master) are ovoviviparous, giving birth to well formed young snakes. Very few are viviparous. A primitive placenta is present, allowing the exchange of materials between the embryonic and maternal blood streams. Snakes are able to store sperms and can lay several clutch of fertile eggs at long intervals just after one mating. Parental care is shown by some pythons which coil around their eggs (Fig. 3.29).

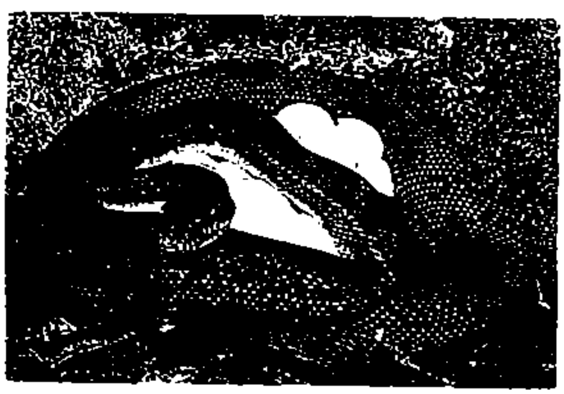


Fig.3.29: The python (*Morelia spilotes*) exhibiting parental care of its eggs by brooding its eggs. Egg brooding (shivering thermogenesis has been described and recorded in some pythons though it may be a universal phenomenon within pythons. The female coils tightly around the egg clutch, so that the eggs are completely hiden. In at least some species encluding *Morelia spilotes*, rhythmic muscular contractions of the mother's body produce sufficient heat to maintain a relatively high and constant temperature in the egg mass.

Snakes are found in temperate and tropical regions and are completely absent in New Zealand. In India there are a large number of non-poisonous and poisonous snakes. Fig. 3.30 shows some of them.

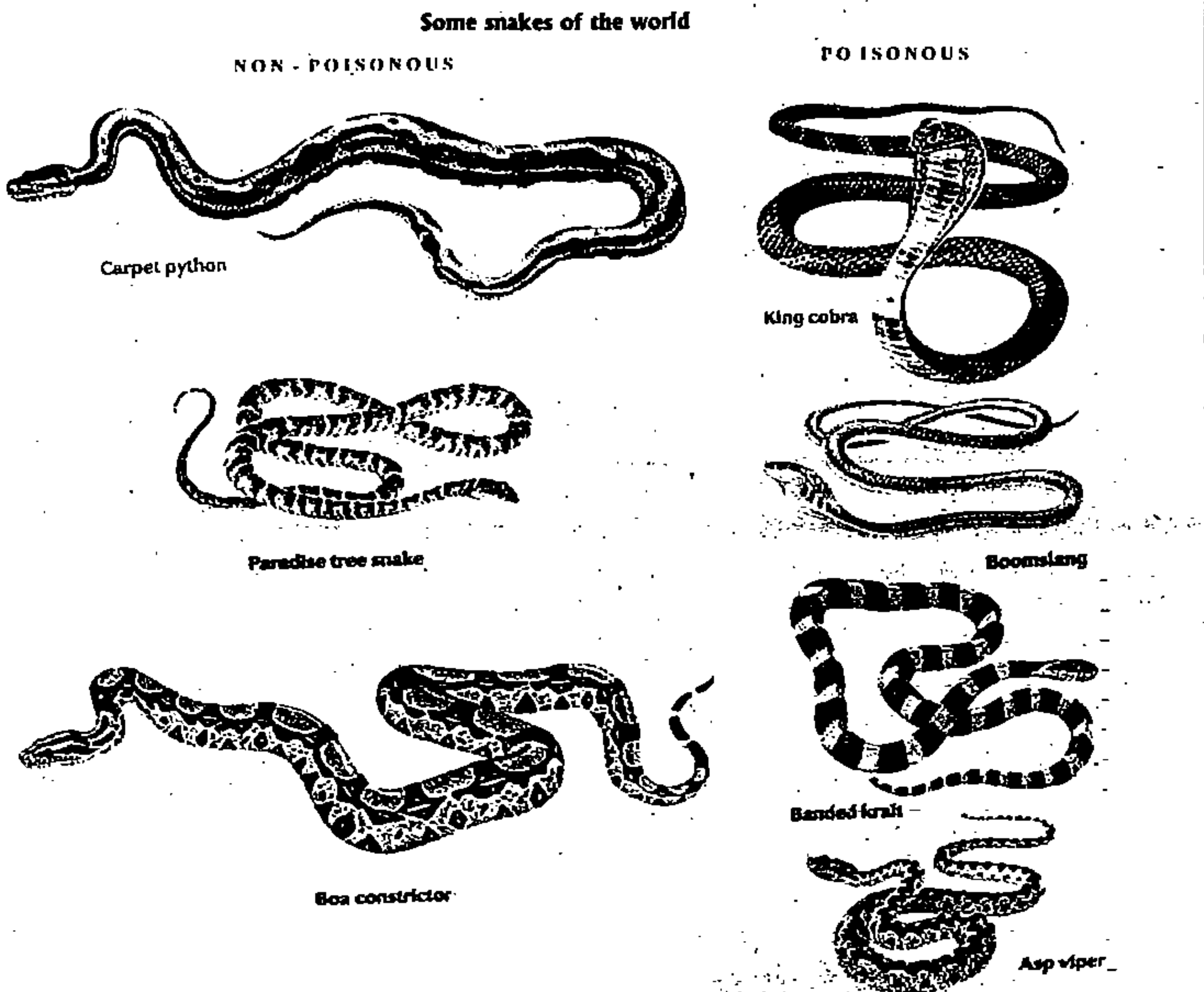


Fig.3.30: Some non-poisonous and poisonous snakes found in India. (a) Non-Poisoncus snakes (b) Poisonous snakes.

Types of Poisonous Snakes

Snakes as you know may be poisonous or non-poisonous. Poisonous snakes are divided into four groups based on the type of fangs (modified teeth which are hollow, grooved, hypodermic needle like structures through which poison is injected into prey).

The vipers (Family Viperidae) which include the Old World true vipers (European adder and African puff adder) and New World pit vipers (rattle snakes, copper heads and cotton mouths) are so called because of special heat sensitive pits on their head between the nostrils and the eyes. These pits are supplied with a dense packing of free nerve endings which respond to radiant energy and are especially sensitive to heat emitted by warm bodied birds and mammals that are their food (Fig. 3.31).

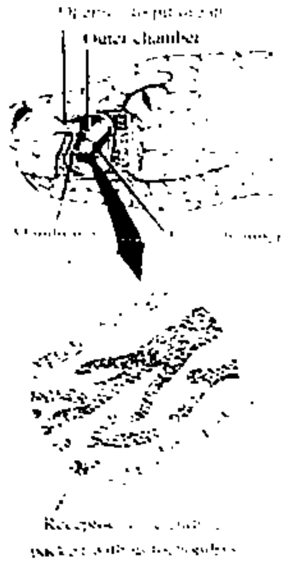


Fig.3.31: Pit organ of rattlesnake, a pit viper, cutaway showing location of a deep membrane that divides the pit into inner and outer chambers. Heat sensitive nerve endings are concentrated in the membrane.

All vipers have a pair of large tubular hollow fangs at the front of the mouth that are articulated to the maxillary bones of the upper jaw and palate in such a fashion that they are folded against the roof of the mouth when the mouth is closed and automatically brought forward when the mouth is opened (Fig. 3.27).

A second family of poisonous snakes (**Family - Elapidae**) which include the kraits, cobras (Fig. 3.26), the mambas, coral snakes etc. have short, permanently erect fangs so that the venom must be injected by chewing.

The highly poisonous sea snakes are usually placed in a third family (**Family Hydrophiidae**) and their fangs are similar to the snakes of family Elapidae.

The very large **family Colubridae** contains most of the familiar and usually non-venomous snakes. However, it does include at least two poisonous snakes that have resulted in human deaths; the African boomslang and the African twig snake. Both these are rear fanged species which have grooved teeth at the back of their jaws and use their venom to quiet struggling prey.

Snake-venon contains many polypeptides and proteins and is traditionally divided into two types (i) **neurotoxins** that block transmission of nerve impulses to muscles, affecting the optic nerves (causing blindness) or the phrenic nerve of the diaphragm causing paralysis of respiration and the (ii) **haemolytic** type consisting of haemolytic enzymes that break down blood corpuscles and blood vessels, produce extensive haemorrhaging (internal bleeding) of blood into the tissue spaces.

Poisonous and Non-Poisonous Snakes

Poisonous snakes can be easily distinguished from the non-poisonous ones. It may not be practical to try indentifying living snakes unless you have the help of a snake charmer. But the knowledge is useful in case of a snake bite. It helps to provide first aid and then get proper medical aid. When dealing with cases of snake bite, try if possible to catch the snake with the help of a snake charmer if he is available or kill the snake and examine. Fig. 3.32 gives the key for identifying non-poisonous and poisonous snakes.

First examine the tail of the snake. (1) If the tail is laterally flattened and it is a sea snake then it is poisonous as all sea snakes are poisonous. (2) If on the other hand the tail is long, rounded cylindrical and whip like it may be or may not be poisonous. In such cases examine the arrangement of scales on the ventral surface (belly) of the snake. (i) If it is covered by small scales or the ventral scales are somewhat broad as shown in the figure then it is a nonpoisonous snake. But (ii) if the ventral scales are large transverse plates extending fully across the ventral side or belly as shown in the figure then it may or may not be poisonous. To find out further examine the dorsal surface of the head of the snake. (a) If the head is covered by small dorsal scales then it is a viper and all viper species are poisonous. (i) If there is a loreal pit between the nostril and eye, then it is a pit viper (ii) If the sub-caudals are double and there is a loreal pit, than it is a Russel's viper (b) Supposing the head is covered by both small and broad shield-like scales (shields) then it may or may not be poisonous. (c) In such cases examine the arrangement of scales along the margins of the jaws. (3) Scales arranged along the margin of the upper jaw are called **supralabials** and those along the lower jaw are called **Infralabials.** (Fig. 3.32). If the third supralabial touches the scale bearing the nasal aperture anteriorly and the eye margin posteriorly then it is poisonous and is a cobra, a king cobra or coral snake. (4) If the upper side of the head has both small scales and large shields but there is no loreal pit and the third supra-labial shield does not touch the eye then examine the back of the snake and ventral side of lower jaw. (i) If the middle row of scales on the back called vertebrals are larger than others and (ii) If ventral side of the lower jaw has fourth infralabial shield larger than others then it is a krait, and these are poisonous. (5) If the snake has small scales and large shields on head but does not have characters of cobra, krait or coral snake, then it is non-poisonous. See Fig. 3.32 which gives the key for identification of poisonous and non-poisonous snakes.

KEY FOR IDENTIFICATION OF POISONOUS AND NON-POISONOUS SNAKES

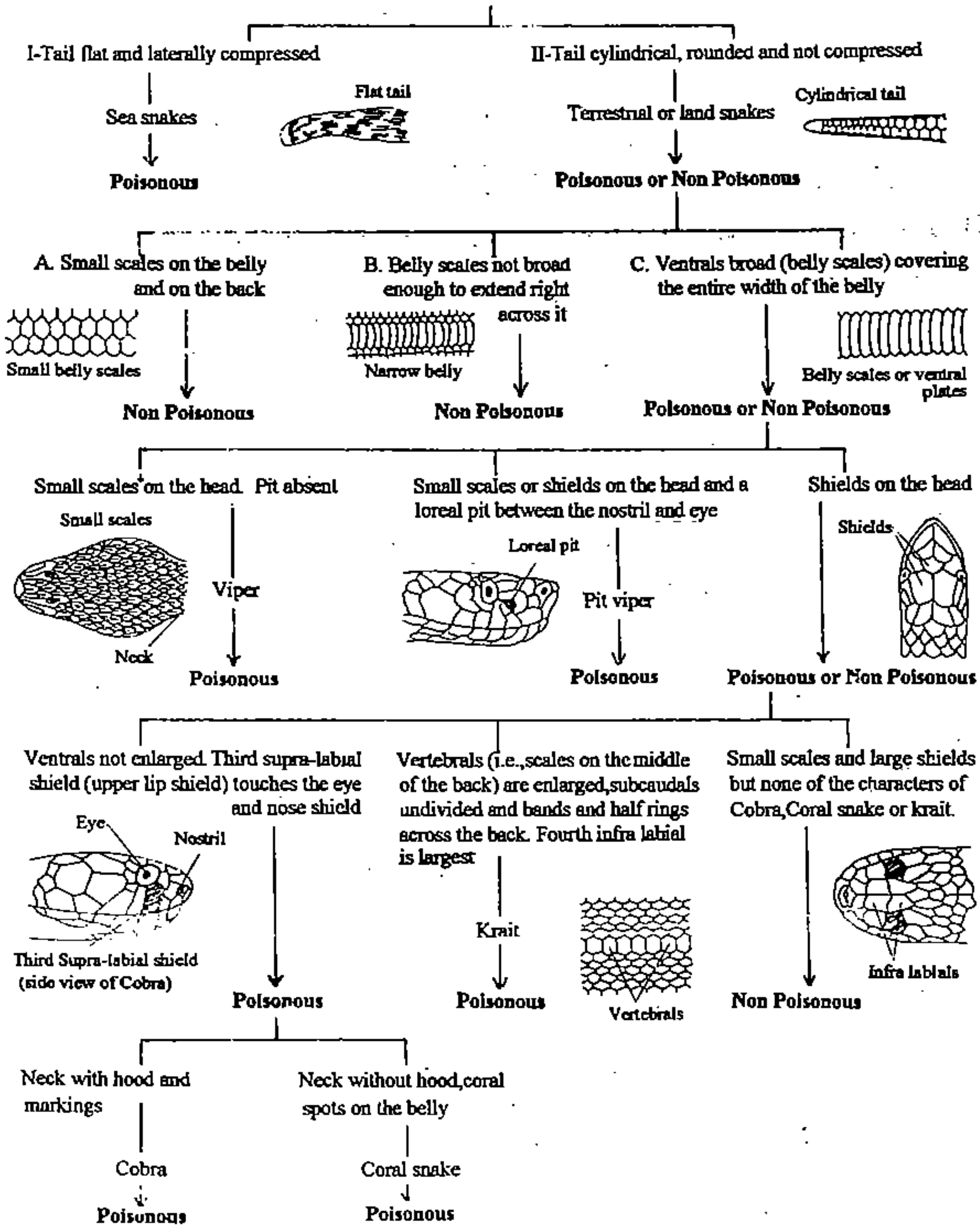


Fig.3.32: Key for indentification of poisonous and non-poisonous snakes.

SAQ 8

In the following statements pick out the suitable word from the alternatives provided in parenthesis.

a) In snakes, spur like rudiments of hind legs are only present in the (boas/cobras.)

b) In snakes, during swallowing the glottis may be projected (backwards/forwards).

c) The arboreal snakes possess (poor vision/good vision).

d) Most snakes in order to hunt their prey use (sight/chemical) sense.

e) The snake, African puff-adder belongs to the family (Viperidae/Elapidae).

f) Except for the tropical bush masters all pit vipers are (ovoviviparous/oviparous).

g) In snakes the sternum is (absent/present).

3. SUBORDER AMPHISBAENIA — EXAMPLE: AMPHISBAENIANS (WORM LIZARDS)

The worm lizards (Fig. 3.33) are neither worms nor true lizards, though they are certainly related to the latter. The name of their suborder Amphisbaenia refers to their ability to move backward nearly as effectively as forward.

In the amphisbaenians, structural features are even more reduced than they are in snakes. Worm lizards have elongate, cylindrical bodies of nearly uniform diameter. The soft skin of the amphisbaenians is divided into numerous rings. These rings alongwith the absence of visible eyes and ears that are hidden beneath the skin make them look like earth worms. Most amphisbaenians lack any trace of limbs except for one genus with short front legs.

The worm lizards lack tympanic membrane but can detect ground vibrations by an extension of the stapes to the lower jaw. Since their rudimentary eyes are concealed beneath the skin they track their prey primarily by hearing and smell.

The amphisbaenians like earthworms live an extensively subterranean life, burrowing after worms and small earthworms. They use their spade shaped, very strong skull and tail to push through the soil. The amphisbaenians have an extensive distribution in South America and tropical Africa. In the United States one species the *Rhineura florida* (called the 'graveyard' snake) is found in Florida. At present about 140 species of Amphisbaenians are known to occur in the tropics and subtropics.

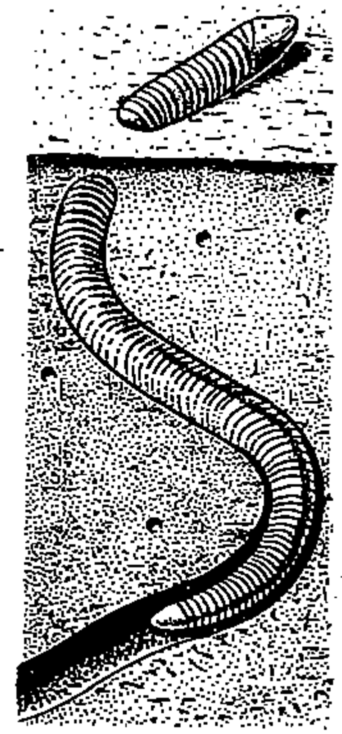


Fig. 3.33 : A worm lizard of the Suborder Amphisbaenia. Worm lizards are burrowing forms with a solidly constructed skull which is used as a digging tool.

SAQ 9

In the following statements pick out the suitable words from the alternatives provided in the parenthesis.

a) The worm lizards lack (eyes/tympanic membrane)

b) The worm lizards feed on (earth worms/shrimps)

c) The Amphisbaenians found in Florida are called *(Fleura florida/ Rhineura florida)*.

(B) SUBCLASS DIAPSIDA : b) Super order : Archosauria (Advanced Diapsids) : i) Order Crocodilia

ORDER CROCODILIA - EXAMPLES: CROCODILES, ALLIGATORS AND GAVIALS (GHARIAL)

Crocodilia is the scientific name for groups of reptiles that include many species of Alligators, Crocodiles, Caimans and Gavials. Modern crocodilians are the largest living reptiles. They are the only surviving representative of the archosaruian lineage that gave rise to the great Mesozoic radiation of dinosaurs and their kin (relatives) and to birds. The present day crocodiles differ very little in structural details from the primitive crocodiles of the early Mesozoic that began their radiation in the late Cretaceous period.

Having managed to survive virtually unchanged for some 200 million years, the contemporary crocodiles face an uncertain and perhaps short future in a world dominated by humans.

Ancestral species were terrestrial but modern ones have become specialized for an amphibious mode of life. Their tail is laterally compressed and is a very effective swimming organ. They have two pairs of short legs. There are five toes on the forefeet and four on the hind feet. The hind feet are webbed. The tympanic membrane is exposed but protected by a fold of skin. Eye, ear and nose openings are in a straight line and are situated on elevations on the top of the head, so, they protrude above water. This allows most of the animal to be submerged as it stalks its prey. Valves close the ear and nose when under water. The anal opening like that of testudines is a longitudinal slit. The skin is thick, with bony plates underlying the horny scales on the back and ventral sides.

All Crocodilians are predatory and carnivorous and have robust, elongate, well reinforced skull forming a snout and massive jaw musculature arranged to provide a wide gape and rapid, powerful closure. Their sharp teeth are set in sockets, a type of dentition called **thecodont** that was typical of all archosaurs as well as of the earliest birds. Another adaptation found in them and in no other vertebrate except mammals is the presence of a secondary palate. This innovation enables the crocodilians to breath even when their mouth is filled with water or food or both. The shape and length of the snout vary considerably with diet.

Modern crocodilians are divided into three families; (1) Alligatoridae that include the alligators and caimans, mostly a New World group (exception being the Chinese alligator). Alligators and caimans (or caymans) are freshwater forms (ii) Crocodylidae which comprise, the crocodiles that are widely distributed and include the salt water crocodiles, one of the largest living reptiles; and the (iii) Gavialidae that contains the gavials (also called gharials). It is represented by a single species that occurs in India and Myanmar (Fig. 3.34).

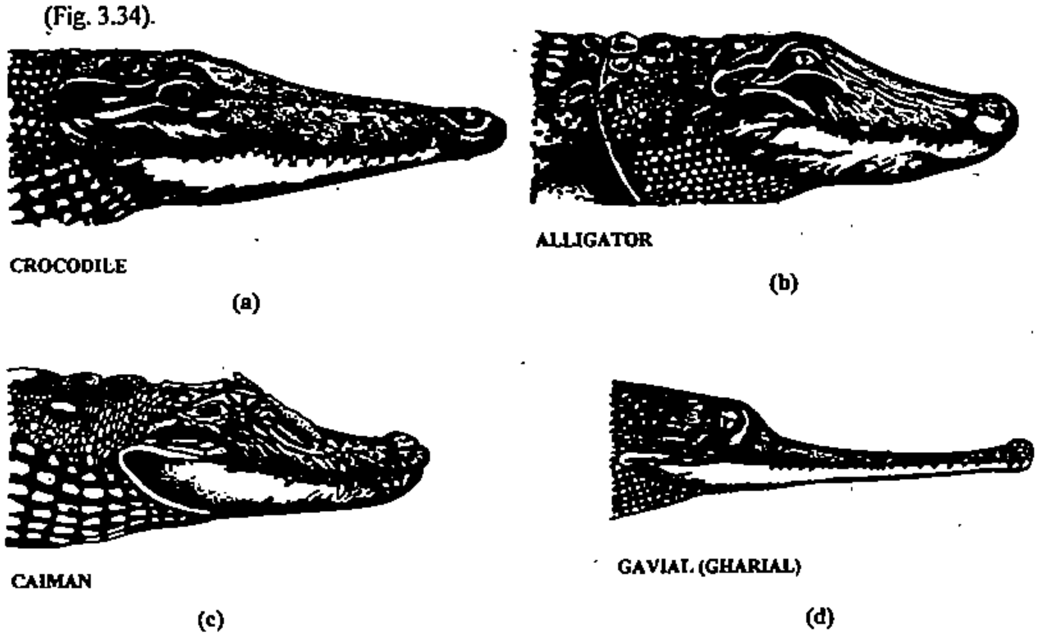


Fig.3.34: The modified snouts of four species of crocodilians reflect their different feeding habits. (a) crocodile (b) alligator (c) caiman (d) gavial.
The crocodile and alligator can be easily distinguished if you carefully observe their head. The snout of alligator is comparatively broader and rounder and the teeth fit inside jaws, while in crocodile the fourth teeth on the lower jaw protrudes outside. (c) The caiman which is very similar to the alligator is difficult to tell apart. It is more aggressive than the alligator. The gavials are quite distinct from crocodiles and alligators, as they can easily be recognized by long narrow snout, and sharp teeth. Males have a protuberance at the end of snout.

The crocodiles (Fig. 3.34 a) have long pointing snouts that appear to be triangular. The obvious feature that distinguishes crocodiles from alligators is that in alligators the fourth tooth on each side of the lower jaw fits into a pit in the upper jaw when mouth is closed. In most crocodiles the fourth tooth of the lower jaw fits into a notch on the outer side of the upper jaw and is exposed when the mouth is closed. All crocodiles live in or near water in tropical or subtropical regions of the world. Crocodiles are largely nocturnal animals found in Africa, Asia and the Americas, including Florida.

An odd feature about alligator reproduction is that the sex of the offspring is determined by the incubation temperature. Low nest temperatures produce females, while high nest temperatures produce only males. This results in highly unbalanced sex ratios in some regions.

The man-eating members of the crocodile are found mainly in Africa and Asia.

Alligators: Alligators (Fig. 3.34 b) are less aggressive than crocodiles and live in China and Southern United States.

Caimans: The caimans (Fig. 3.34 c) closely resemble alligators and are native to Central America. Some have become established in Florida.

Gavial: (Fig. 3.34 d) Gavial is a fish eating member which has an unusual snout that looks like a saw. It extends from its face like a long handle. It has extremely sharp teeth. Its slender snout is an excellent tool for side-swiping fish. It is generally a timid animal.

Alligators and crocodiles are oviparous. Usually 20-50 eggs are laid in a mass of vegetation and guarded by the mother. The mother hears vocalization from the hatching young and responds by opening the nest to allow the hatchlings to escape.

Parental care is generally lacking in reptiles, though in crocodilians nesting behaviour and parental care overlaps that of many birds. In one species of crocodilia, both parents carry the young in their jaws from the nest to a special nursery area, where they oversee their development (Fig 3.35).

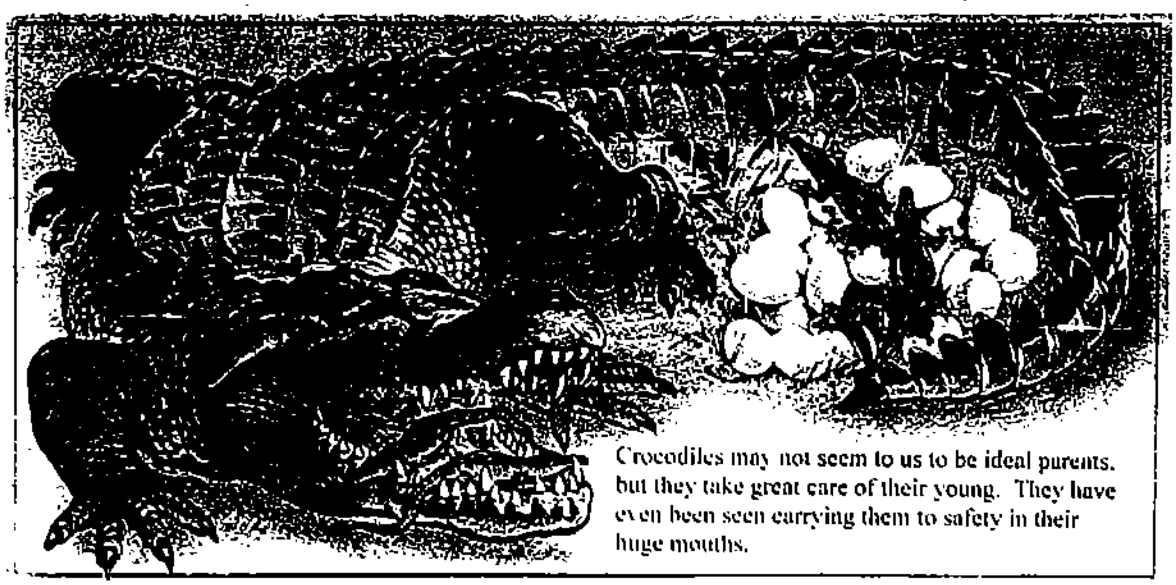


Fig.3.35: Crocodile showing parental care.

SAQ 10

Fill in the blanks with the appropriate words in the following statements.

a) In all crocodiles, dentition is______________.

b) Crocodilians can breathe even when the mouth is filled with water or food or both because of the presence of a secondary ________________.

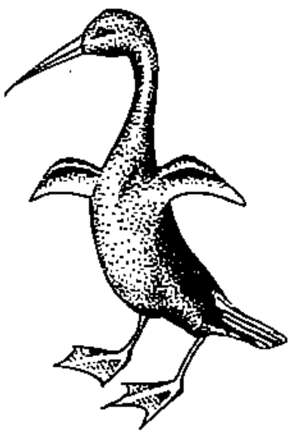
c) Alligators are ________________ aggressive than crocodiles.

3.4 BIRDS-AVES

Birds of the class Aves are easily recognisable from the other vertebrates due to the presence of feathers. Birds are homeothermic like mammals, but share many of the reptilian characters. Birds are the only vertebrates capable of intense and sustained flight. However they cannot live in the air all the time and have to come to land or to water in order to feed, roost and nest.

Birds share with mammals the highest organ development in the animal kingdom. However, their entire anatomy is designed around flight and its perfection which thus restricts diversity and imparts great structural and functional uniformity to all of them.

Like any other flying machine birds have sacrificed every thing for low weight and high power.



HESPERORNIS

Fig.3.37 : Another bird *Hesperornis* has also been found in Cretaceous deposits. However, it is an aquatic bird which had completely lost its wings due to an aquatic mode of life. It had also lost the long reptilian tail. It had a well developed sternum. A true pygostyle had not evolved by then and jaws still had teeth. It was a large diving species with powerful bird legs.

3.4.1 Ancestry and Evolution of Birds

Birds, first made their appearance during the Cretaceous period. The typical modern birds made their appearance by the Cenozoic Era. Not many birds fossils have been found, as bird bones are perforated with air cavities and so disintegrate easily and leave no remains. The earliest known bird fossil *Archaeopteryx lithograpica* (ar-kee-opter-ix-lith-o-graf-e-ca, means ancient wing inscribed in stone"), was found near Bavaria in Carboniferous deposits which were 150 million years old, being of the Jurassic period (Fig. 3.36). *Archaeopteryx* was the size of a modern crow. It was a land bird showing both reptilian and avian characters. The whole body axis was elongated and lizard like. The vertebrae articulated by simple concave facets as in reptiles without the saddle shaped articular facets of the centrum present in birds. The skull resembled that of modern birds, except that the elongated jaw forming the beak had bony teeth set into sockets (thecodont) like those of reptiles. The skeleton was decidedly reptilian with a long bony tail, clawed fingers, abdominal ribs and thick walled bones. The thoraic ribs were slender and had no uncinate processes. The pelvic girdle and hind limbs resembled those of archosaur with elongated ilum and back wordly directed pubis. Trunk or sacral vertebrae were not fused. There were three fingers with claws on each hand and four toes on the feet. Their structure thus was very similar to reptiles, except for the presence of a feathery covering and a furculum and small sternum (which is the fused collarbones commonly called a wish bone). The long tail had two rows of feathers as well. Birds-like tendencies were evident in the enlarged eye orbits, in some expansion of the brain case and in the wing-like structure of the hand. This was because the forelimb or hand was modified for flight, bearing remiges and 3 digits each. These fossil birds are recognised to be a link between reptiles and birds and provide proof of the evolution of birds from reptiles. After *Archaepteryx* the next bird fossils date from about 90 million years ago, in the Cretaceous period. Hesperornis, (Fig. 3.37) a large, flightless diving bird probably resembled the modern loon but had reptilian teeth.

(a)

(b)

Fig.3.36: *Archaeopteryx*, the 150 million years old ancestor of modern birds which lived in the upper Jurassic period (a) cast of the second and most nearly perfect fossil of *Archaeopteryx* which was discovered in a Bavarian stone quarry. (b) reconstitution of *Archaeopteryx*, Six specimens of *Archaeopteryx* have been discovered, the most recent in 1987.

The similarity between reptiles and birds has long been recognised by zoologists due to many shared morphological development and physiological homologies. The English zoologist Henry Huxley classified birds along with a group of dinosaurs called theropods. Theropods belong to a lineage of diapsid reptiles, the archosaurians that include pterosaurs and crocodilians as well as dinosaurs. However, birds originated neither from the flying pterosaurs nor from the crocodilians (although the crocodilians are the bird's nearest living relatives). Evidence shows that the bird's nearest phylogenetic affinity is to the theropod dinosaur linkage that was evolving distinct bird like characteristics. Infact, the only anatomical features needed to link bird ancestry with theropod dinosaurs was feathers and this proof was provided by the discovery of *Archaeopteryx*.

Birds show monophyletic origin in their evolution. It means birds evolved from a single ancestor. There have not been many structural changes during their evolution and during the 60 million years of their existence. This is said to be due to the restricted aerial mode of life that the birds adapted. Fig. 3.38.

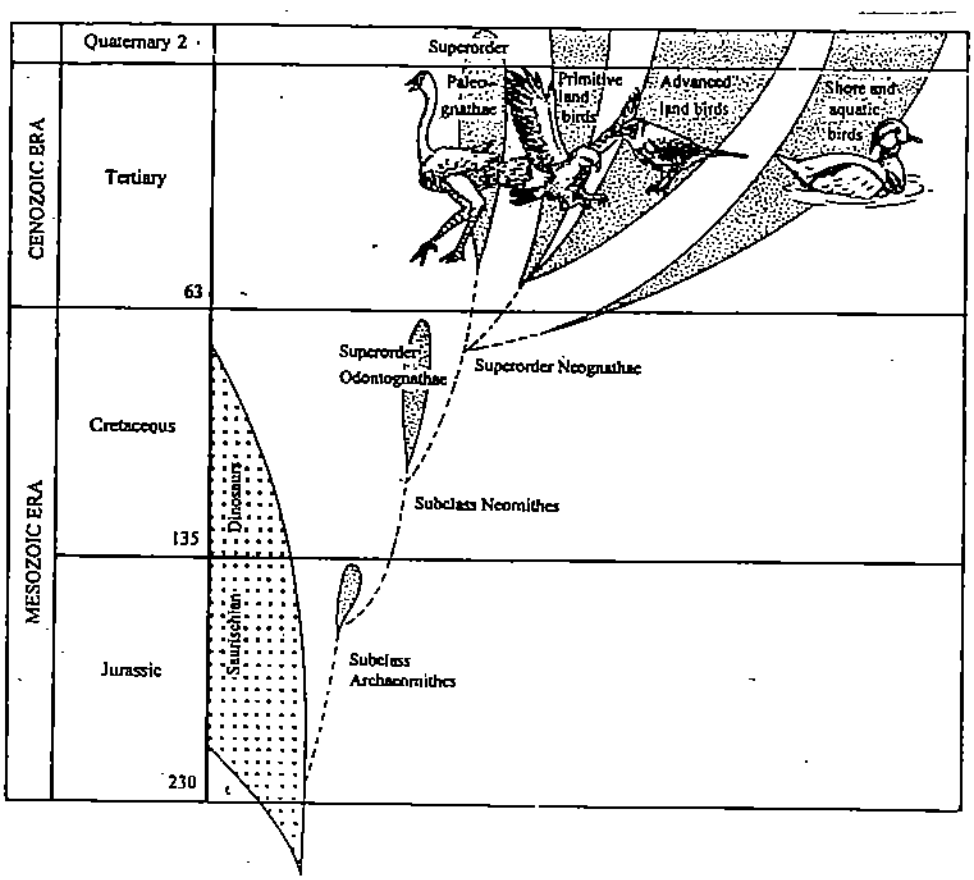


Fig.3.38: Phylogeny, geological distribution and evolution of modern birds. Evolution of modern bird occurred rapidly during the Cretaceous and early Tertiary periods.

Living birds (Neornithes) are broadly divided into two groups:

(a) Ratite and (b) Carinate

(a) **Ratite:** Ratites have lost the keel in their sternum as a result of which their sternum is flat and the flight muscles are reduced. They are thus flightless. Examples: Cassowaries, Emu, Kiwi, Ostrich.

(b) **Carinate:** Carinates are flying birds that possess a keeled sternum on which large, well developed flight muscles are inserted. Carinates are believed to be more primitive.

The two divisions - Ratites and Carinates originated from the view that flightless birds represented a separate line of descent that never passed through a flying stage, as did all other. This idea has been discarded since ostrich - like ratites have clearly evolved from flying ancestors. Furthermore, not all carinate or keeled birds can fly and many of them even do not have the keels. Flightlessness has occurred independently among several groups of birds.

3.4.2 Classification of Birds

There are more than 9600 species of birds distributed among 28 orders of living birds and a few fossil orders. Very few bird species remain to be discovered but many subspecies are added each year. Of the 28 living orders, 4 are ratite, although flightlessness is not limited to these groups alone. The remaining are carinate birds. Bird species altogether are grouped into about 170 families. Fig. 3.39 shows the classification of birds upto the level of order, the various characteristics of the orders of living birds.

3.4.3 Characteristics of Birds

1. Birds are endothermic vertebrates.
2. Body is usually spindle shaped, with four division; head, neck, trunk and tail. Neck disproportionately long for balancing and gathering food.
3. Two pairs of limbs present. Anterior pair modified into wing for flying. Posterior pair variously adapted for perching, walking or swimming (with webs). Each posterior foot usually has four toes.
4. Epidermal covering of feathers and leg scales; shanks and toes sheathed with cornified epidermal skin; thin integument comprises of epidermis and dermis; cutaneous or sweat glands are absent; uropygial oil or preen glands present at root of tail; pinna of ear is rudimentary.
5. Skeleton is delicate looking but actually, strong, fully ossifed, usually pneumatic (light) with air cavities. Skull bones are fused with one occipital condyle as in reptiles. This makes it possible for the bird to turn its head almost 180°.
6. Pectoral appendages form wings. Pelvis is fused to numerous vertebrae but open ventrally. Small ribs with strengthening process; tail is not elongate. Sternum is broad, well developed usually with median keel or reduced with no keel. Flight muscles are attached to keel. Last thoracic, all lumber, all sacral and first few caudal vertebrae have thus fused with the pelvic girdle to form a synsacrum which supports weight of the body on bird's limbs, while walking or standing. The posterior caudal vertebrate are fused together to form pygostyle. Single bone in middle ear.
7. Nervous system well developed, with brain and 12 pairs of cranial nerves. Eyes and visual centers in brain are large and important. Inner ear contains a cochlea but it is not long and coiled.
8. Narrow jaws form horn-covered beak in contemporary species; Teeth are absent. Gullet has crop which helps in storing food. Stomach is divided into an anterior proventriculus and a posterior muscular gizzard. Gizzard helps in mastication of food and substitutes for the absence of teeth in the buccal cavity. Villi are present in the small intestine.
9. Respiration is by means of compact, spongy and only slightly expansible lungs which are attached to ribs and also connected to thin walled air sacs extending among the visceral organs and skeleton. Lungs and air sacs form an unusual pattern of air passages and air sacs that produce an exceptionally efficient one-way passage of air across the respiratory surface. Voice box (syrinx) is present near junction of trachea and bronchi (i.e. at base of trachea).
10. Circulatory system of four chambered heart (two atria, two separate ventricles) so that oxygen depleted blood and oxygen rich blood are completely separate. Only right systemic arch is present which forms the dorsal aorta carrying oxygenated blood to limbs, trunk and the tail; reduced renal portal system, red corpuscles nucleated, oval and biconvex.
11. Urinogential excretory system is of metanephric type (as the adult kidney in all amniotes is formed from metanephros); ureters open into cloaca; bladder absent. Uricotelic type excretion; excretion of urine is semisolid, in order to conserve water; uric acid main nitrogenous waste.
12. Sexes are separate; testes are paired with vas deferens opening into cloaca; females with only left ovary and oviduct. Right ovary and oviduct atrophy during development. Copulatory organs found only in ducks, geese, and a few other species.
13. Birds are oviparous (lay eggs) and fertilization is internal. Eggs are amniotic and cleidoic with large amount of yolk. All the four foetal membranes (amnion, chorion, yolk sac and allantois) are present during development within the egg. Albuminous material and a hard calcareous shell are secreted around egg as it passes down the oviduct. Incubation is external. Parents incubate eggs, take care of their hatchlings; young may be active at hatching (precocial) or naked and featherless (altrical). Sex determination is by females (heterogametic).

In most animals including us the characterstic sex genotype of females is XX and of males is XY. However, in birds, moths and butterflies the sex genotypes are reveresed females are XY (heterogametic) and males are XX (homogametic). Thus sex (male or female) is determined by ovum and so consequently by female.

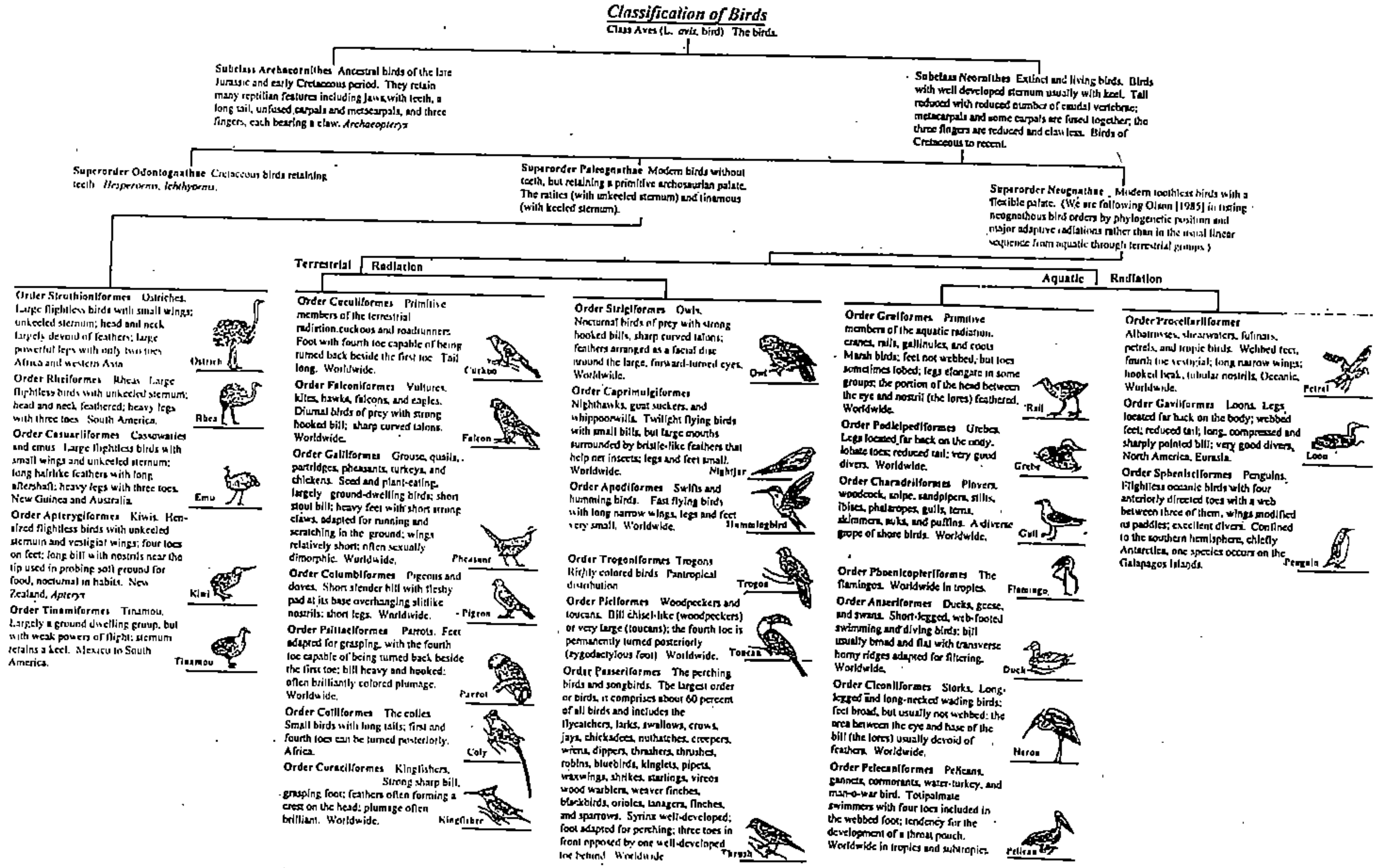


Fig.3.39: All living birds have been divided by ornithologists into 28 orders. The figure lists and briefly describes each order.

SAQ 11

Fill in the blanks with suitable words:

a) Living birds are divided into two groups__________ and __________.

b) The first fossil bird, the __________ dates back to the Jurassic period.

c) The __________ are the birds closest living relatives.

d) The *Archaeopteryx* fossil is recognised to be a link between __________ and __________.

3.4.4 Form and Functions of Birds

In order to fly, birds have various, special adaptations which relate mainly to two things, more power and less weight. Let us study some of the important features.

Size

The largest living birds include the ostrich of Africa which stands fully 2.13 meters high and weighs upto 136.4 kg and so is too big to fly. The smallest is Helen's hummingbird of Cuba being 6.35 cms. long and weighing only about 3 grams. Fig.3.40 shows some unusual birds.

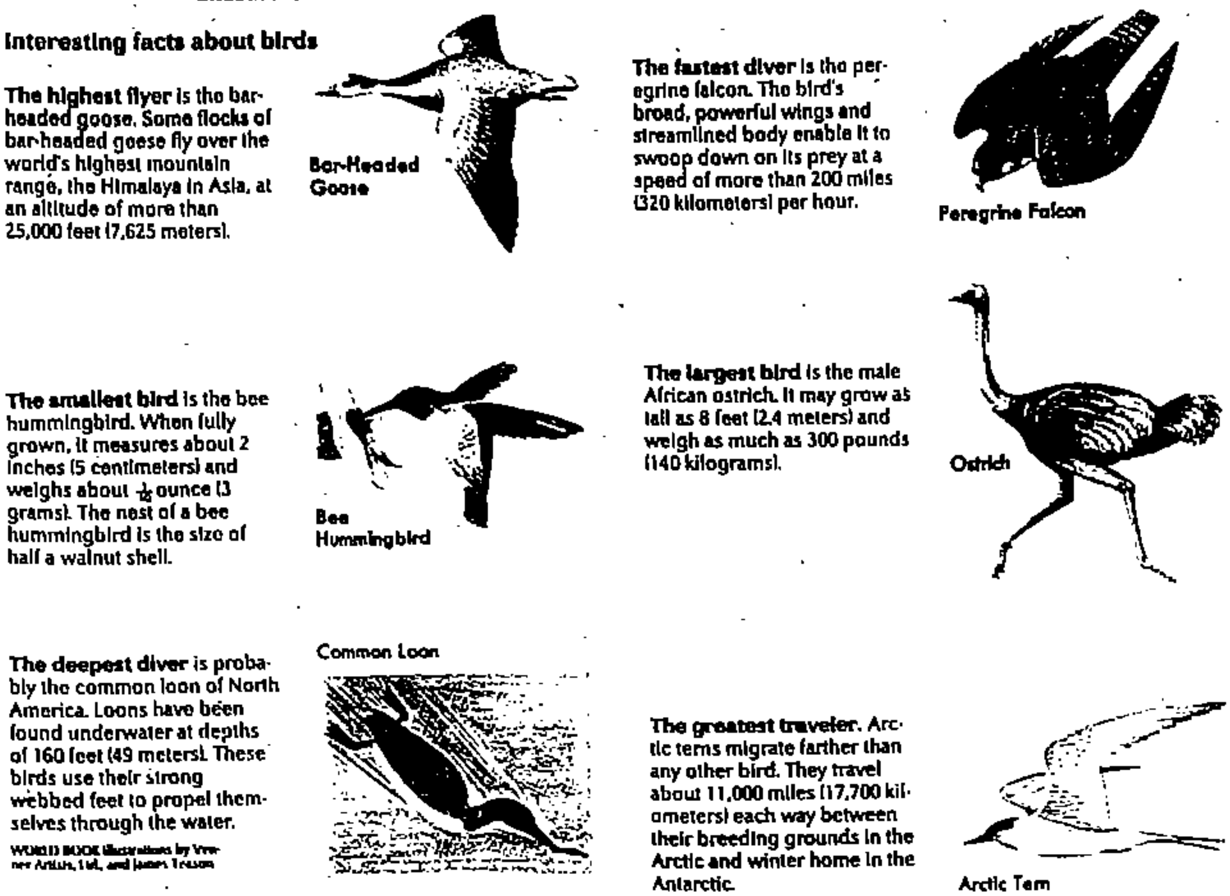


Fig.3.40: Some interesting birds.

Endothermy

Birds require a very high energetic output for flying and so have evolved true endothermy. They maintains body temperatures at relatively high levels of 40-43°C. Their metabolic rate is many times that of reptiles. Heat is produced internally and its loss is controlled at body surface. Insulation is provided by subcutaneous fat and by feathers. Water (a very good conductor of heat) is prevented from penetrating the feathers by an oily secretion produced by the uropygial gland (Gr, oura = tail + puge = rump), located on the back, near the tail base and spread on the feather surface. (Fig. 3.41).

Heat loss by feet is reduced in many birds by a vascular countercurrent mechanism. Arteries that supply blood downwards to the feet break into a maze of tiny blood vessels and surround the fine venous vessels of the feet that are returning to the body. The network of the entwined fine arterial and venous vessels constitute a '*rete mirabile*'. This ensures that the heat flowing peripherally in the arterial blood is transferred to the cooler venous blood returing to the body so that the warmth is short circuited from the arteries to the vein and back into the body and heat is conserved.

When a bird preens or draws the feathers through the bill, it spreads an oily secretion from the uropygial gland over the feathers to prevent the water from penetrating them.

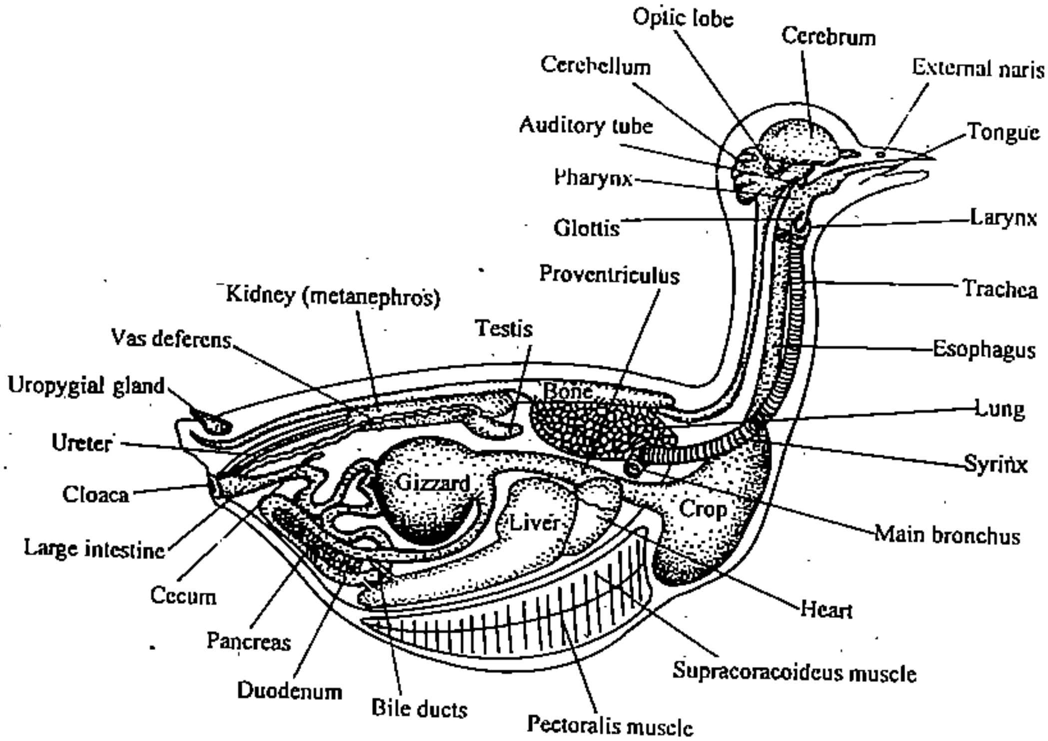


Fig.3.41: Major internal organs of a pigeon as seen in a lateral dissection.

Skin & Feathers

The skin (Fig. 3.42) of bird diffes from that of mammal in being thin, loose and dry. There are no sweat glands as these would be of no use in a body covered densely with feathers. The only large cutaneous gland present is the uropygial gland for preening feathers. The feathers of modern birds provide a covering whose uses vary from heat insulation, to heat conservation, to flight, to protective colouration, to sexual display.

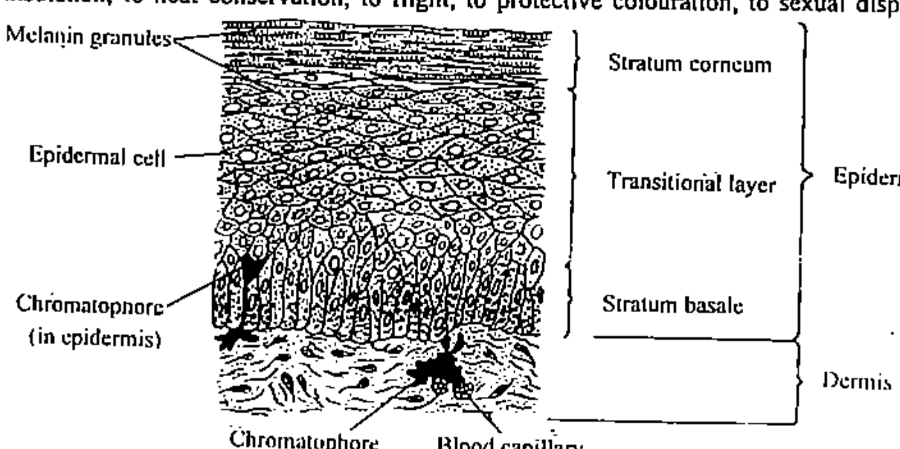


Fig. 3.42 : Bird skin. Section of skin showing the stratum basale and the keratinized surface layer, the stratum corneum. Cells moving out of the basal layer spend time first in the transitional layer before reaching the surface. This middle transitionl layer is equivalent to the spongiosum and granulosum layers of mammals.

Feathers more than any other single feature characterize birds. Feathers similar to the scales of feet of birds have evolved from reptilian scales to which they are thus homologous. Both feathers and scales of feet of bird are epidermal outgrowths of the integument. (Fig. 3.43) Feather cells accumulate large amount of keratin and so are dead structures. The brilliant colouration of feathers is due to pigments deposited in these cells during the development of the feather. Dark colours of feather may be due to pigments transferred from special colour bearing cells in dermis. Brighter hues are partially due to pigments obtained by the cells of the developing feathers from the blood stream. However, much of the colour and iridescence of feathers is believed to be not due to pigment but due to surface modifications of the horny feather substance that reflect certain rays (all blue are produced in this manner).

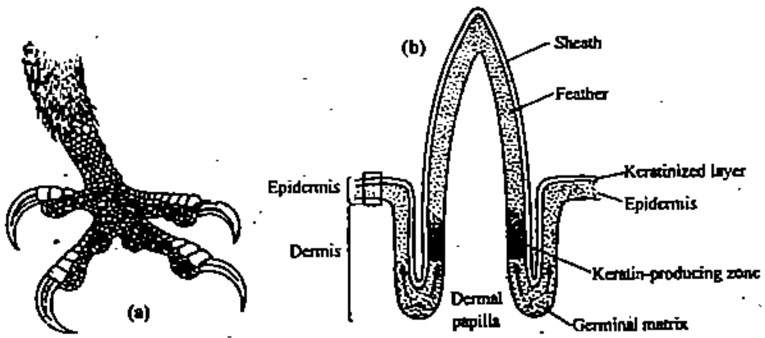


Fig.3.43: Figure shows epidermal derivatives in bird. (a) Epidermal scales are present on the feets and legs of bird. (b) feather is an epidermal derivative as can be seen in this figure of growth of a feather follicle. The feather itself forms within a sheath, that similar to the feather is a keratinized derivative of the epidermis.

In most species feathers covering birds, fan out from localized bands, the feather tracts which are called **pterylae**. The featherless spaces in between pterylae are called **apterylae**. (Fig. 3.44) The various bones of the forelimb form a base supporting the large wing feathers which are called remiges the (1) primaries or metacarpal digits are attached to various bones of the wrist and hand (2) secondaries or cubitals are attached to the ulna and (3) and humerals are supported by the humerus. Contour feathers of tails are called retrices.

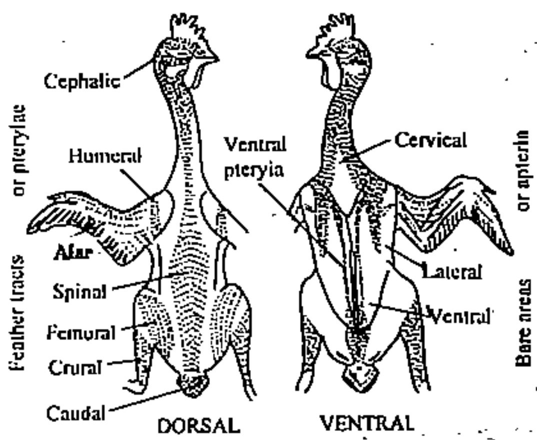


Fig.3.44: Feathers arise along specific pterylae tracts.

A feather is extremely light in weight, yet is remarkably tough with high tensile strength. The most typical bird feathers are contour feathers that cover and streamline the bird's body. Each contour feather consists of a hollow **quill** or **calamus (Gr kalamos = quill)** which is embedded in the follicle or dermal papillae of the skin and a rachis or stiff central shaft, which is a continuation of the quill and which bears the vane composed of numerous side branches, the barb. (Fig. 3.45B (a)) Barbs are arranged in a closely parallel manner and spread diagonally outward from both sides of the central shaft, to form a flat, expansive, webbed surface of the vane. There may be several hundred barbs in the vane. Many body feathers have free barbs often reduced to a tuft arising from the distal end of calamus at the junction of the principal shaft and quill, forming a secondary shaft called **aftershaft**. (Fig. 3.45 b). The cavity of quill opens out through an aperture at the junction and is called superior umblicus.

...microscopically, then each barb looks like a miniature replica of the feather with numerous minute hooked filaments or branches called **barbules** along its side. The barbules of one barb interlock with the barbules of the adjacent barbs spreading laterally from it. There may be 600 barbules on each side of a barb, adding upto more than 1 million barbules for a feather, in a herringbone pattern that are held together with great tenacity by the tiny hooks called **barbicels** or **hooklets**. If two adjoining barb become separated (quite a lot of force is needed to pull apart the vane), the bird then preens its feather with its bills until the barbules again hook together. The vane is thus a light but a strong, and easily repairable surface and is ideal for both insulation and flight. In birds such as ostrich which have lost their ability to fly, feathers lack hooks, functioning only in insulation. The arrangement of contour feathers determine the shape of a bird.

Types of feathers:

There are different types of feathers serving different functions. Some of them as shown in Fig. 3.45.

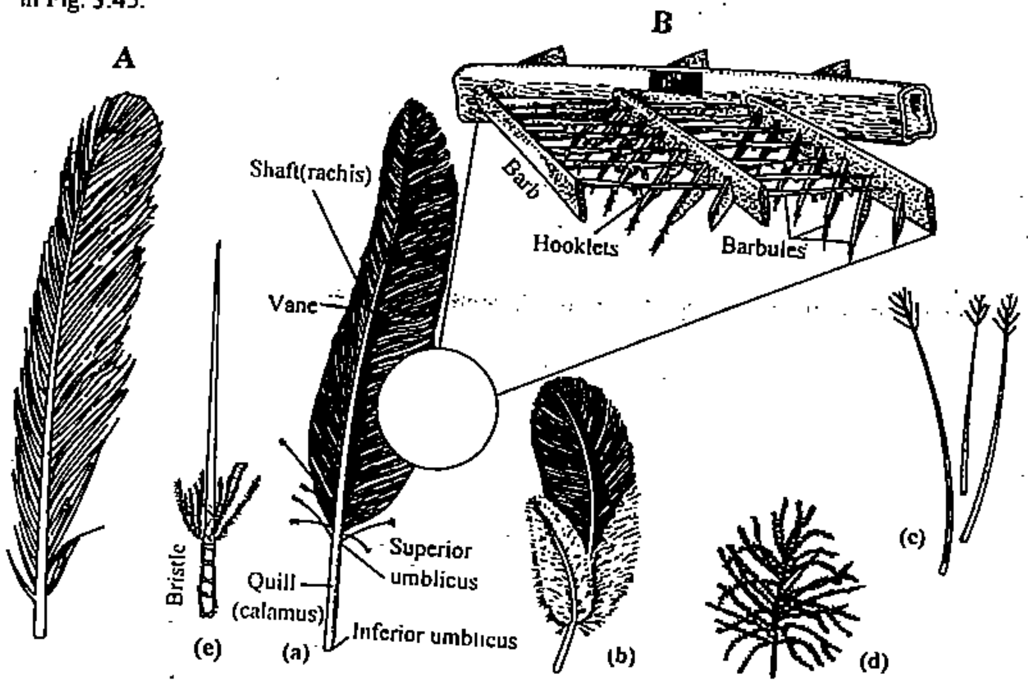


Fig.3.45: **Types of bird feathers: (A) *Archaeopteryx* feather (B) Feathers of modern birds: (a) A contour feather (flight feather), inset enlargement showing minute hooks on the branches that interlock together, to form a continuous surface of vane. (b) pheasent vane feather with after shaft. (c) filoplumes (d) down feather (e) bristle.**

Moulting

A fully grown feather, is a dead structure that eventually frays and may even break. Most birds shed their feathers atleast once a year during moult that generally occurs in late summer after the breeding (nesting) season when birds are not under stress.

A number of birds also undergo a second partial or complete moult just before the breeding seasons to equip themselves with their breeding finery which is essential for courtship display.

During moulting, old feathers are discarded and replaced by new ones in a sequence characteristic for each species.

SAQ 12

Tick appropriately the following statements as true or false.

(a) Feathers of bird are homologous to scales of reptiles. True/False

(b) Nearly all birds moult atleast once a year, usually in late summer after the nesting season. True/False

(c) The featherless tracts in between the feathers are called pterylae. True/False

Skeleton

The skeleton of bird is modified in relation to flight, bipedal locomotion and laying of large eggs with hard shells. One of the major adaptations of modern birds that allow it to fly is its light but sturdy skeleton, unlike the skeleton of *Archaeopteryx* which was solid with reptilelike bones, and so too heavy for flight. The bones of modern birds are amazingly light, delicate, thin, hollow, pneumatic being laced with air cavities due to extensions from the lungs into them. They are however strengthened by internal struts of bone (Fig. 3.46). The skeleton of all birds weighs less in relation to their body weight as compared to the skeletons of mammals.

The skeleton of a frigate bird with a 2.1 metres using span weighs only 114 grams which is less than the weight of all its feathers

Fig.3.46: Longitudinal section of bone of wing of a songbird, showing its hollow structure and the stiffening struts (similar to that in an aeroplane wing) and air spaces that replace bone marrow. Such pneumatized bones are remarkably light and strong.

Skulls of modern birds are so highly specialized that it becomes difficult to see any trace of the original diapsid condition. Skull is light and mostly fused into one piece. The cranial region or brain case and the orbits are large to accommodate a bulging brain, needed for quick motor coordination and superior vision (Fig. 3.47).

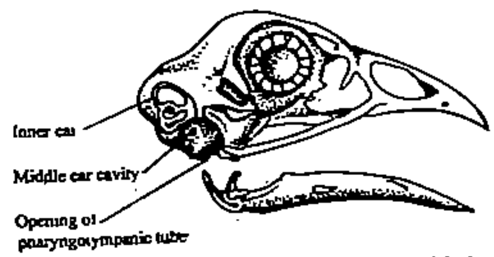


Fig.3.47: Skull and hearing complex of birds.

The anterior skull forms the jaws which extend forward into a horny (keratinous), toothless beak. The toothlessness in the beak of modern birds reduces weight in comparison with the toothed and heavy jaws of the *Archaeoptryx*. The upper jaw in modern bird is formed by two upper mandibles each consisting of premaxillae, maxillae and other bones and is usually fused to the forehead. In many birds like the parrot which have kinetic skulls the upper jaw is hinged to the skull. This adaptation increases mouth gape permitting greater flexibility in food manipulation and in feeding while flying. The lower jaw of birds is formed by two mandibles, each of which is a complex of several bones that hinge on two small movable bones, the quadrate, connecting to the squamosal. This provides a double jointed action that allows the mouth to open wide.

The kinetic mobility of the skull is due to the skull bones of birds which have four major mobile units (Fig. 3.48)—brain case, upper jaw, lower jaw and palatal complex. The quadrate bone is always mobile (streptostyle) and forms several ball and socket joints that allow considerable movement of the mandible and concurrent movement of the upper jaw. The quadrate is pulled directly forward by the quadrate protractor and pterygoid protractor and indirectly by the mandibular depressor, which lowers the mandible, an action that pushes the jugal and pterygoid—palatine bones and thus lifts the upper jaws.

In addition a joint or band of flexible bone is present near the junction of the nasal and frontal bones (prokinetic joint) that allows the upward movement of the upper jaw. Sometimes however instead of this there may be a flexible joint near the beak tip (rhynchokinetic joint) that permits the tip to be lifted.

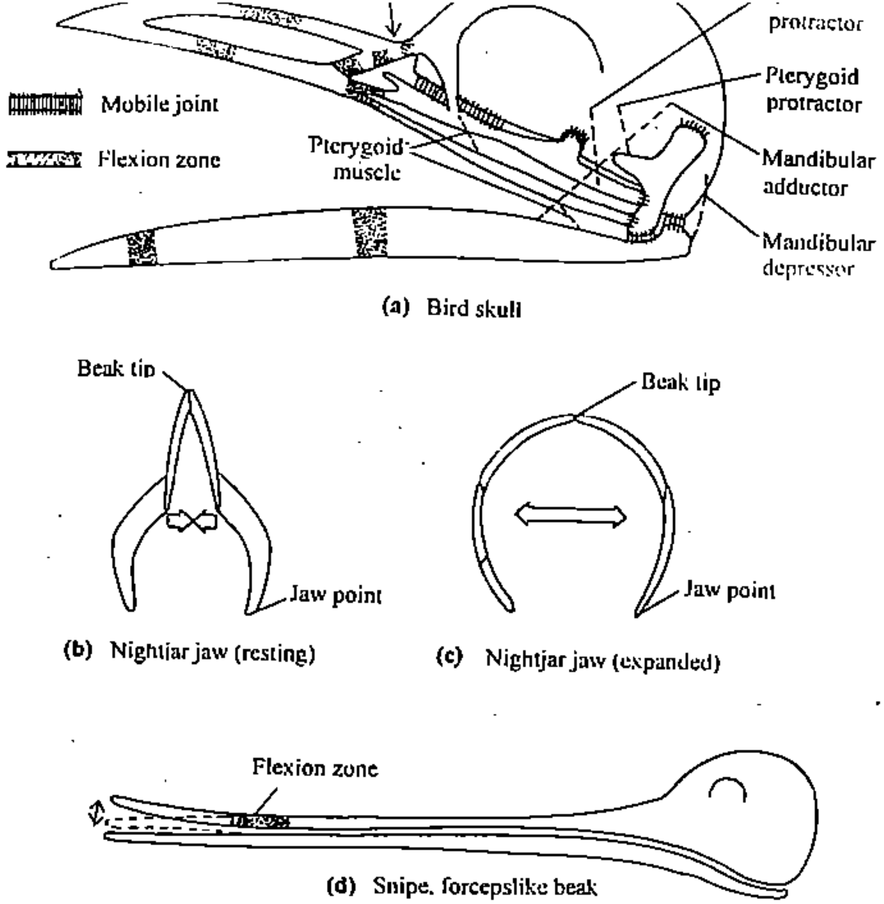


Fig.3.48: Skull kinesis in birds. (a) The bird skull has numerous mobile joints and several zones of flexion that permit even slight adjustments of jaws. The most important zone of flexion that allows independent movement of the upper beak is indicated by an arrow. (b) In some birds, such as this nightjar, the lower jaws can be spread apart. In b the jaw is in resting position, whereas in (c) the jaws are spread, increasing the mouth opening as a scoop for catching insects while flying. (d) Flexion zones in the beak, especially of long-beaked forms such as the snipe allow the tip to be opened slightly. The beak is used as a forceps to catch worms as the bird forages in the mud along a shoreline.

The skull of birds (Fig. 3.49) articulates on a single occipital condyle with the first neck vertebra of the vertebral column. The vertebral column of birds is highly specialized for flight. Its most distinctive feature is its rigidity. The neck region is very long and the cervical vertebrae are articulated in such a fashion that the head and neck are very mobile, as freedom of movement of the head is very essential. The trunk region in comparison is shortened and most of the vertebrae except the cervicals, are fused together and with the pelvic girdle to form a stiff but light framework to support legs and to provide rigidity for flight. To assist in this rigidity, ribs are mostly fused with the vertebrae, pectoral girdle and sternum. The trunk vertebrae are firmly united to form a strong fulcrum for the action of the wing and for a strong point of attachment for the pelvic girdle and hind legs.

The sternum in all, except the flightless birds is keeled, to which the powerful flight muscles are attached.

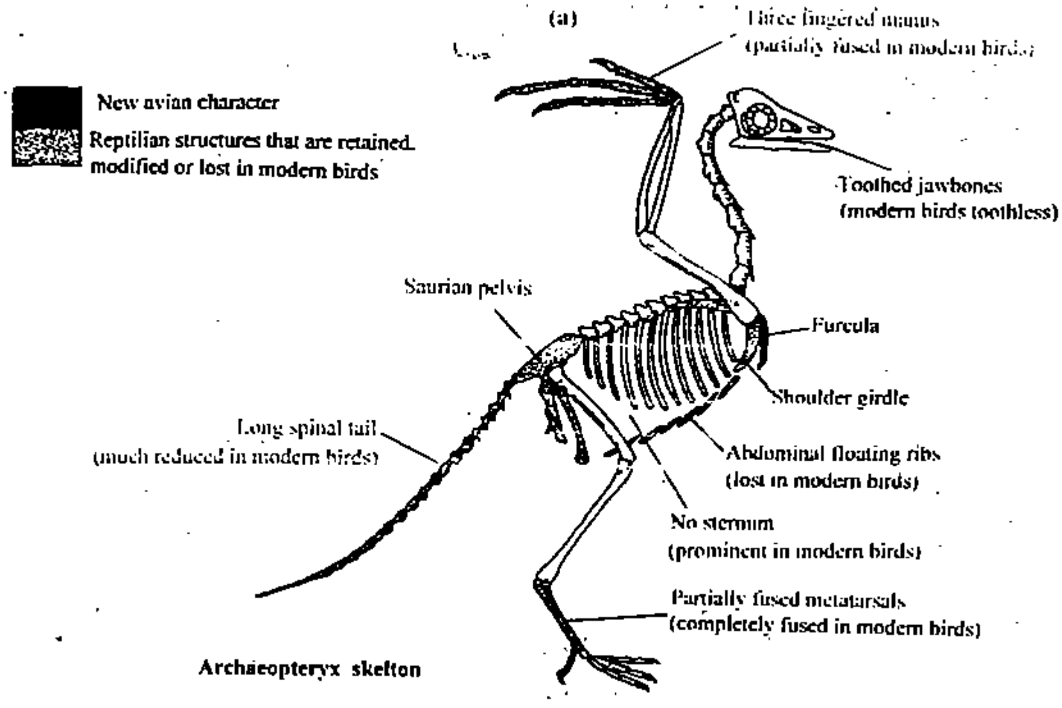
In *Archeopteryx* the absence of sternum (Fig. 3.49a) indicates that there was no anchorage for attachment of flight muscles equivalent to that of modern birds. This seems one of the main reasons why the *Archaeopteryx* could not have done any strenuous wing beating. *Archaeopteryx* however did have a wish bone (furcula) on which enough pectoral muscles could be attached to enable weak flight. The heavy, solid reptile-like skeleton was another factor that limited flight in the *Archaeopteryx*.

The bones of forelimbs in modern birds are also highly modified for flight. They are hollow and reduced in number. Several bones are fused together. Wings of birds are clearly a rearrangement of the basic vertebrate limb in which all the elements-upper arm, fore arm, wrist and fingers are present in modified from (Fig. 3.49b).

Bones distal to the wrist have been greatly modified though. Three short fingers arise from a fused **carpometacarpus**. The most anterior of these digits, digit A, as shown in Figure 3.49b supports the alula.

The shoulder and pectoral girdle of the bird are also highly specialized, especially in flying birds because of the extremely powerful primary flight muscles (pectoralis and supracoracoideus). Sufficient power for downstroke requires an enormous pectoralis muscle, which is attached to a surface that is greatly enlarged forming a ridge (keel or carina) so that the large muscle mass could be accommodated. Shoulder stability in flying is essential and is accomplished by several struts and braces. In modern birds the coracoid bone, which links the scapula with the sternum functions as a sturdy strut to prevent medial collapse of the shoulders when these flight muscles operate. The clavicle which is important as a brace and spring is present (the right and left clavicle together are called furcula or wish bone) and has a large mass of muscle attached to it too.

The bird's legs resemble hind legs of bipedal dinosaurs and have undergone less pronounced modifications than the wings, since they are mainly designed as were those of their reptilian ancestors for walking, perching and occassionally for swimming . The tibia and some of the tarsals fuse to form a **tibiotarsus.** The remaining tarsal and the elongated metatarsals fuse to form a **tarsometatarsus.** The fifth toe has been lost in all birds. The first toe is turned posteriorly in many species and is absent in some. It functions as a prop and enhances the grasping action of the foot when the bird perches. The efficiency of the leg in running on the ground and jumping at take off is increased by the elongation of the metatarsals and by the elevation of the heel off the ground. Fusion of certain limb and pelvic bones reduces the chance of dislocation and injury as the bird's legs must function as shock absorbers when they land. The pubes and the ishia of the two sides of the pelvic girdle are directed backwards and do not unite to form a midventral pelvic symphysis as they do in other terrestrial vertebrate. This allows more posterior displacement of the viscera which together with the shortened limbs shifts the center of gravity of the body over the hind legs.



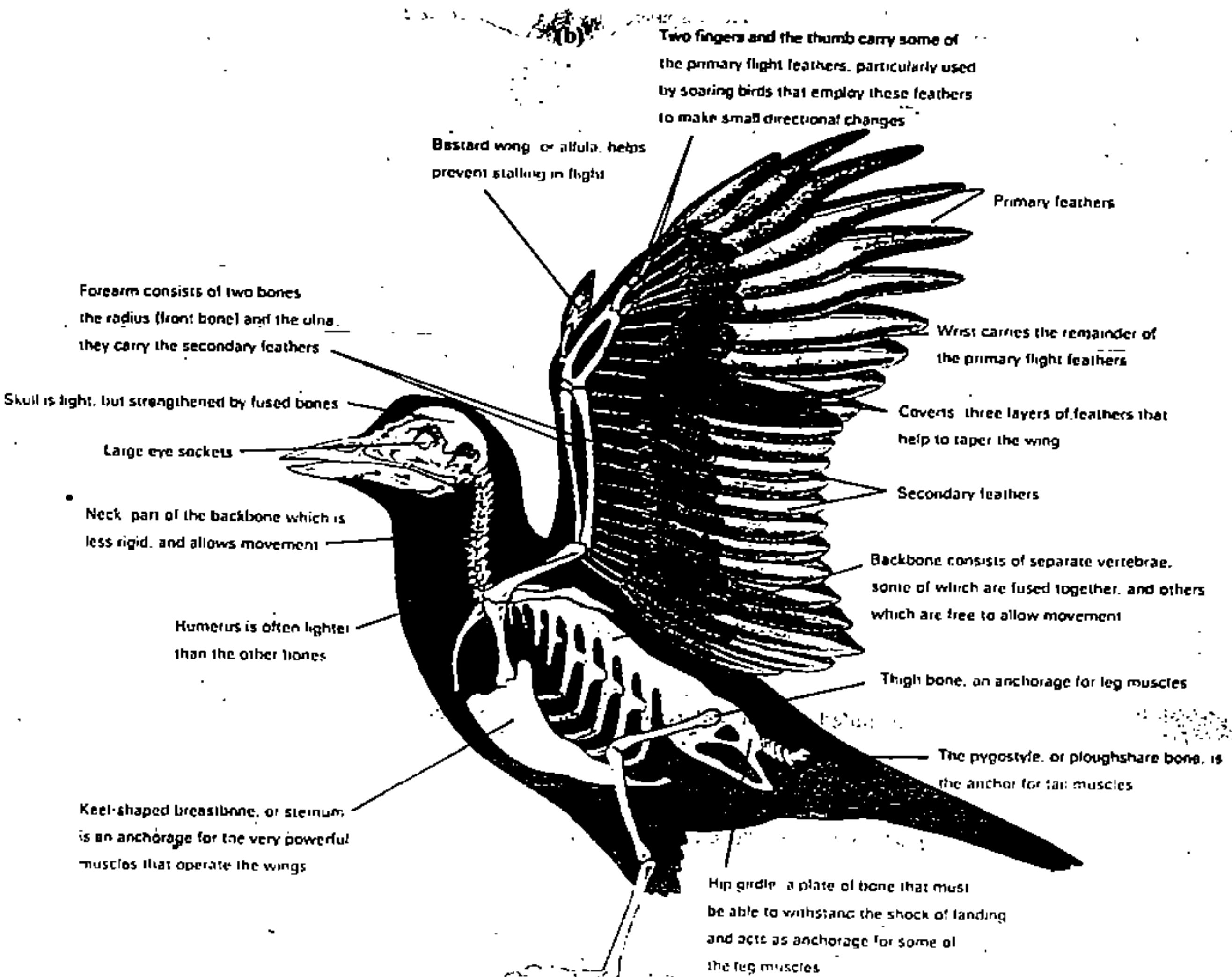


Fig.3.49: (a) skeleton of *Archeopteryx* showing reptilian structure (red) that have been retained, lost or drastically modified in modern birds. The furcula (wishbone) is a new avian character (b) The skeleton of a bird showing the arrangement of bones that are specially adapted for flight as well as part of the flight feathers.

Muscular System

In ducks and other birds that fly a great deal flight muscles consist mainly of aerobic slow phasic fibres which are rich in muscle haemoglobin (myoglobin) and dark in colour. In chickens and other birds that are not strong fliers and who beat their wings rapidly but intermittently, flight muscles are primarily fast phasic or glycolytic fibres and are whitish in colour.

The strong and intricate movement of wings, and the support of the body as well as a single pair of legs involve a number of modifications of the muscular system. The locomotor or flight muscles of the wings are relatively massive to meet the demands of flight. The largest of these is the pectoralis major which originates on the sternum and are inserts on the ventral surface of the humerus of the fore limb. The forelimbs as you know are modified into wings. The pectroralis major is responsible for the powerful downstroke of the wings as it depresses the wing in flight (Fig. 3.50). You might expect that the dorsally placed muscles would be responsible for the recovery stroke, but instead another, ventral muscle the supra coracoideus is responsible for the recovery or upstroke and hence is the antagonist to the pectoralis major. The origin of the supra coracoideus is on the sternum, dorsal to the pectoralis major and so it is positioned under the pectoralis on the breast. It is attached to the upper side of the humerus of the wing by a tendon so that it pulls from below by an ingenious rope and pulley arrangement. Both these muscles are anchored to the keel. These two muscles are exceptionally large in birds that are powerful fliers and together constitute upto 25-35% of their body weight in such birds.

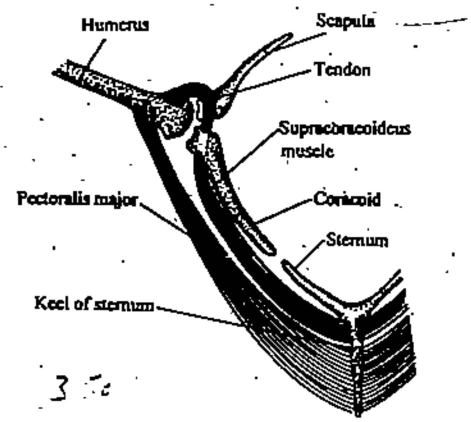


Fig.3.50: A diagrammatic cross section through the shoulder region and sternum of a bird, showing the flight muscles, which are arranged in a manner to keep the center of gravity low in the body. Both major flight muscles are anchored to the sternum keel. Contraction of the pectoralis major muscles pulls the wing downwards. When pectoralis relaxes the supra coracoideus muscles contracts acting as a pulley system, that raises the wing upward.

In the legs, the main muscle mass is located in the thigh surrounding the femur and a smaller mass lies over the tibiotarsus (shank or drumstick). Strong but thin tendons extend downward through sleeve like sheaths to the toes. As a result, the feet which are nearly devoid of muscles appear thin and delicate. This arrangement places the main muscle mass near the bird's center of gravity and at the same time allows great agility to the slender, light weight feet. Since the feet are composed mostly of bone, tendon and tough scaly skin, they are highly resistant to damage from freezing.

Birds have lost the long reptilian tail still fully evident in the *Archaeopteryx* and have substituted it by a pincushion like muscle mound into which the tail feathers are rooted. The pincushion of the tail contains an amazing array of tiny muscles, as many as 1000 in some species, which control the crucial tail feathers. However the most complex muscular system of all is found in the neck of birds; the thin and stringy muscles, which are elaborately interwoven and subdivided providing the bird neck with extra-ordinary flexibility.

Nervous and Sensory Systems

The nervous and sensory systems of the birds indicate accurately the complex problems of aerial life and a highly visible life style. The brain of a bird has well developed cerebral hemispheres (cerebrum), cerebellum and midbrain tectum (optic lobes) (Fig. 3.51). The large cerebrum results from enlargement of the deeply situated mass (core) of grey matter, the corpus striatum. It is not due to the cerebral cortex which is thin, unfissured and poorly developed unlike in mammals where it is the main coordinating center. The corpus striatum is the main integrative centre of the brain in birds and controls such activities as singing, flying, eating and all other complex, instinctive, reproductive activities. Intelligent birds such as parrots and crows have large cerebral hemispheres in comparison to less intelligent birds such as chickens and pigeons. The cerebellum is also an important co-ordinating center where muscle—position sense, equilibrium sense and visual cues are assembled and used to coordinate movement and balance. The optic lobes which are laterally bulging outgrowths of the midbrain form the visual association apparatus, which is comparable to the visual cortex of the mammals.

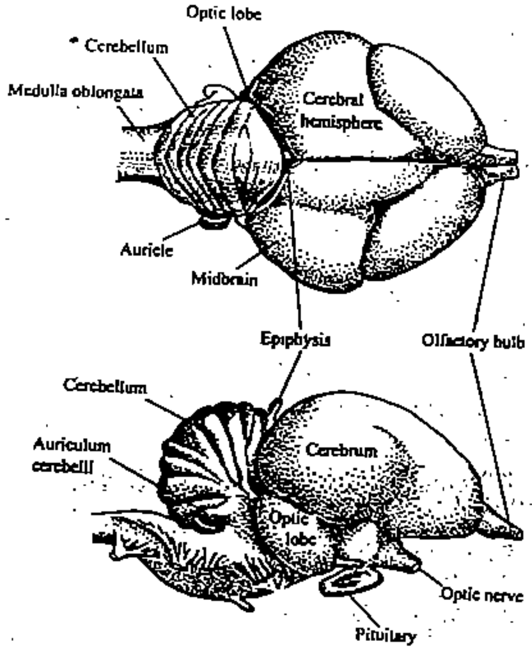


Fig.3.51: Brain of bird, showing the main regions.

Except in flightless birds, duck and vultures, the senses of smell and taste are poorly developed in most birds so that olfactory organ and olfactory parts of the brain are reduced in most species. This deficiency is however, more than compensated for, by good hearing and extra-ordinary vision.

The avian ear as in mammals has three regions (Fig. 3.47) (i) the **external ear,** a sound conducting canal extending to the ear drum (ii) the **middle ear,** containing a rod like columella that transmits vibrations and (iii) the **inner ear,** where the cochlea of birds is much shorter than that of mammals, yet birds can hear approximately the same range of frequencies as humans.

The capacity of avian ear to distinguish differences in sound intensities and its response to rapid fluctuations in pitch, far exceed that of humans.

Sight is very important to flying animals and so the eyes of birds are relatively large, constituting 15% or more of the weight of the head (they are only 1% of head weight in human). The eyes of birds in gross structure (Fig. 3.52) resemble that of other vertebrates, though they are relatively larger, less spherical and almost immobile. Instead of turning their eye, birds turn their head to scan the visual field. Colour vision is well developed. Rods (for dim light vision) and cones (for colour vision) are more densely packed in the light sensitive retina of the birds than in mammalian retina, making the visual acuity (the ability to distinguish objects as they become smaller and closer together) - several times greater than that of humans. Cones predominate in day birds and rods in nocturnal birds. The fovea, a slightly depressed area of retina where cones are particularly abundant is the area of greatest acuity and hence of keenest vision is located in a deep pit in birds of prey and some others which makes it essential for the bird to focus exactly on the subject. A distinctive feature due to which the avian eye resembles the reptilian eye, is the presence of pecten, a highly vascularized organ attached to the retina near the optic nerve and jutting out into the **vitreous humour.** (Fig. 3.52). Pecten is thought to provide nutrients to the eye. It may do more, but it's function remains largely obscure.

In birds the placement of eyes in the head, is correlated to the bird's mode of life. Vegetarian birds that have to evade predators, have laterally placed eyes in order to obtain a wide view of the world, and so are able to see, behind themselves as well as in front. Predaceous birds such as owls and hawks have eyes directed to the front. The eyes of bitterns a species that searches for food in the marshes are directed downwards.

Hawks have an extra, laterally placed fovea (plural foveae) in addition to the central one. The central fovea is for sharp monocular views and the posterior one for binocular vision. The visual actuity of a hawk is about eight times that of human so that it can clearly see a crouching rabbit two kilometers away. The ability of an owl to see in dim light is more than ten times that of human.

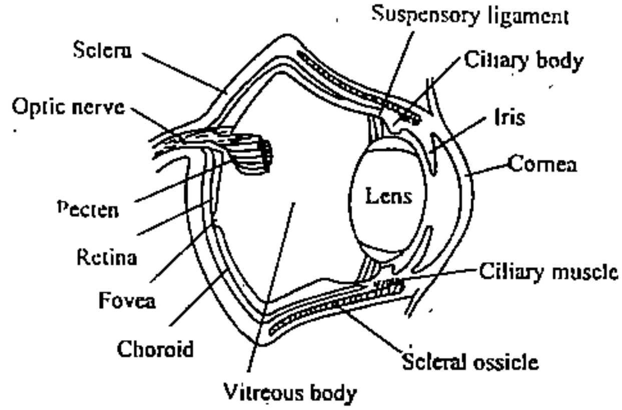


Fig.3.52: The eye of a bird of prey. The avian eye has all the structural component of the mammalian eye as well as a peculiar pleated structure the pecten, which is believed to provide nourishment to the retina and which also occurs in the reptilian eye.

SAQ 13

Correct the following statements with appropriate words:

a) In birds, the cerebral cortex is the crucial coordinating center where the muscle position sense, equilibrium and visual cues are assembled and used to coordinate movement and balance.

b) The sense of smell and taste are poorly developed in flightless birds and ducks.

c) Many birds have three fovea on the retina of the eye, one for sharp monocular vision, one for binocular vision and one for colour.

d) A distinctive feature in which avian eye resembles the mammalian eye is the presence of pecten.

Food, Feeding, Digestion

Birds in nearly every environment on earth have evolved alongwith the food resources Birds may be carnivorous or herbivorous or both. Some birds are omnivorous (often termed euryphagous or 'wide eating' species) and eat whatever is seasonally abundant. Others are specialised eaters (called stenophagous or "narrow eating" species).

The preference for specialized food by stenophagous bird, acts as limitation since reduction or destruction of these foods (due to some reasons like diseases, adverse climate and the like) may jeopardize their chances of survival.

Beaks of birds are highly specialized for the type of food they eat. They range from the generalized types such as the strong, pointed beaks of crows, to grotesque, highly specialized ones in flamingoes, horn bills and toucans. Fig. 3.53 shows different birds with variously adapted beaks.

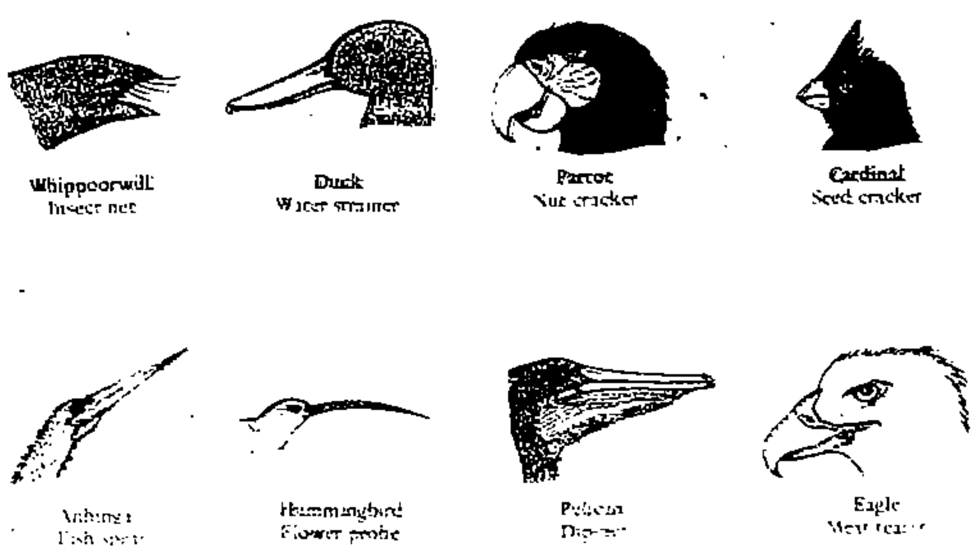


Fig.3.53: Different beak types adapted for different modes of feeding.

Birds are voracious feeders and subsist on an energy rich or caloric diet. They eat large quantities of food which is processed rapidly and thoroughly in an efficient digestive system, because they need to sustain a high metabolic rate. A shrike bird can digest a mouse in three hours, and a thrust digests berries in just 30 minutes. Since birds lack teeth, jaw bones and jaw muscles, they are not able to chew their food which passes from the mouth cavity through the short pharynx straight to the relatively long muscular, elastic oesophagus. The **salivary glands** present in the mouth are poorly developed and primarily secrete only mucous for lubricating both the food as well as the slender, horn-covered tongue. There are few taste buds, although all birds can taste to some extent. Many birds such as pigeons, finches and similar seed - and grain-eating species have an enlarged **crop** at the lower end of the oesophagus that serves as a storage chamber. Food is temporaily stored here and moistened and softened by water. (See figure 3.54 a for the internal structure of crop and 3.41 for the digestive system of birds).

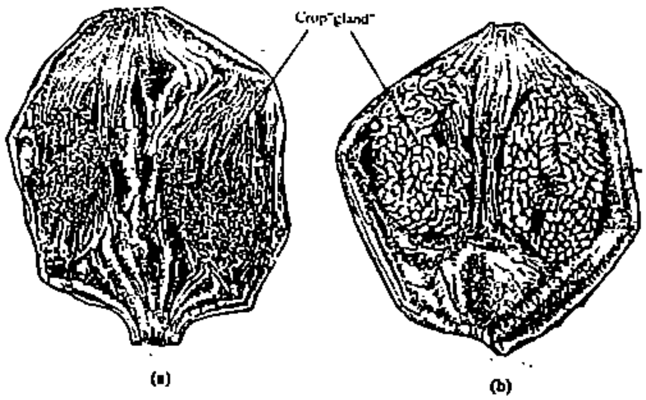


Fig.3.54: Crop of pigeon, cut open to show crop glands.

Food passes from the oesophagus and the crop into stomach consisting of (i) a proximal **proventriculus** into which the oesophagus opens and which secretes the gastric juice and (ii) the distal highly modified part of the stomach, the muscular **gizzard**. The gizzard is characterized by thick muscular walls and modified glands that secrete a horny lining which forms horny plates. These serve as millstones to assist in grinding food thus performing a function similar to that of teeth and jaws. Many species swallow coarse, gritty objects or pebbles which lodge in the gizzard and further help in grinding the food to a pulp and mixing it with gastric juices. In many carnivorous species, the gizzard functions as a trap, preventing sharp bones, hair and similar indigestible material from entering the intestine. This indigestible, material is then ejected through the mouth in the form of pellets. The gizzard leads through the **pyloric sphincter to the small intestine** also called **duodenum**, in which the digestion process continues since bile and enzyme manufactured in the liver and pancreas respectively are secreted here and further break down the food. Villi are present on the lining of the small intestine. A pair of small **caeca** (blind pouches) which may be well developed in some species are present at the junction of the small and large intestine **(rectum)**. Rectum enters **cloaca** which is the terminal part of the digestive canal and which also receives **genital ducts** and **ureters**. Two **bile ducts** from **gall bladder**, or **liver** and two or three **pancreatic ducts** empty into the duodenum. Liver is bilobed and relatively large. In young birds the dorsal wall of cloaca bears the **bursa of Fabricius**, which possesses the B Lymphocytes that are important in immune response.

In pigeons, doves and some parrots, the crop not only stores food but also produces milk by the breakdown of the epithelial cells of the lining. This 'bird milk' is regurgitated by both female and male into the mouth of the young chicks (squabs). It has, a much higher fat content than cow's milk.

SAQ 14

Give one word for each of the following statements :

a) Birds that eat only limited type of food________.

b) The enlarged lower end of oesophagus present in some birds that serves as a storage for food________.

c) The muscular portion of stomach in birds, lined with horny plates that serves for grinding food________.

Circulatory System

The general plan of bird circulation (Fig. 3.55a) is quite similar to that of mammals. Heart is large, four-chambered with strong ventricular walls and completely divided into right and left sides, keeping oxygen-depleted and oxygen-rich blood from mixing. (Fig. 3.55b).

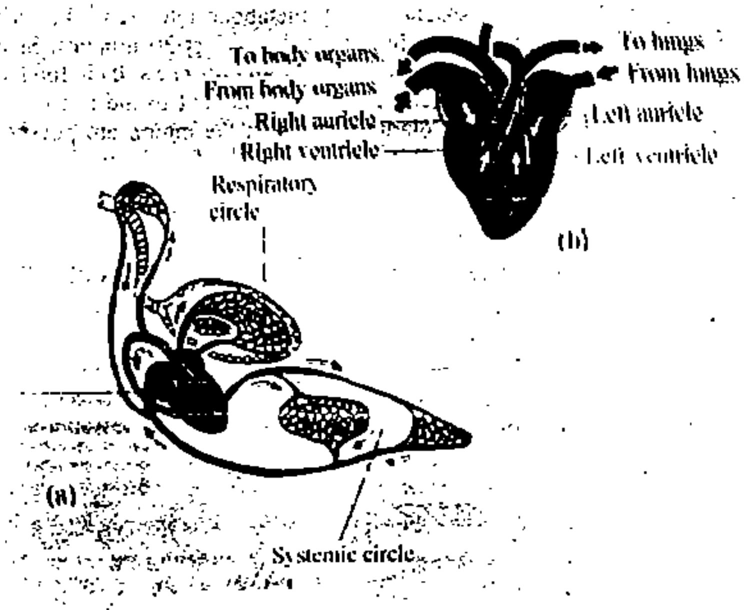


Fig.3.55: (a) Circulatory system of bird. (b) Ventral view of avian heart.

In birds, similar to mammals there is complete separation of the respiratory and the systemic circulation.

The circulatory system of birds is very efficient and as in mammals heart beat is extremely rapid. There is an inverse relationship between heart rate and body weight. For example at rest a turkey has a heart rate of approximately 93 beats per minute, a chicken 250 beats per minute. Blood pressure in birds is roughly equivalent to that in mammals of similar size.

Red blood corpuscle of birds differs from that of mammals in being slightly larger, oval and nucleated. The mobile amoeboid cells (phagocytes) of the blood are unusually active and efficient in birds in the repair of wounds and in destroying microbes.

Respiratory System

The respiratory system of birds differs radically from that of reptiles and mammals and is marvellously adapted for meeting high metabolic requirements of flight. (Fig. 3.56 a shows the respiratory system of birds). Nostrils of birds lead to internal nares above the mouth cavity. The slit like glottis in the floor of the pharynx opens into the long, flexible trachea. The trachea continues to the syrinx. From the syrinx a primary bronchus leads to each lung. The lungs are small paired, spongy organs with little elasticity.

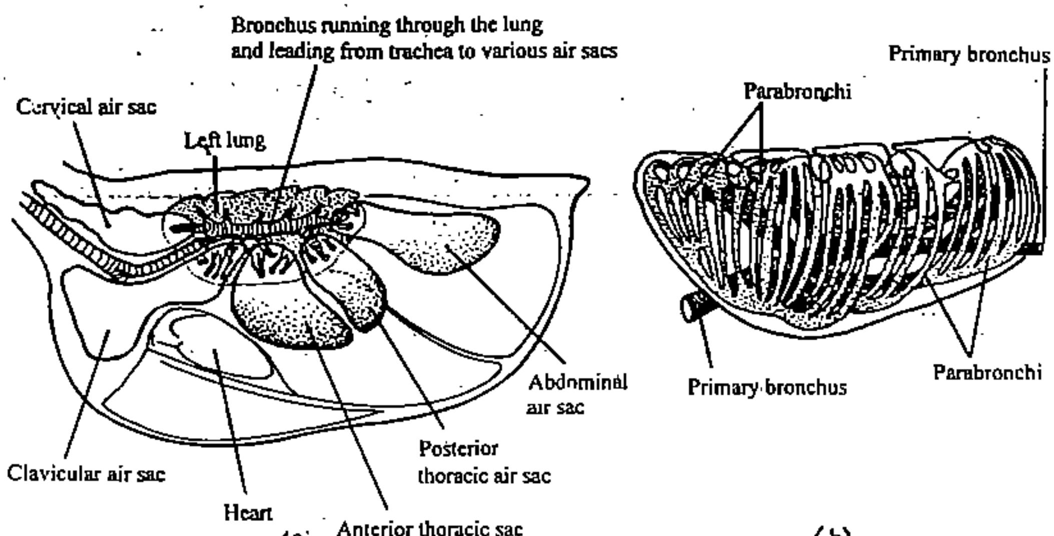


Fig.3.56: Respiratory system of a bird showing lungs and air sacs. (a) Left side of the trunk of bird showing air sac system. (b) Diagrammatic medial view of left lung of chicken showing the relationship between bronchus, mesobronchus, secondary bronchi and para bronchi.

The paired primary bronchi do not immediately branch within the lungs into sac-like alveoli as in other amniotes; instead each bronchus runs through the lungs, giving off branches to the lungs substance and continues beyond, posteriorly to the inspiratory air sacs.

Each primary bronchus as it enters the lungs gives rise to a number of lateral or secondary bronchi which branch again and give rise to a number of tertiary branches called parabronchi. These unlike in mammals that end in sac-like alveoli are tube-like, through which air flows continuously (Fig. 3.56b).

There are nine interconnected aspiratory air sacs (Fig. 3.56a) which lie in various organs of the bird. The paired **abdominal** air sacs lie one on each side of the body among the coils of the intestine. The other, the **posterior thoracic air sac**, is also paired and each is closely applied to the side wall of the body. Each bronchus also gives off near its entrance into the lung, three short branches. One of these leads to **anterior thoracic air sac**, situated just in front of the posterior thoracic air sac. Another leads to a median, **inter-clavicular air sac**, which is connected with both lungs and is unpaired. The third enters a **cervical air sac**, placed at the root of the neck. Each side of the intraclavicular gives off a **diverticulum** or **axillary air sac**, lying in the axilla. All these nine sacs extend into the bones, forming the pneumatic cavities and replacing a substantial amount of bone marrow in them. Some birds can thus respire through the humerus and other bones if they are fractured and exposed even if their trachea is blocked.

The lungs of birds are comparatively smaller than those of mammals but are more efficient ones because air flows through them in one direction rather than back and forth. One way flow of air through the lungs functions to maintain a much greater concentration of oxygen at the epithelial exchange surfaces than in other terrestrial vertbrates that ventilate their lungs bi-directionally. Birds can thus obtain enough oxygen even when flying at high altitude where partial pressure of oxygen is low. The unidirectional flow is due to the extensive system of nine interconnected air sacs that acts as bellows and connect to the lung in a such a way that perhaps 75% of the inspired air bypasses the lungs and flows directly into the postérior air sacs which serves as a reservoir of fresh air.

Both the structure of the respiratory system as well as the mechanism of gas exchange ensures that the lungs of birds receive fresh air both during expiration and inspiration, so that an almost continuous flow of oxygenated air passes through a system of richly vascularised parabronchi.

Many details of the bird's respiratory system are still not fully understood; however, it is clearly the most efficient of all the vertebrates.

Birds are the first vertebrates to produce sound in their trachea. The voice box of birds is called syrinx and is not homologous with the larynx of mammals. The syrinx is present at the position of bifurcation of trachea into bronchi and is a modification of both the bronchi and trachea. Sound is produced by vibrations of a bony ridge and semilunar membranes stretched across it. Muscles associated with syrinx vary the pitch of the notes. Melodious birds like nightingale, robin etc. are called song birds. But not all birds are song birds. Birds like crows are known for their harsh calls.

Birds use their calls to invite other members of their species, or to warn them of dangers, or to communicate with chicks or to warn off other males of its species from their territory.

Excretory System

In common with amniotes birds have paired relatively large, metanephric kidneys (Fig 3.57) which are attached to the dorsal wall in a depression against the sacral vertebrae and pelvis. Urine from kidneys passes by way of ureters (one from each kidney) to the cloaca. The urinary bladder has been lost in birds, possibly as an adaptation towards weight reduction. Each kidney is composed of many thousands of nephorns, consisting of a renal corpuscle and nephric tubule. (Fig. 3.58.) Urine is formed in the usual way by glomerular filteration followed by selective modification of the filterate in the tubule (See unit 4 of LSE-05).

Birds despite having less efficient kidneys as compared to mammals with regard to their concentrative ability are able to excrete uric acid nearly 3000 times more concentrated than its concentration in blood.

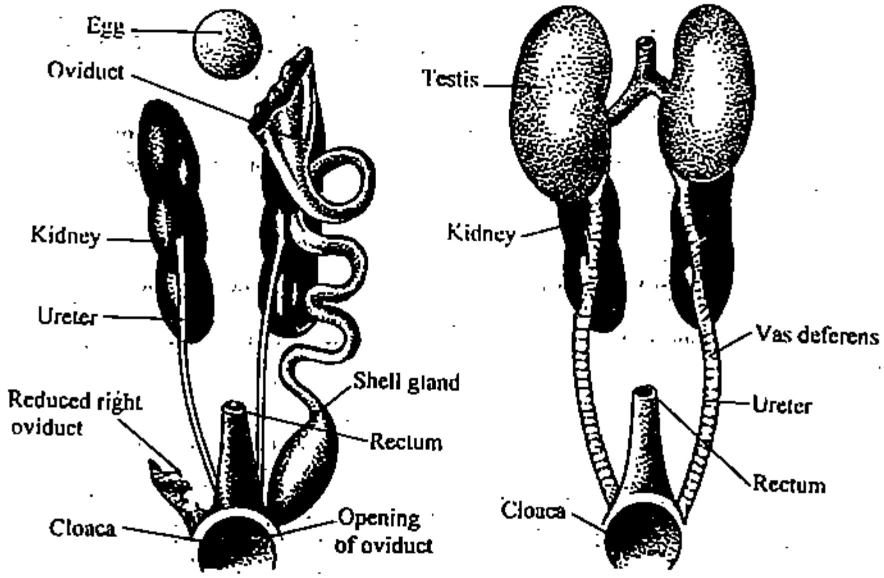


Fig.3.57 : Urogenital system of a bird (a) female (b) male.

The number of kidney tubules is large in birds due to the high rate of metabolism, yet water has to be conserved. That is why only some and not all tubules have Loops of Henle, that allow water to be resorbed from tubules. Birds cannot produce as concentrated a urine in this way as mammals do; instead like reptiles from which they evolved, they secrete their nitrogenous wastes as uric acid instead of urea, an adaptation that originated with the evolution of cleidoic egg. In this type of egg all excretory wastes must remain within the eggshell, alongwith the developing embryo. If urea were produced it would quickly accumulate in the solution to toxic levels. Uric acid, however, crystallizes out of the solution and can be stored harmlessly within the egg shell. Thus from an embroyonic necessity arose an adult virtue. As a result adults also excrete uric acid. Because of uric acid's low solubility, a bird can excrete 1 gram of uric acid in only 1.5 to 3 ml. of water, whereas a mammal may need about 60 ml of water to secrete 1 gm of urea. Thus birds conserve most of their body water by excreting 75-90% of their nitrogen wastes as uric acid. Furthermore, since most of the uric acid is secreted into the tubules rather than entering by filteration, a great amount of water need not be filtered by the renal corpuscle. The renal corpuscles of birds are small. The water needed to carry off uric acid and other waste products is resorbed in the cloaca and the uric acid is discharged as a white crystalline paste, mixed with faeces.

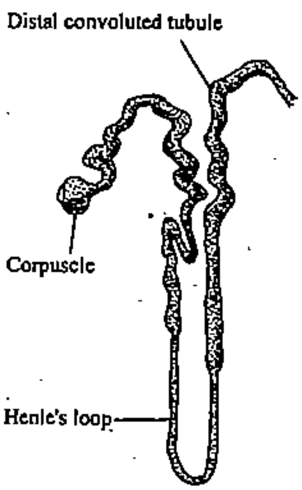


Fig.3.58: Renal tubule found in kidney of birds and mammals.

Marine birds (as well as marine turtles) have evolved a mechanism for eliminating the excess salt which they gain during eating and by drinking sea water. Sea water contains about 3% salts and is three times saltier than the bird's body fluids, and so the kidney is unable to concentrate salt in urine above about 0.3%. The problem is solved by special, paired salts glands, one above each eye (Fig. 3.59), which are able to excrete a high concentrated solution of sodium chloride, upto twice the concentration of seawater. The salt solution is discharged out by the nasal cavities giving the petrels, gulls and other sea birds a perpetual running nose.

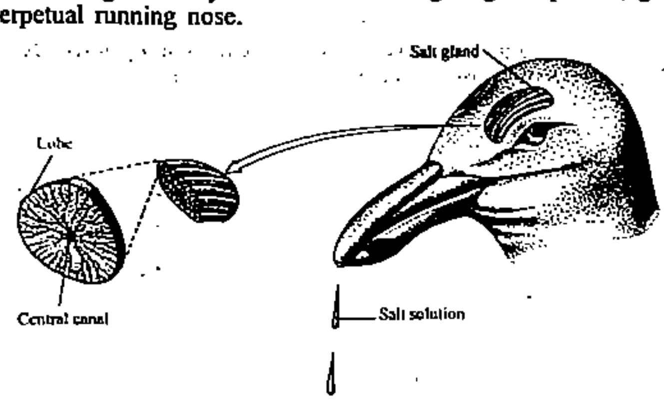


Fig. 3.59: Paired salt glands of a marine bird (gull), each located above each eye. Each gland has several lobes arranged parallel to each other. A cross section of a much enlarged lobe is shown. Salt is secreted into many radially arranged tubules, which then flows into a central canal that leads into the nose.

SAQ 15

Tick the following sentences as True or False.

a) In birds, three fourth of the inspired air, bypass lungs and flows directly into the posterior air sacs which serve as a reservoir for fresh air. T/F

b) Excess salts in marine birds is excreted by a pair of special glands located under the wing. T/F

c) The red blood corpuscles in birds are oval and non-nucleated. T/F

d) The syrinx of birds is homologous with the larynx of mammals.

e) In birds, some and not all nephric tubules have the loop of Henle. T/F

FLIGHT

Since flight has played a key role in the evolution and adaptation of birds, let us examine how birds fly. Bird exhibit four types of flight (a) **gliding**, moving from high altitude to a lower altitude. This is done without beating the wings; (b) **soaring** when birds make use of air currents in the sky to move without beating the wings; (c) **hovering** when the bird may stay at the same place and flap wings. Wings move back and forward and the upward thrust which develops counterbalances the birds weight. A lot of energy is used while hovering (d) **flapping**, the regular flight involving beating of the wings up and down and which is discussed here in detail.

Bird wing as a lift device

Birds's flight, especially the familiar flapping flight is a complex process. Despite careful analysis by conventional aerodynamic techniques and high speed photography it is still not well understood. Nevertheless we know that bird wing is an airfoil that is subject to recognized laws of aerodynamics. It is adapted for high lift at low speed. Wings of early low speed air crafts were patterned on its shape.

The bird wing (Fig. 3.60) is streamlined as seen in cross-section. It has a slightly concave (cambered) lower surface and small tight fitting feathers where the leading edge meets the air. Air slips efficiently over the wing, creating lift with minimum drag. Some lift is produced by positive pressure against the undersurface of the wing. But on the upper side, where the air stream must travel farther and faster over the convex surface, a negative pressure is created that provides more than two thirds of the total lift. The lift to drag ratio of an air foil is determined by the angle of tilt (angle of attack) and the airspeed.

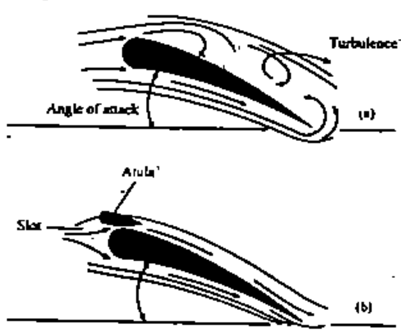


Fig.3.60: Bird wing (a) air flow across a wing becomes turbulent when the angle of attack is increased (b) Slots formed by the alula increase air speed, reduce turbulence and maintain lift.

A wing carrying a given load can pass through the air at high speed and small angle of attack, or at low speed and larger angle of attack. However, as speed decreases, a point occurs at which the angle of attack becomes too steep; turbulence appears on the upper surface, lift is destroyed and stalling occurs. Additional stalling can be delayed or prevented by the wing slots along the leading edges so that a layer of rapidly moving air is directed across the upper wing surface. This is because lift increases in direct proportion to the surface area of the wing which can be increased or decreased by means of slots that alter the wing area. Wing slots were and still are used in aircraft travelling at low speeds. In birds two kinds of wing slots occur (i) the alula or group of small feathers on the first digit (thumb) which provides a mid-wingslot and (2) Additional slotting between the primary feathers often formed along the trailing margin of the wing and at the wing tip. The latter slots reduce the turbulence known as **tip vortex**. Some birds obtain additional lift on landing by fanning out the tail feathers and bending them down. The tail then acts both as a high lift, low speed air foil and as a brake (Fig. 3.61).

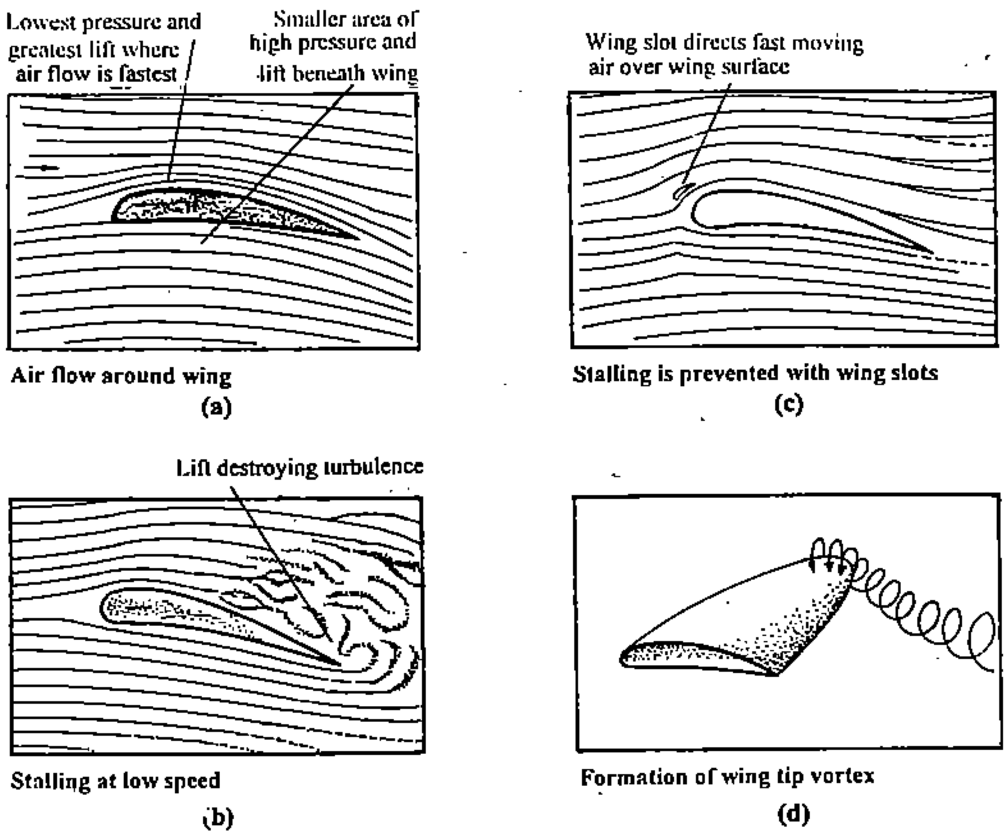


Fig.3.61: Air pattern formed by an air foil or wing, moving from right to left (a) normal flight with low angle of attack. As air moves smoothly over the wing, areas of negative pressures on the upper wing surface and high pressure on the lower wing surface create lift, (b) when the angle of attack becomes too great, lift destroying turbulence develops on the upper wing surface and stalling occurs. (c) Prevention of stalling by directing a layer of rapidly moving air over upper surface with a wing slot. (d) Wing tip vortex, a turbulence that tends to develop at high speeds, reduces flight efficiency. The effect is reduced in wings that sweep back and taper to a tip

Flapping Flight

Two forces are needed for a flapping flight: a vertical lifting force to support the bird's weight and a horizontal thrust to move the bird forward against the resistive forces of friction. In flapping flight, thrust is provided by the primary feathers at the wing tips while the secondary feathers of the inner wing, which do not move so fast or so far, act as an air foil, mainly providing lift. Greatest power is applied on the down stroke. The primary feathers are bent upward and twist to steep angle of attack, biting into the air like a propeller (Fig. 3.62 a and b). The entire wing as well as the bird's body is pulled forward. On the upstroke, the primary feathers bend in the opposite direction so that their upper surfaces twist into a positive angle of attack to produce thrust, just as the lower surfaces did on the downstroke. A powered upstroke is necessary for hovering flight as in humming birds and for fast, steep take offs by small birds with elliptical wings.

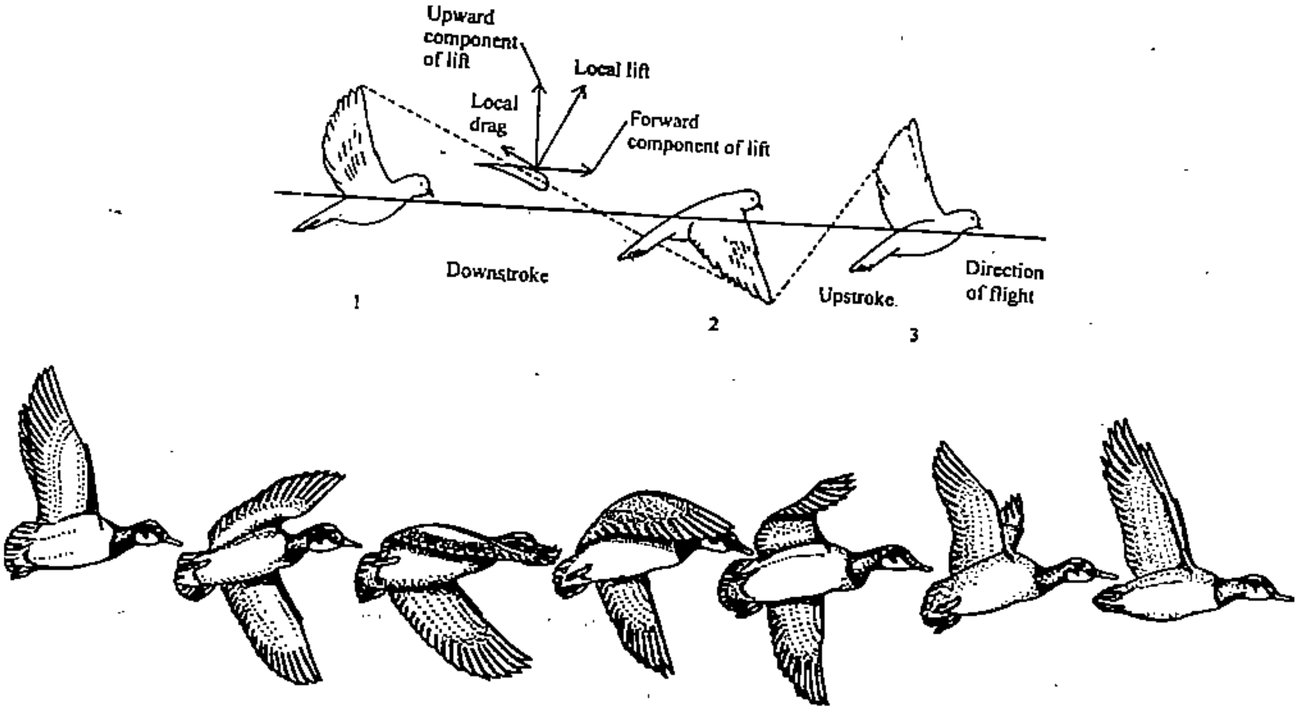


Fig.3.62: **Flapping flight (A) Stages is a wing cycle showing how the forward and downward tilt of the wings on the downstroke generates a foward thrust. (B) The normal flapping flight of a strong flier like duck, in which the wings sweep downward and forward fully extended. Thrust is provided by the primary feathers at the wing tips. To begin the upbeat, the wing is bent, bringing it upward and backward. The wing then extends, ready for the next down beat.**

Reproduction and Development

All birds are oviparous, and produce cleidoic eggs which undergo internal fertilzation. Most of the female birds have only the left ovary and oviduct (Fig. 3.63a). The right pair dwindles to a vestigial structure, probably as an adaption for the weight reduction in flying. The left ovary is small but enlarges greatly during reproductive season as eggs accumulate yolk. Eggs discharged from the ovary are picked up by the expanded end of the oviduct, the ostium. The oviduct opens posteriorly into the cloaca. While passing down the oviduct, eggs get covered by albumen or egg white, secreted by special glands. Further down the oviduct, the shell membrane, shell and shell pigments are also secreted around the egg. Fertilization occurs in the upper oviduct, several hours before the layers of albumen, shell membranes and shell are added.

Sperms remain viable (alive) in the female oviduct for many days after a single mating. Hen's eggs show good fertility for 5-6 days after mating, but then fertility drops rapidly. However, occasionally an egg could be fertile as long as 30 days after the separation of the hen from the rooster (male).

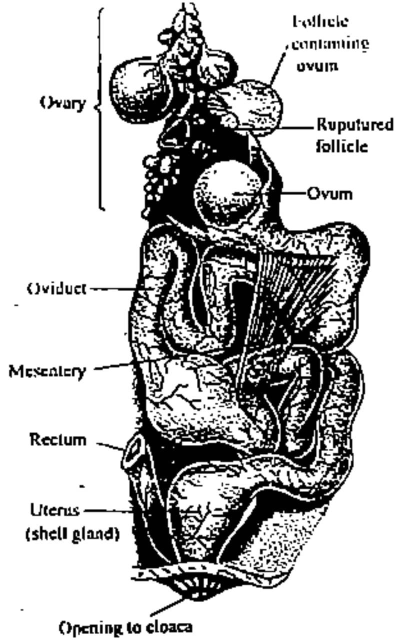


Fig.3.63 : Reproductive system of a female bird showing the developing ova.

In males the paired testes and accessory ducts are similar to those in many other vertebrates (Fig. 3.57b). Testes are bean-shaped bodies during most of the year but become greatly enlarged at breeding time, sometimes as much as 300 times larger than the non-breeding size. From each testes, the sperm carrying tube, the vasa deferentia runs to the cloaca. Before being discharged, millions of sperms are stored in the seminal vesicle, the enlarged distal end of the vas-deferens which like the testes enlarges during the breeding season. Some birds including ducks and geese have a well developed copulatory organ (penis), provided with a groove on its dorsal side for sperm transfer. However, in the more advanced birds copulation is a process in which cloacal surfaces, come in contact, usually brought about by the male standing on the females back (Fig. 3.64). Some swifts copulate in flight.

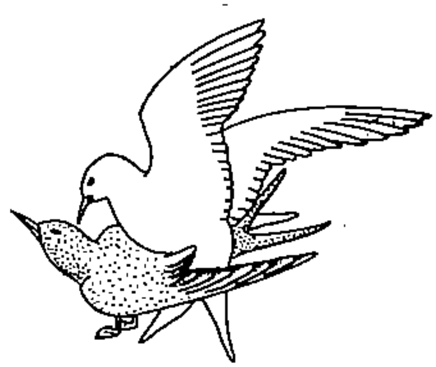


Fig.3.64: Copulation in birds. In advanced bird species, male lacks a penis. Male copulates by standing on the back of the female, pressing his cloaca against that of the female, and passing the sperm to the female.

3.4.5 Social Behaviour

(i) Mating Systems

The most common form of polygamy in birds is polygyny (many females) where a male mates with more than one female.

The two most common types of mating system in animals are **monogamy** and **polygamy** Monogamy is rare in most animal groups but in birds it is the normal rule, and more then 90% of the birds are **monogamous**. Some bird species such as geese and swans choose partners for life and often remain together throughout the year. Seasonal monogamy, however, is more common. The majority of migrant birds pair during the breeding season but live independently for the rest of the year.

Most male birds exhibit specialized patterns of behaviour before mating. It is necessary for the male bird to stimulate the female bird in order to mate and reproduce. This is called courtship. It may be simple or an elaborate and ritualistic dance. Melodious songs, nest buildings, food offering are some of the acts of courtship behaviour.

Peacocks spread their long and beautifully coloured tail feathers and dance, vibrating the feather rhythmically during courtship, while penguins offer food in the form of a fish to the females.

(ii) Nesting and Care of Young

Ancestral birds may have buried their eggs as crocodiles do and depended upon the environmental temperature to incubate them. The Egyptian plover still does this today and many species cover their eggs with vegetation when they leave them to forage for food. However, most species build nests in which to keep their eggs and rear young ones. The nests may be simple or elaborate. After eggs have been laid adults brood and incubate them. In gulls and many other sea and aquatic birds both parents share equally in brooding but in most song birds the female is usually the chief or sole brooder, and the male brings her food. Near the end of the embryonic period, the chick, in the egg develops powerful dorsal neck muscles and a horny thickening or egg tooth on the end of its bill (beak) which it uses to break through the shell at the time of hatching out.

The whippoorwills lay their eggs in a depression on ground while the oriole, humming bird and beaver bird and many others build very elaborate nests. Some birds on the other hand such as common cuckoo (koel) do not build nests of their own, instead they lay their eggs in some other bird's nests. The Koel lays eggs in crow's nest. Such birds are called parasitic. Hawk cuckoo (papiha) lays its eggs in the nest of seven sisters.

Newly hatched birds are of two types: (i) **Precocial** and (ii) **Altricial**. The precocial young like fowl, quail, ducks and most water birds are covered with down at birth, their eyes are open and they can run or swim as soon as their plumage is dry (Fig. 3.65a). The altricial ones, on the other hand, are naked and helpless at birth and their eyes are closed. (Fig. 3.65b). They remain in the nest for a week or more and the parents must continue to brood and feed them till they are ready to leave the nest. The young ones of both type however, need parental care for some time after hatching.

The eggs of most songbirds require approximately 14 days for hatching while those of ducks and geese require atleast twice that long a time.

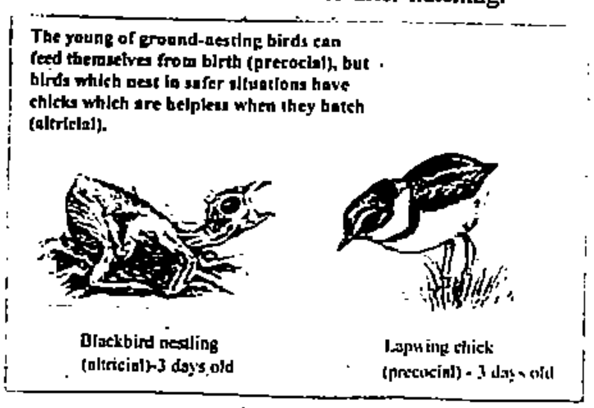


Fig. 3.65: Comparison of three day old precocial and altricial young (a) The precocial, ruffed grouse has his eyes open, is covered with down, is alert, strong legged and able to feed itself, (b) The altricial meadow lark is born nearly naked, blind and helpless.

(iii) Migration and Navigation

The term migration refers to the regular extensive, seasonal movements that birds undertake between their summer breeding regions and wintering regions. The main advantage of this appears to be that it allows birds to be in an optimal climate all the time, where abundant and regular sources of food are available to sustain their intense metabolism. Migration also provides optimal conditions for rearing the young when demands for food are especially great. Migration also greatly increases the amount of space and reduces aggressive territorial behaviour.

Most migratory birds have well established routes trending north and south. The majority of the birds (as well as other animals) live in the Northern hemisphere where most of the earth's landmass is concentrated. As a result most birds are south migrants in winter and north migrants in summer.

Direction finding in Migration

Most birds navigate mainly by sight, recognising topographic land marks and following the familiar migration routes. Apart from visual navitation, birds also use a variety of direction orientation cues at their disposal. They have an inbuilt time sense, an innate clock of extreme accuracy and also an inbuilt sense of direction. Furthermore, recent evidence indicates very strongly that birds can detect and navigate by earth's magnetic fields. They can also navigate by celestial cues, using the sun by day and stars by night. They are able to maintain compass direction by referring to the sun irrespective of the time of the day. This is called **sun-azimuth orientation** (azimuth-compass-bearing of the sun). All these resources of the birds are inborn and instinctive, though the bird's navigational skills may improve with experience.

More than 4000 of bird species which comprise one half of the total bird species are migratory. Most of the migratory birds breed in the more northern latitudes of the Hemisphere. Some use diverse routes in fall and spring.

Certain navigational feats of birds however can still not be explained. Without doubt many birds use a combination of environmental and innate cues to migrate.

SAQ 16

Tick the following statements as True or False.

a) The left testes and ureter are lost in males of most birds. T/F

b) In birds, fertilization and incubation of eggs is internal. T/F

c) Monogamy is rare in birds. T/F

d) Precocial chick birds need parental care for a week after hatching. T/F

e) Most migratory birds have well established routes trending north and south. T/F

f) Birds can also navigate direction with the help of the sun. T/F

g) A wing carrying a given load can pass through the air at high-speed with a small angle of attack. T/F

h) Stalling of birds can be delayed or prevented by tail feathers. T/F

3.5 SUMMARY

Reptiles

- Reptiles, diverged phylogenetically from a group of labyrinthodont amphibians during the late Paleozoic era, some 300 million year ago. Their success as the first true terrestrial vertebrates is attributed greatly to the evolution of the shelled, amniotic egg which with its four extra embryonic membranes provided support for full embryonic development within the protection of a shell. As a result the embryo of the reptiles did not require water for development as for the first time amniotic eggs could be laid on land.
- Before the end of the Paleozoic era, the amniotes underwent an extensive radiation that diverged into three lineages; (1) the anapsids which gave rise to the turtles; (2) the synapsids, a link of mammal like reptiles that led to the present day mammals; (3) and the diapsid lineage which led to all other reptiles and to the birds.
- Reptiles are better adapted to terrestrial life than the amphibians. Their dry, nearly glandless skin, covered with horny scales limit water loss. Gas exchange during respiration occurs only through lungs. Jaws are more powerful. Circulatory system is more advanced than amphibians, and heart is nearly completely divided into four regions.
- Excretory system is also more advanced and nitrogen from metabolic wastes is excreted mainly as uric acid rather than as ammonia or urea, in order to minimise water loss.
- Fertilization is internal and the cleiodoic egg is laid either on the land or retained within the uterus. A few species of lizards and snakes are viviparous.
- Like amphibians however reptiles are ectothermic, but most of them can maintain a high and nearly constant body temperature during periods of activity by behaviourally regulating their exposure to sun.

Extant members of reptile belong to only four orders: (1) Testudines (2) Sphenodonta (Rhynchocephalia) (3) Squamata (4) Crocoidilia.

- The turtles (order Testudine) with their distinctive body shell have changed little in their design since the Triassic period. They are a small group of long living, terrestrial, semiaquatic, aquatic and marine species. They lack teeth. All are oviparous and all including the marine forms bury their eggs.
- The tuatara of New Zealand Order Sphenodonta (*Rhyncocephalia*) is a relict species and the sole survivor of a group that otherwise disappeared 100 million year ago. It bears several primitive characters that are almost identical to those of the Mesozoic fossil reptiles.
- Lizards, snakes, amphisibaenians (Order Squamata) have a modified diapsid skull that increases jaw flexibility. Members of this order comprise 95% of all reptiles. Lizards are a diverse and successful group which are distinguished from snakes by having typically two pairs of legs (some species are legless), united lower jaw halves, movable eyelids, external ears and absence of fangs. Snakes are entirely limbless and are characterized by elongate bodies, highly kinetic skull which enables them to swallow whole prey that may be much larger that their own body diameter. Most snakes rely on chemical sense, especially Jacobson's organ, to hunt prey rather than on the weakly-developed visual and auditory senses. Many snakes are poisonous. The worm lizards (amphisbaenians) are a small group of legless, burrowing squamates with both eyes and ears hidden beneath the skin.
- The crocodiles, alligators gavial, and caiman (Order Crocodilia) are the only living reptilian representatives of the archosaurian linkage which gave rise to the extinct dinosaurs and the living birds. Crocodilians have several adaptations for a carnivorous, semi aquatic life, including a massive skull with powerful jaws and a secondary palate. Among the reptiles they have the most advanced social behaviour.

Birds

- Birds are egg laying, endothermic vertebrates covered with feathers, with the forelimbs modified into wings. Phylogenetically birds are closest to the theropods a group of dinosaurs of the Mesozoic era which had several bird-like feathers. The oldest known fossil bird Archaeopteryx from the Jurassic period of the Mesozoic era had a mosaic of reptilian and bird-like characteristic and was almost identical to certain theropod dinosaurs with the exception of feathers, wing like structures of the hand and enlarged eye orbits. Most probably it is not in direct lineage leading to modern birds but can be regarded as a sister group to modern bird. At present there are 9600 species of birds distributed among about 28 orders of living birds and a few fossil orders.
- Adaptation for flight is the key theme in bird evolution and is of two main types: reduction of body weight and those promoting more power for flight. The main identifying feature of birds are feathers which are ectodermal and complex and derivatives of reptilian scales. They are light, yet strong, water repellent and highly insulative. Body weight is reduced by elimination of some bones, fusion of others (to provide rigidity for flight) and the presence of hollow, air-filled spaces in many bones. The heavy jaw with teeth of the reptiles are replaced in birds by a toothless, light horny beak that serves both as mouth and hand for them, and is adapted variously for diverse feeding habit.
- Adaptations that provide power for flight include high metabolic rate and body temperature coupled with an energy rich diet, and extremely efficient respiratory system comprising of lungs and air sacs, arranged to allow to pass air only in one direction across the respiratory surfaces, thus maintaining a high level of oxygen at the gas exchange surfaces. Powerful flight and thigh muscles are arranged to place muscle weight near the bird's center of gravity.
- Birds have keen eye sight, good hearing, poorly developed sense of smell and superb coordination for flight.
- Digestive system is extremely efficient, digesting food very rapidly.

- A well developed high pressure, circulatory system exists, in which oxygen depleted blood and oxygen rich blood are completely separated by the double circulation through a four chambered heart.
- Water is conserved by the metanephric kidneys, which eliminate the nitrogenous metabolic wastes as uric acid. The urinary bladder has been lost.
- Birds fly by aerodynamic principles using wings for support and lift, a tail for steering and landing control, and wing slots for control at low flight speed.
- Flightlessness in birds is unusual but has evolved independently in several bird orders. However, both flightless and flying birds have evolved from flying ancestors.
- Not all birds migrate but a large number do, migrating between summer nesting places and wintering regions. Paths are specific for each bird species. Birds use a combination of cues in navigation—an innate sense of direction;- visual land marks, a sun compass, star pattern and magnetic field.

  Birds have well developed social behaviour which is exhibited in courtship displays, mate selection, preparation of nests, incubation of eggs and care of the young.

3.6 TERMINAL QUESTIONS

(1) What are the three main reptile lines that evolved from the amniotes during the Mesozoic era and from which lineage did mammals evolve? How would you distinguish among the anapsid, diapsid and synapsid types of skull.

(2) Describe at least six ways in which reptiles are more advanced functionally and structurally than amphibians.

(3) Describe the distinguishing features of turtles (Order Testudines) that could distinguish them from any other reptile order.

(4) Describe the Jacobson's organ of snakes and its function.

(5) How would you identify a poisonous snake from a non-poisonous one?

(6) How to crocodiles and alligators differ from each other?

(7) Describe three anatomical feathers of lizards (including legless members) that distinguish them from snakes.

(8) Describe the primitive features of the tuatara (Order Rhynococephalia).

(9) Where was the Archaeopteryx discovered? How did this fossil prove that birds share a common ancestory with the reptiles?

(10) Explain how design of a wing helps in providing life. Also describe wing features that help to prevent stalling at low flight speed.

(11) Write short notes on:

  (a) Moulting

  (b) Migration

  (c) Precocial chicks

  (d) Altrical chicks.

3.7 ANSWERS

Self Assessment Questions

1. (a) (i) False; (ii) False; (iii) False; (iv) False; (v) True; (vi) False; (vii) True; (viii) True.

   (b) (i) Lacertilia; (ii) Serpentes; (iii) Amphisbaenia.

   (c) (i) c; (ii) b; (iii) d; (iv) a

2. (a) True; (b) False; (c) False; (d) False; (e) True.

3. (a) Keratin; (b) behavioural thermoregulation; (c) parietal; (d) similar.
4. (a) True; (b) False; (c) False; (d) True; (e) False; (f) False; (g) True.
5. (a) False; (b) False; (c) False; (d) False; (e) True.
6. (a) lepidosaur; (b) petrels; (c) diapsid; (d) absent; (e) present.
7. (a) *Hemidactylus brooki* (b) present; (c) moveable; (d) Komodo.
8. (a) boas; (b) forward; (c) good; (d) chemical; (e) Viperidae; (f) ovoviviparous; (g) absent.
9. (a) tympanic membrance; (b) earthworms; (c) *Rhineura florida*.
10. (a) thecodont; (b) palate; (c) less.
11. (a) ratites, carinates; (b) *Archaeopteryx*; (c) crocodilians; (d) reptiles, birds.
12. (a) True; (b) True; (c) False.
13. (a) Cerebellum; (b) well developed; (c) two (none for colour); (d) reptilian
14. (a) narrow eating/euryphagous; (b) crop; (c) gizzard.
15. (a) True; (b) False; (c) True; (d) False; (e) True
16. (a) False; (b) False; (d) False; (e) True; (f) True; (g) True; (h) False.

Terminal Questions

1. Refer subsection 3.3.1
2. Refer subsection 3.3.5
3. Refer subsection 3.3.3
4. Refer subsection 3.3.6, under suborder Serpentes;
5. Refer subsection 3.3.6, under suborder Serpentes; Snakes in 'Poisonous and non poisonous snakes'.
6. Refer subsection 3.3.6, under suborder; Archosaurs (Advanced Diapsids): Order Crocodilia.
7. Refer subsection 3.3.3
8. Refer subsection 3.3.6, under Subclass Diapsida; Superorder Lepidosauria (a) Order Sphenodonta.
9. Refer subsection 3.4.1.
10. Refer subsection 3.4.4, under Flight and Flapping Flight.
11. (a) Refer subsection 3.4.4, under moulting (b) refer subsection 3.4.5 Migation and Navigation (c) Refer subsection 3.4.5, social behaviour, under (ii) Nesting and Care of young.

UNIT 4 MAMMALS

Structure

4.1 INTRODUCTION

You have so far studied about vertebrates which lay eggs and take little or no care of their young ones. Now you will study a group of vertebrates that give birth to young ones and take care of them by nourishing them. They are called mammals. The name is derived from Latin word "mamma" meaning breasts. Mammals are provided with mammary glands or breasts which secrets milk that is fed to young ones. The fertilized egg is retained within the uterus of the mother where it undergoes development in relative security. During development a structure called placenta is formed. It helps in supplying nourishment and oxygen to the developing embryo. It also helps the embryo in getting rid of nitrogenous wastes and carbon dioxide. All the four foetal membranes are formed during embryonic development. Allantois and the yolk sac establish close contact with the uterine wall and form the placenta. Mammalia represent the most successful and at present the most dominant group of tetrapod vertebrates on earth. There are about 5000 species of mammals alive today. As the body of reptiles is covered by scales and that of birds by feathers and the body of mammals is covered by hairs. Hairs also form an insulation to the body like feathers and helps in maintaining constant body temperature. So mammals are also warm blooded (Homeothermic) as birds. Mammals are widely distributed. They occur in the coldest regions of the earth like the arctics and the hottest regions like the sand deserts. They occupy all types of land habitats. They walk, run, swim, burrow and fly. There are mammals adapted to flying and aquatic life. The brain of mammals is well developed. They are more intelligent than other vertebrates. Mammals represent the zenith of vertebrate evolution at present. The present geological period is called the GOLDEN AGE OF MAMMALS. Man belongs to this group of vertebrates and stands at the pinnacle of evolution today.

Objectives

After reading this unit you should be able to:

- explain important characters of mammals which have contributed to the success of their life on land,
- give an account of nonplacental mammals,
- describe adaptations in bats for flight and whales for aquatic mode of life,
- explain dentition in mammals,
- discuss the evolution of man,
- list the names of threatened species of mammals in India.

4.2 GENERAL CHARACTERS AND CLASSIFICATION

1. The body of mammals is covered by hairs. Hairs and other structures like claws, hoofs and nails on the digits as also scales found in some mammals as on the tail of rats, form the epidermal exoskeleton of mammals.

2. Mammals are homeothermic. The hairy covering of the body and sweat glands found in the skin help in maintaining constant body temperature.

3. A number of glands like sebaceous, sweat, scent and mammary (milk) are present in the skin of mammals.

4. The skeleton of mammals is well ossified. The cranium in the skull is large. The skull is bicondylar i.e., two occipital condyles. Teeth are heterodont (occurrence of different types of teeth), thecodont (teeth fitted into pits on the jaw bones) and diphydont (occurrence of two sets of teeth in the life of a mammal). The lower jaw is made of only one bone, the dentary. The upper jaw is fused with the skull and the lower jaw articulates directly with the skull. There are seven vertebrae in the neck of mammals irrespective of the length of the neck. An external ear opening and an external ear, the pinna are present. There are three ossicles in the middle ear (incus, malleus and stapes). They help in transferring sound waves to the internal ear.

Ossify : make or become hard like bone or change into bone.

5. The brain is comparatively large when compared to other vertebrates. The cerebrum is well developed. There are four optic lobes (called corpora quadrigemina) as opposed to only two in the brain of other vertebrates. There are 12 pairs of cranial nerves.

6. The heart of mammals is four chambered. Both auricle and ventricle are completely divided into right and left chambers. The opening between the left auricle and the left ventricle is guarded by the bicuspid valve whereas the opening between the right auricle and the right ventricle is guarded by the tricuspid valve (Fig.4.1). The presence of these valves is characteristic of mammals. There is only one aortic arch, the left aortic arch which curves around to the dorsal side and forms the dorsal aorta. The red blood corpuscles are non-nucleated except in camels where they are nucleated.

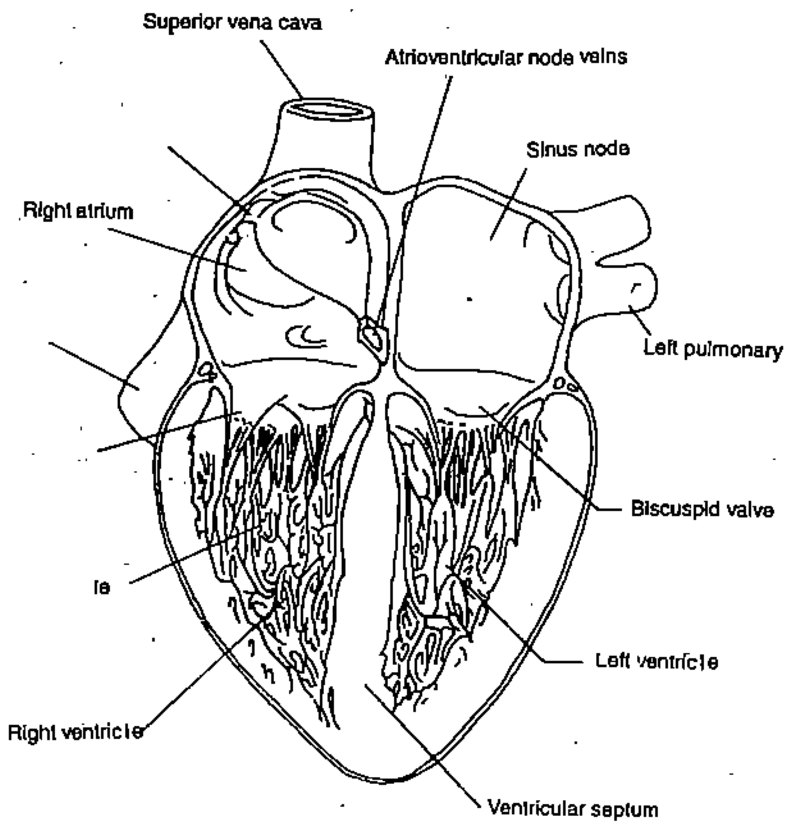


Fig.4.1: Cutaway view of the human heart showing bicuspid and tricuspid valves.

7. There is a muscular diaphragm separating the abdominal cavity from the thoracic (Fig. 4.2). The diaphragm helps in respiration. Lowering and raising of the diaphragm sucks in and pushes out air from the lungs during respiration.

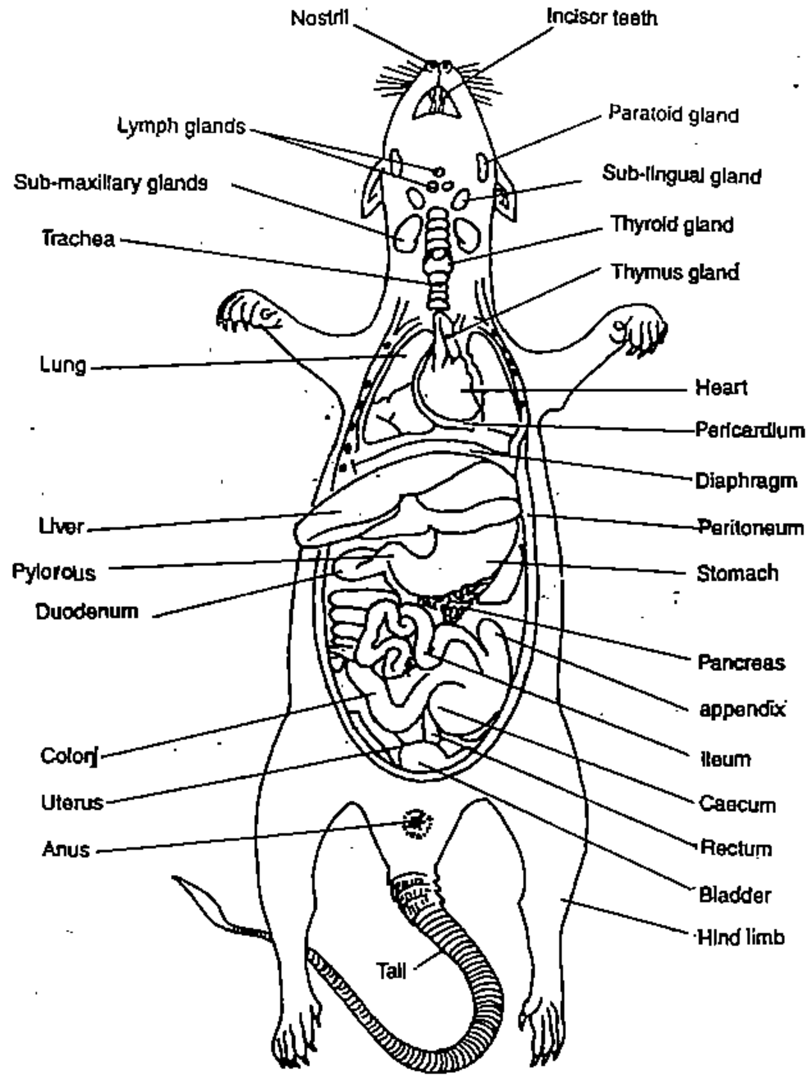


Fig.4.2: Dissection of rat showing diaphragm which separates the abdominal cavity from thoracic.

8. Lungs are elastic and contain small air cavities called **alveoli**. There is a voice box called **larynx** in the trachea. It helps in producing sound.

9. The kidney of an adult mammal is formed from metanephros. A urinary bladder is usually present.

10. Sexes are separate. There is sexual dimorphism. The male mammals are provided with copulatory organ called **penis**. It helps in transferring sperm (semen) to the female genital tract during copulation. Testes are usually present in extra abdominal sac like structures called **scrotum**. Fertilization is internal. Mammals are viviparous (having offspring which develops within mother's body). A placenta is formed during embryonic development. The **anus** and the urinogenital openings are separate and a **cloaca** is absent except in **Monotremata**.

Classification:

Mammals are classified on the basis of the nature of teeth, limbs and the presence of claws, hoofs or nails on the digits. The class **Mammalia** is divided into three subclasses based on the nature of reproduction.

Subclass I : Prototheria / Monotremata:

It includes primitive reptile-like mammals. They lay yolky eggs yet secrete milk and are fundamentally different from all other members of the class mammalia. Testes are abdominal in position. They possess a cloaca. The external ear (pinna) is absent. They are restricted to Australia, Tasmania and New Guinea.

Examples: The spiny ant eater **(Tachyglossus)**/*Echidna*, (Fig. 4.3).

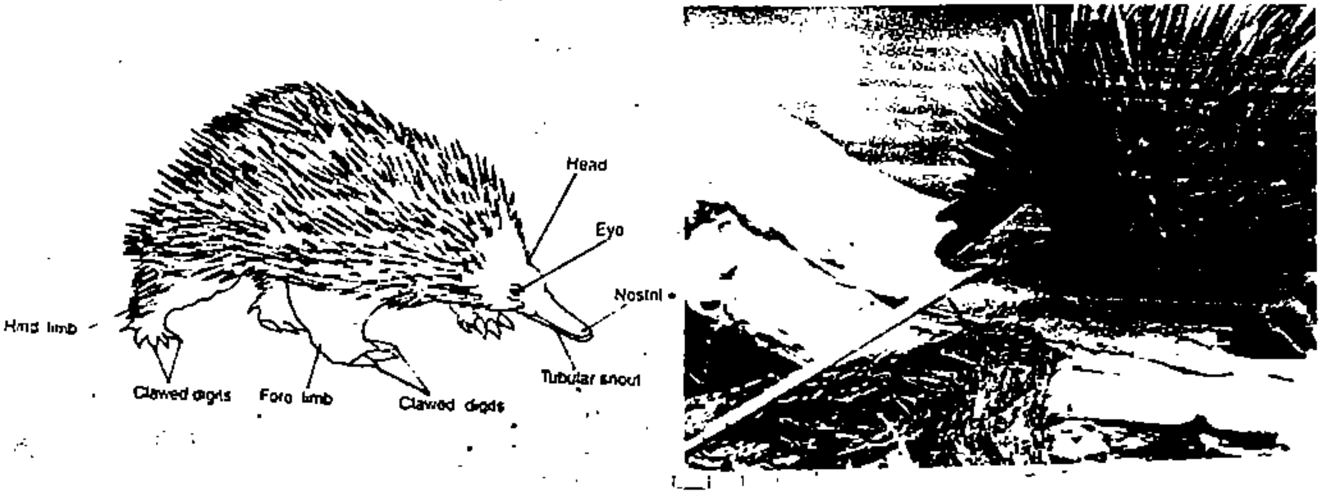


Fig.4.3: *Echidna*, The mouth is small but it has a long sticky tongue to gather up its mites and ants.

The duckbill Platypus **(Ornithorhynchus)** (Fig. 4.4) is an egg laying mammal and exhibits a combination of reptilian and mammalian characters. Reptilian features are uninogenital system, precoracoids, absence of pinna etc. Mammalian features include hair, diaphragm, 4-chambered heart; 3 ear ossicles etc. Duckbill inhabits rivers, pools, and creeks and burrows to 40 feet long in river banks. The animal feeds on freshwater invertebrates, carried in cheeck pouches. Upper jaw forms a flattened beak covered with a smooth, hairless skin which forms a free fold at the base of the beak. Adult has no teeth and jaws are covered with horny plates. Limbs have 5-clawed and webbed digits. Tail happens to be flat and adapted for swimming. Mammary glands are without nipples. Female makes nest of roots and leaves during spring in burrows and lays 1-3 eggs. Young ones hatched out of eggs are nursed by milk secreted by scattered mammary glands on the abdomen of female.

Fig.4.4: *Ornithorhynchs.*

Subclass II: Metatheria / Marsupialia

There is a ventral abdominal pouch called marsupium in the females. The young ones are retained and protected in this pouch. The young pups born after a short gestation period (13 days in the kangaroo) are transferred to the marsupium, nourished and protected there until they are able to look after themselves. The animals are confined to Australia and America.

Fig.4.5: *Macropus*

The Kangaroos (*Macropus conguru*) (Fig. 4.5) have become mostly terrestrial and developed a bipedal method of progression. Their bipedal locomotion involves modification of the ilia and thigh muscles for whose attachment the tibia bears a marked anterior crest. The foot gains increased leverage by elongation of metatarsal of digit 4. Digits 2 and 3 are very small and syndactylous. Due to hopping habit of kangaroos, it is no surprise to see that their hind limbs are long but it is somewhat surprising to find that their fore-limbs are quite short. Most of the length is provided by the long forearm bones which are considerably longer than the humerus. If the animal bends forward, its fore-limbs soon touch the ground. Do they have any function in locomotion? The fact is that they do, because kangaroos have a crawling gait in which the forelimbs and tail are used as props.

Kangaroos (Marsupials) are pouched, ovoviviparous mammals that exhibit a second pattern of reproduction. These marsupials do have a primitive type of placenta, called a choriovitelline or yolksac, placenta. The embryo or blastocyst of a marsupial is at first encapsulated by shell membranes and floats free for several days in the uterine fluid. After hatching from the shell membranes the embryo does not implant, or take root in uterus as it does in eutherians, but it does erode a shallow depression in the uterine wall in which it lies and absorbs nutrient secretions from the mucosa by the way of vascularised yolk sac. **Gestation** the period of intrauterine development is brief in marsupials and all marsupials give birth to tiny young which are still embryos both anatomically and physiologically. However, early birth is followed by prolonged interval of lactation and parental care. After gestation the young is born, attaches to nipple. The mother immediately becomes pregnant again, but the presence of a sucking young in the pouch arrests development of the new embryo in uterus about 'the 100 celled stage'.

Subclass III: Eutheria / Placentalia

The embryo develops completely in the uterus of the mother. A placenta develops to protect and to nourish the embryo. The young ones are born at a relatively advanced stage of development. They are fed with milk secreted by the mammary glands. There are a total of 28 orders of which only 16 orders are represented by living examples. A few important orders are mentioned here. For a complete classification of living mammals see Appendix II at the back of this block.

Order

1. **Insectivora** (Insect eaters) : Insectivorous and burrowers. Examples are : Shrews and moles (Figs. 4.6 & 4.7).

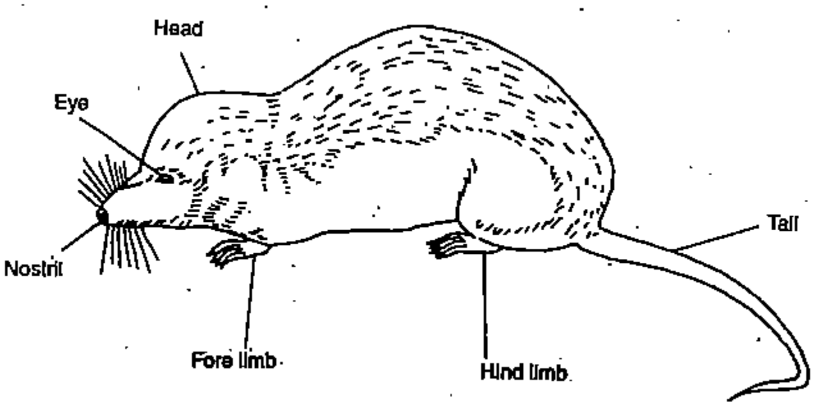


Fig.4.6: ***Sorex*** **(Shrew).**

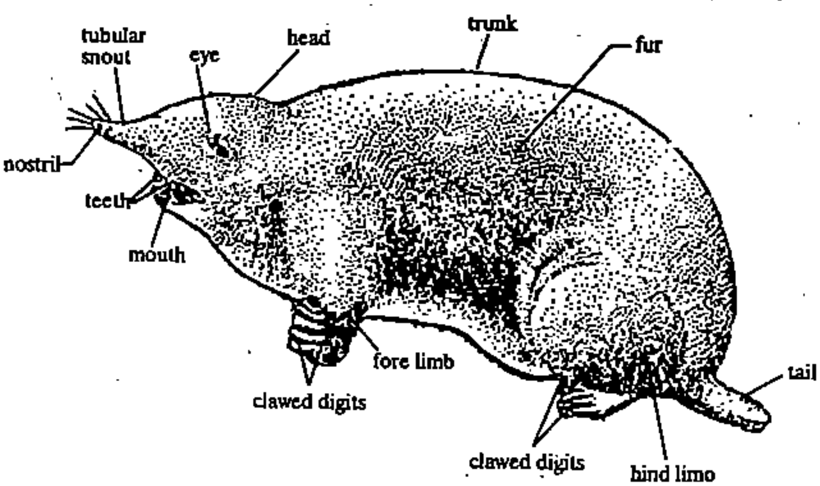


Fig.4.7: ***Talpa*** **(Mole)**

Insectivores are mostly small, nocturnal animals, maintaining many of the earliest mammalian features, possibly because of their special habits. They are adapted for sub-terranean burrowing habit and they live in tunnel. They are usually opportunistic feeders which feed on a variety of small invertebrates such as worms and grubs as well as insects. Insectivores represent primitive eutherian characters of having small cranial cavity, low grade brain as exhibited by the presence of smooth cerebral hemispheres, inguinal testes, discoidal and deciduate placenta with provision for yolk sac placenta. Many insectivores hibernate in winter and are provided with special reserves of fat for this purpose. Most of them are solitary but some have social habits, exchanging auditory and olfactory signals. They make simple nests.

Chiroptera (G.K. Cheir : hand, pteron : wing) are Flying mammals (Fig. 4.8). Except for their specialisation for flight the bats stand very close to the insectivores. These animals diverged early and their characteristic features developed in the early Eocene. They are the only mammals which truly fly by flapping the wings. In acquiring the power of flight they have evolved many features which are parallel with the birds such as economy of weight in the skeleton and gut and active metabolism. Bats usually hang their heads downwards when not flying and to excrete they turn and hang by the claw of the pollex, so that wing is not soiled. There is no upward temperature regulation when a bat is hanging. The animal becomes very cold everytime it rests. The cooling provides a great economy of food. When first wakened the bat can walk, open its mouth and bite or cry out, but can only fly after a period of some minutes of warming up by jerking the legs and shivering.

Fig.4.8: Bat

3. **Edentata** (toothless) : Teeth are lost or reduced because of insectivorous diet. Examples : armadillo and scaly anteater (Figs. 4.9 & 4.10). They all possess a long snout and tongue, very large salivary glands. The special features of Edentates are mostly as a result of special ways of life, often leading to bizarre external appearances such as the long snout of the great ant-eater or the carapace of the armadillo. Armadillos are nocturnal and fossorial and obtain protection by the development of bony plates in the skin, these being covered by horny scutes. The teeth are simple uniform pegs like without enamel and with open roots and continuous growth. Tail is prehensile when disturbed. Manis rolls its body with head between the fore-legs and tail around body. Manis are commonly called scaly anteaters or pangolins. The absence of teeth, the elongated snout, long thin tongue, simple stomach, reduced ears and long claws are all features found in other anteaters as well as in Manis.

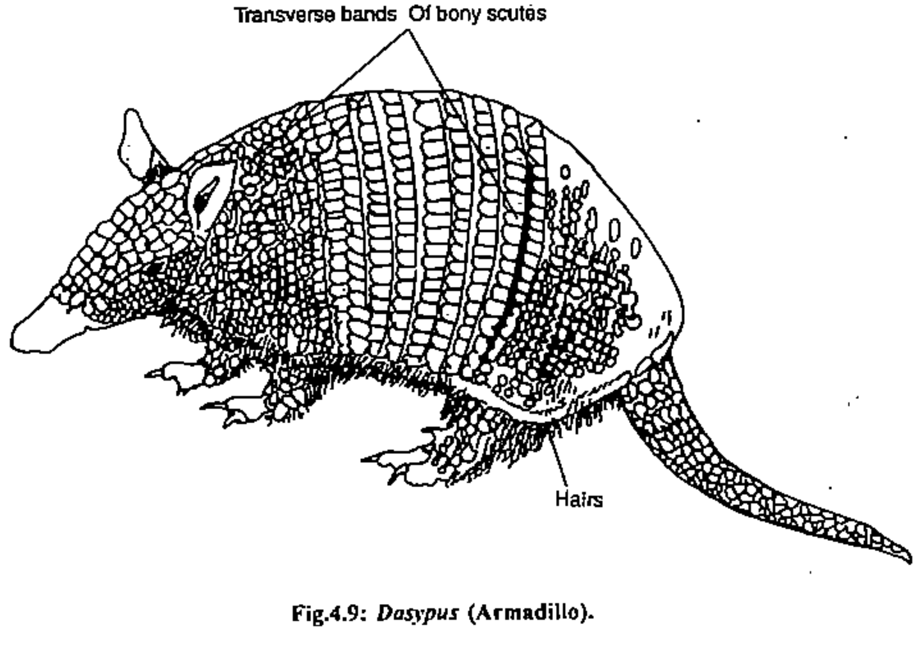


Fig.4.9: ***Dasypus*** **(Armadillo).**

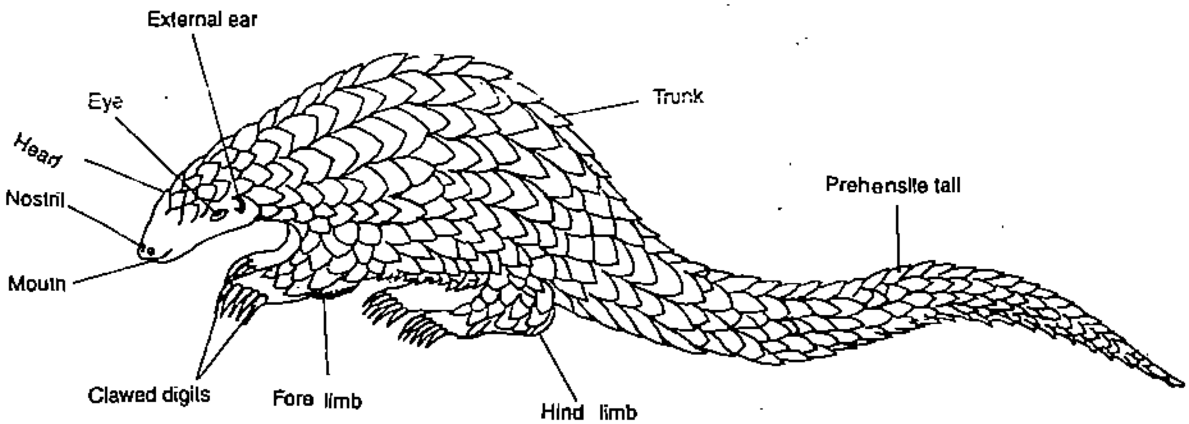


Fig.4.10: ***Manis*** **Scaly anteater or pangolin.**

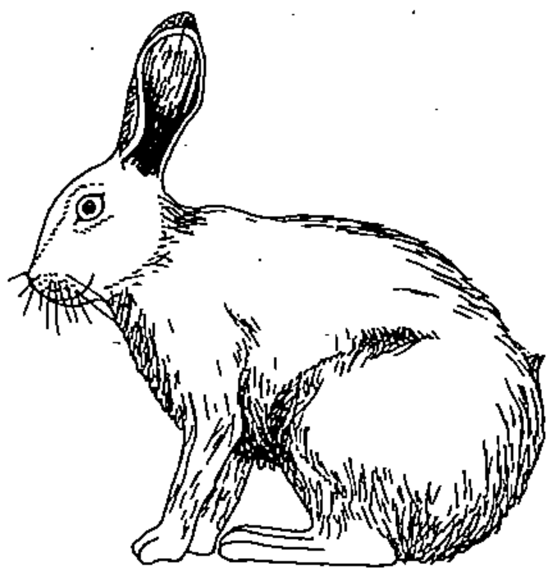


Fig.4.11: Hare *(Lepus).*

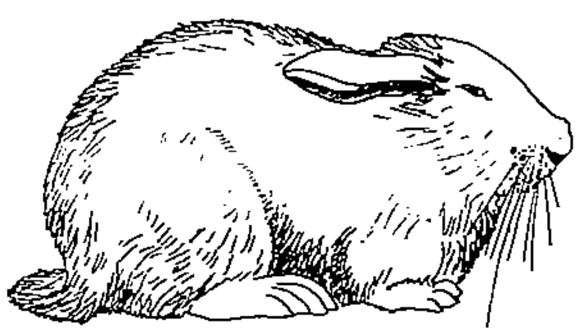


Fig.4.12: Rabbit *(Oryctolagus)*

4. **Lagomorpha** (hare shaped) : have long, constantly growing incisors, like rodents, but unlike rodents they have an additional pair of peglike incisors growing behind the first pair. So they possess 3 pairs of incisors. Examples are hares and rabbits (Figs. 4.11 & 4.12). All lagomorphs are herbivores with cosmopolitan distribution.

Hares and rabbits and some rodents often eat their faecal pellets (Coprography), giving the food a second pass through the fermenting action of the intestinal bacteria. This way coprography may also provide an opportunity for the animal to obtain vitamin produced by the cecal bacteria.

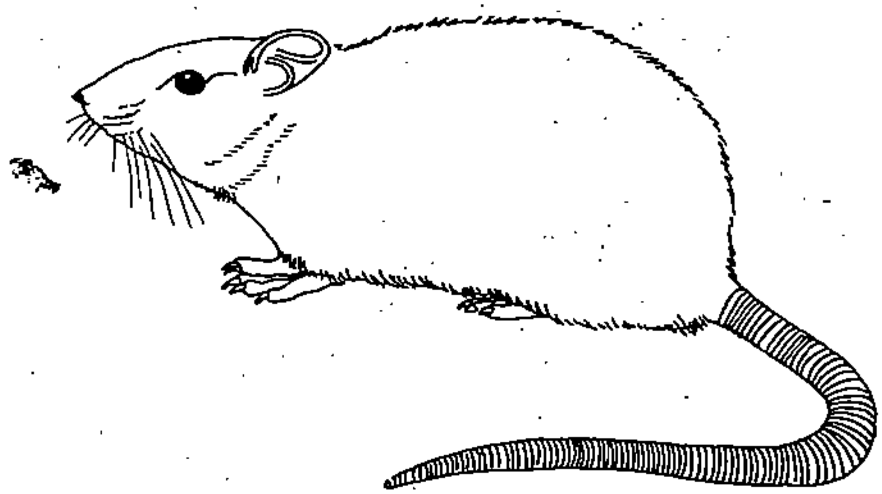


Fig.4.13: ***Rattus rattus.***

Fig.4.14: Squirrel *(Funambulus).*

5. **Rodentia** are gnawers (rats, squirrel, Figs. 4.13 & 4.14, Mice etc). They, comprising nearly 40% of all mammal species, are characterised by two pairs of razor, sharp incisors used for gnawing through the toughest pods and shells for food. With their impressive reproductive power, adaptability and capacity to invade all terrestrial habitats, they are of great ecological significance.

Fig.4.15: *Platanista gangeticus* (Ganga dolphin).

6. **Cetacea** (whale-like) : are aquatic mammals. Fore limbs are modified as flippers. Hind limbs are absent. Body is covered by scanty hair. The nostrils are represented by a single or double blow-hole on top on the head. Examples are whales, dolphins (Fig. 4.15) and porpoises. Large whales and dolphins sleep in the sea. In many respects the whales have reverted to the characteristics of a fish form of life particularly in body shape with elongated head, no neck and tapering, streamlined body. Dolphins can swim at upto 40 km/h for many hours. The propulsive thrust comes largely from the horizontally placed tail flukes. In the forelimb the humerus is short, the elbow joint is hardly mobile and the hand increased in length and sometimes expanded. The number of fingers is often reduced to four, the phalanges of some of the digits may be considerably increased in number (hyperphalangy). The scapula is flattened and there is no clavicle. The behaviour of whale is elaborate involving social life, communication by sound, and probably much learning. Play is common and rhythmical dancing has been observed. Also homosexual behaviour and masturbation in captivity are noticed.

Porpoise sea animal rather than like a dolphin or small whale.

Fig.4.16: ***Elephas maximus*** **(Elephant).**

7. **Proboscoides** (with a trunk) are herbivorous and huge terrestrial mammals (Fig. 4.16) with an efficient nervous organisation for finding the food, efficient means of collecting it, and large well, organised surfaces for grinding it. When a suitable tree is found the elephant shakes it with his trunk for its fruits and then uses his weight to push it down with forehead. He may scrape off the bark with the tusks. The trunk is main organ of collection with enormously elongated nose and upper lip, with appropriate muscles and sensitive tip. Each jaw has 3 molars but at a time only one (or sometimes two) is functional. This is because molars develop in a series. After several years of working the functional molar wears away and falls off and the next molar takes its place. All this is possible because inspite of being thecodont the molars of elephants do not fix in a socket but are lodged in a bony canal. Large size and large brain go with long life and by serial use of their molars. Female elephants live upto 60 and males to 50 years in grasslands, perhaps to 80 years in montane areas.

8. **Carnivora** (flesh eaters) They all have predatory habits and possess sharp claws on digits. Teeth are specialised for catching and tearing prey. They are carnivorous in diet. Examples are cats, Cheetah (Fig. 4.17) leopard, lion (Fig. 4.18), tiger, domestic cat (Fig. 4.19), dogs, fox, wolf, (Fig. 4.20) common dog etc.

Fig.4.17: *Acinonyx jubatus* (Cheetah).

Fig.4.18: *Panthera* leo (lion).

Fig.4.19: *Felis bengalensis* (Leopard cat).

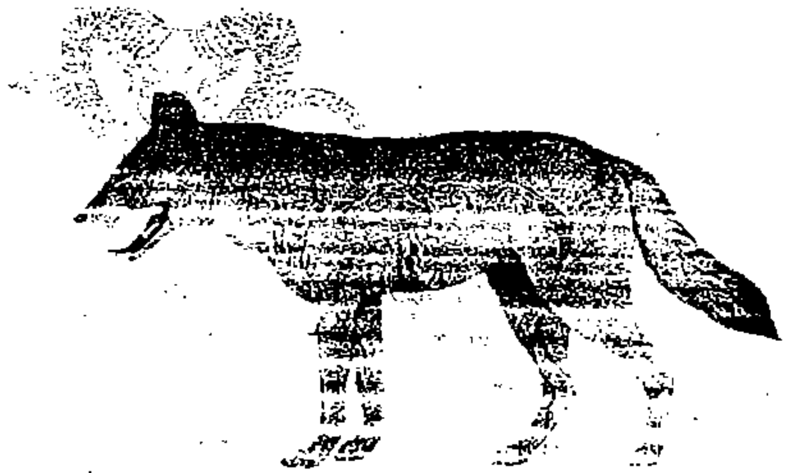


Fig.4.20: *Canis lupus* (wolf).

9. **Artiodactyla** (even toed) arc hoofed mammals with a ruminant stomach and possess even number of toes in limbs. Animals also possess horn and antlers. Examples are pig (Fig. 4.21), cattle, ox, (Fig. 4.22), sheep (Fig. 4.23), goat, deer (Fig. 4.24), camel (Fig. 4.25), giraffe (Fig. 4.26). Most of these ungulates have two toes, although the hippopotamus and some others have four. Each toe is sheathed in a cornified hoof. Many such as the cow, deer and sheep have horns. Many are ruminants which mean animals that chew the cud. They are strictly herbivorous.

Fig.4.21: *Sus scrofa* (Pig or Wild boar).

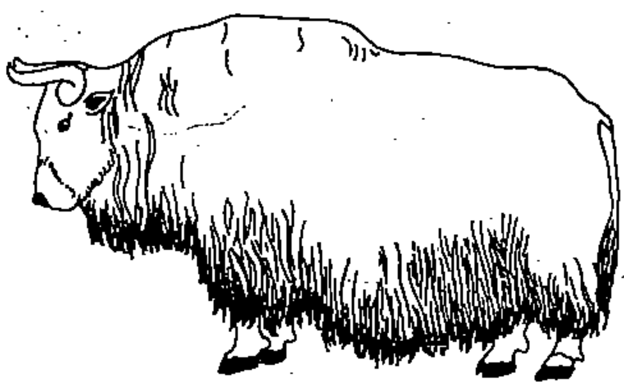


Fig.4.22: Musk Ox.

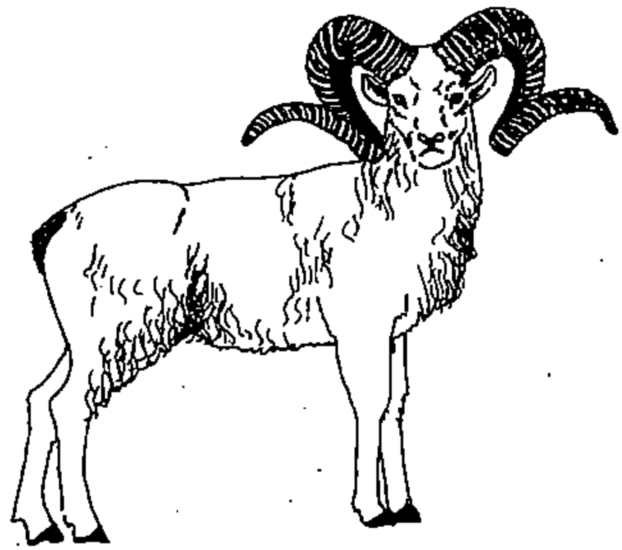


Fig.4.23: *Ovis* (Sheep).

Fig.4.24: musk deer.

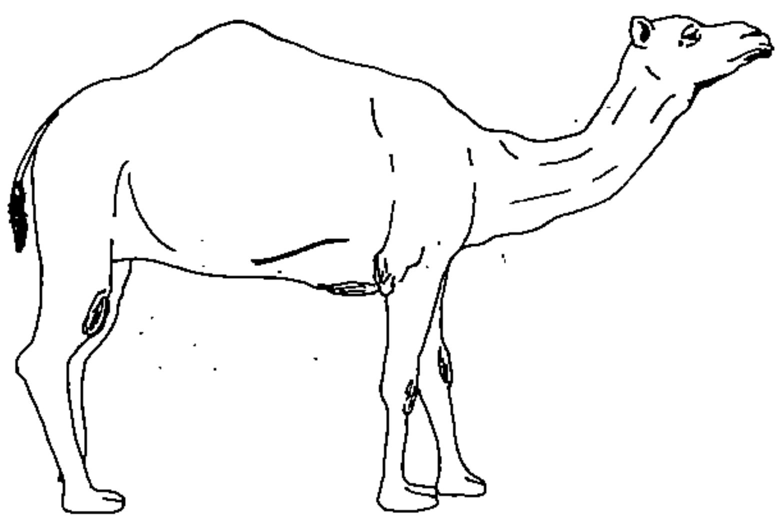


Fig.4.25: *Camelus dromedarius* (Arabian camel).

Fig.4.26: *Giraffa camelopardalis* (Giraffe).

10. **Perissodactyla** (odd toed) are hoofed mammals with odd number of toes, and herbivorous in diet. Examples are horse (Fig. 4.27), zebra (Fig. 4.28), rhinoceros, (Fig. 4.29), donkey (Fig. 4.30), etc. The horse family (Equidae), which includes horses, and zebras has only one functional toe. Tapirs have a short proboscis formed from the upper lip and nose.

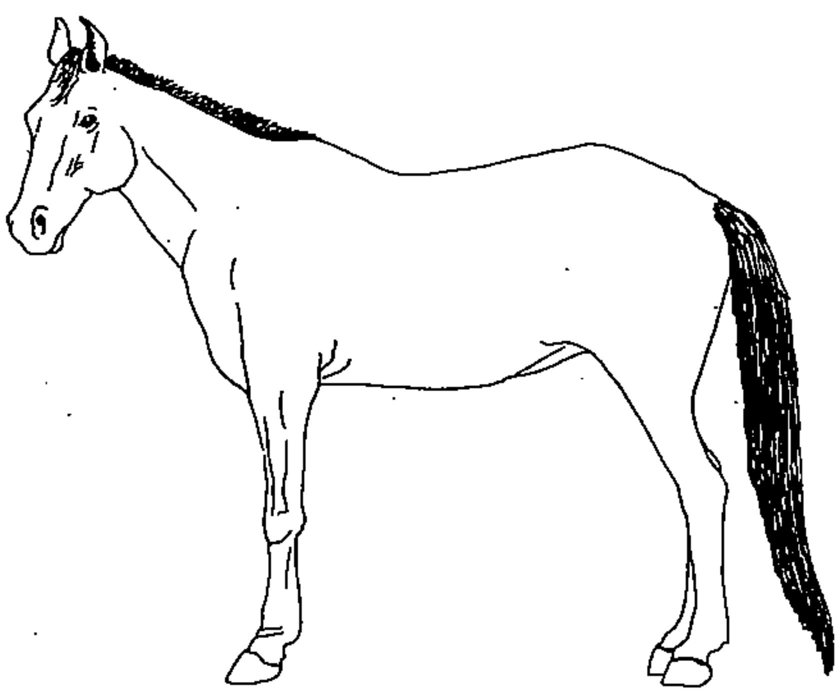


Fig.4.27: *Equus caballus* (Horse).

Fig.4.28: *Equus zebra* (Zebra).

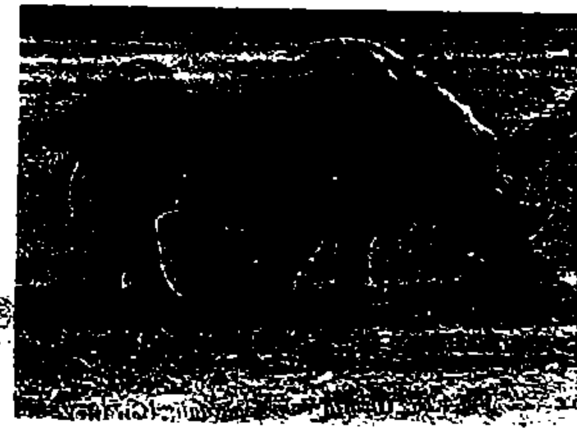


Fig.4.29: Rhinoceros.

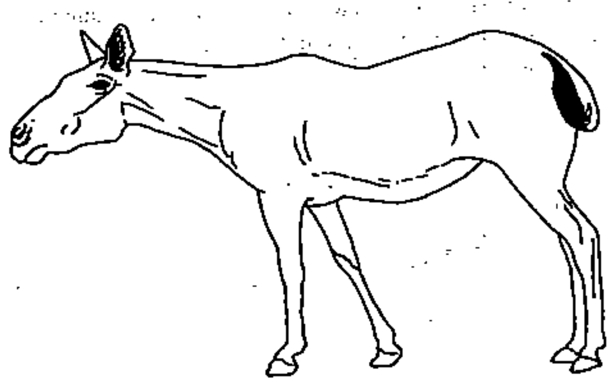


Fig.4.30: *Equus hemionus* (Ass or Donkey).

11. **Primates** (highest) as a group they are generalised with five digits on both fore-limbs and hindlimbs and possess opposable thumb. All digits have nails. All have their bodies covered with hair except humans. Forelimbs are often adapted for grasping, as are the hindlimbs sometimes. Examples are lemurs, tarsiers, monkey (Fig. 4.31), ape; gibbon (Fig. 4.32).

Fig.4.31: Rhesus monkey *(Macaca)*.

Fig.4.32: Gibbon (*Hylobates lar*) on the ground gibbons are the only non-human primates that move on their hind legs.

SAQ 1

i) Mention four important characters of class Mammalia.

ii) In group A names of mammals and in group B places of their availability are given. Match the names in group A with places in group B.

	Group A		Group B
1.	Echidna	a.	Africa
2.	Opossum	b.	Assam/India
3.	Rhinoceros	c.	America
4.	Zebra	d.	Australia

iii) Match the mammals given in group A with orders given in group B.

	Group A		Group B
1.	Bats	a.	Rodentia
2.	Rats	b.	Carnivora
3.	Cats	c.	Chiroptera
4.	Goats	d.	Artiodactyla

iv) Match the method of locomotion given in group A with mammals given in group B.

	Group A		Group B
1.	Flying mammals	a.	Whales
2.	Swimming mammal	b.	Bat
3.	Swinging mammal	c.	Man
4.	Walking mammal	d.	Chimpanzee

v) Mention the three subclasses of class Mammalia with 2 examples for each.

....

....

....

4.3 NATURAL HISTORY

The class Mammalia includes the most successful tetrapod vertebrates. Mammalia are interesting for their behavioural patterns. They are very alert and are provided with highly developed nervous system, particularly the brain. This character has given them the advantage of adapting to any condition and any habitat. They display the highest level of intelligence among vertebrates. They exhibit remarkable range of activities. The body temperature of mammals ranges from 37°C to 42°C. The normal body temperature of man is 98.6°F. The insulation around the body provided by the hairy covering has made possible maintenance of constant body temperature. There are sweat and sebaceous glands in the skin of mammals. Sweating is a specific physiological process found in mammals only. It helps in getting rid of excess body heat. Sweat glands secrete a watery sweat which, when evaporated on the skin's surface draws heat from the skin and cools it. Sweating helps in cooling the body temperature, when the outside temperature is high. Further, some amount of waste material is also got rid off through sweating. Sweating thus helps in excretion also. These qualities of mammals have helped them to survive in severe competition with other land vertebrates.

Mammals are most widely distributed. They are capable of living in a wide range of habitats. They occur in all the continents of the earth. Polar bears and seals are adapted to live in sub zero temperatures of the arctic regions. Camels and a number of species of rats are adapted to live in the hottest deserts. Seals have succeeded in conquering the seas. Beavers and otters live in freshwater lakes and rivers. Bats are adapted to a life of flying. Still mammals are essentially terrestrial animals. They live in many types of habitats on land. They are arboreal living among branches of the trees, burrow and live underground in dark caves, at all altitudes among high mountain ranges up to 20,000 feet. There are species of goats and sheep which live among the rocky hills and mountains. Most rodents, carnivores, and ungulates live in open grass lands and forests ranging from dense tropical jungles to treeless arctic **tundra**. Most mammals are diurnal and a few are nocturnal in habit.

Tundra : wide, treeless plain of the arctic regions (of Russia, Siberia) marshy in summer and frozen hard in winter.

Mammals differ in their stature, shape, colouration and mode of life, type of the food consumed and shelter used, their social organisation and customs. Each kind of mammal has a definite geographical and ecological range. The range of habitat limitations may be narrow as in beavers or wide spread as in rats. Many are solitary (lions, mink, rodents etc.), others move in packs (wolves and hyaenas), prairie dogs live in colonial burrows mammals like buffaloes and deer live in herds or in social groups as in primates. Food and cover available decide the density of populations; shrews and mice live 50-100 per acre, squirrels 2-10 per tree group, deer 25-40 per acre etc. They occur in large numbers in tropics and least in polar regions. Populations of mammals is usually constant unless modified by natural calamities like drought, flood, scarcity of food and human interference.

There are a number of glands in the skin of mammals, like sweat glands, sebacious glands, scent glands and all the important mammary glands. Mammary glands secrete milk which is fed to the young. The secretion of scent glands is useful to the animals as a means of chemical communication between the sexes of a species or members of a group in the species. The scent gland secretions help in attracting males and females to meet and mate. Skunks are provided with odoriferous glands opening into the anus. The secretion can be thrown as a jet and its bad odour repels the enemies. Thus, it is used in defense against enemies. Sweat glands are helpful in regulating body temperature. The secretions of sebacious glands are discharged into the hair follicles and this helps in keeping the hairs soft, glossy and shining. It also helps to maintain the skin soft. There are tear glands (lachrymal glands) found near the eyes and their secretions help in keeping the eye balls clean and moist. Mammary glands are modified sebacious glands and they are usually well developed and secretary in the female mammals. The development, differentiations and functions of the mammary glands are regulated by hormones. They become secretary soon after the birth of the young. The number and position of mammary glands differ in different orders of mammals. In carnivores and rodents there are more than one pair of mammary glands located along the ventral surface of the thoracico-abdominal region. In ruminant ungulates (cattle, sheep, goat etc.) they are inguinal in position. In Primates (monkeys, apes and human) there is only one pair of mammary glands found on the ventral surface of the thoracic region.

Teeth are well developed. Teeth are absent in the adults of Cetacea, Edentata and Prototheria. The number of teeth present and their arrangement varies in different species. The nature and arrangement of teeth are called dentition and expression of the number of different types of teeth in a particular species is called the dental formula. You will study in great detail about dentition in Unit 6 of Block II of Animal Diversity-II course.

A typical mammalian tooth has two portions. One part embedded in the pit of the jaw bone forms the root and the part exposed and is normally visible above the jaws is the crown. It is the crown that is used for mastication. The tooth is essentially made up of a specific substance called **dentine**. Dentine is found both in the root and the crown. Dentine in the crown part is covered by a shiny substance called the **enamel**, and in the root by cement. There is a cavity in the centre of the tooth which contains the connective tissue, nerves and blood capillaries. This is called the **pulp cavity**. Tooth, in general in vertebrates is derived from the placoid scales of fishes. In other non-mammalian vertebrates teeth are similar in structure, shape and function. This is called **homodont** condition. But in mammals teeth differ in structure and function. This is called **heterodont** condition. In mammals four different types of teeth are found, the chisel shaped incisors at the front, conical canines on the sides and premolars and molars at the extreme ends of the jaws, on either side. Incisors are helpful in cutting the food, the canines in tearing the food, premolars and molars in grinding the food. Most mammals develop two sets of teeth in their life time.

The first set of teeth appears early in life. This is called the milk set. Later this is replaced by a more permanent set which lasts the whole of the adult life of an animal. This condition of developing two sets of teeth during a life time is called **diphyodont** condition.

Dentitition has been used in classifying Placental mammals. Dentition of mammals reflects adaptive radiation with reference to the type of food and feeding habits. The condition of dentition of a mammal is best illustrated by dental formula. In carnivora, canines are large and strong and help in capturing prey and flesh. Further, the last premolar of the upper jaw and the first molar of the lower jaw on each side are specialised and adjusted to cut against each other. This modified set of teeth in Carnivores is called the **carnassial teeth. It is a characteristic of Carnivora. In rabbits the canines are absent.** This results in occurrence of a wide gap between the incisors and premolars on each side. This gap is called **diastemma**. But the incisors are well developed for gnawing. The incisors of **Rodentia** and **Lagomorpha** are endowed with a persistent pulp and continue to grow throughout life. In other herbivorous mammals like **ungulates** the canines are small and rudimentary. But the molars are well developed with prominent grinding ridges at the top.

Only one pair of continually growing upper incisors in elephants forming the two big upcurved tusks composed of solid dentine except for a temporary cap of enamel at the tip. This mass of ivory is useful for defence and perhaps in food collection but this is not just of importance in feeding. Elephants tusks are used for ivory jewellery. This has led to mass killing of the animal for ivory leading to decline in their number. Of late, there is a worldwide movement against purchase of ivory so that animals have chance to survive in future. The tusks are smaller in females. The tusks of the male elephants are modified incisors. In the wild boar the tusk is the modified canine.

The dental formula (the number and the arrangement of different types of teeth) includes the number of each of the four types of teeth on one half of each jaw. There is bilateral symmetry in the arrangement of teeth in each jaw. For explanation you consider the

dental formula of man; $\frac{2\text{-}1\text{-}2\text{-}3}{2\text{-}1\text{-}2\text{-}3}$ or $i\,\frac{2}{2}\;c\,\frac{1}{1}\;pm\,\frac{2}{2}\;m\,\frac{3}{3} = 32.$

The letters i, c, pm and m refer to incisor, canine, premolar and molar respectively. Each type number may be written preceded by the indicative letter or the numbers only be represented. The numbers on the upper row indicate the teeth in one half of the upper jaw and those on the lower row the teeth in one half of the lower jaw. Add the number in the two rows together and multiply it by two to get the total number of teeth in that animal. For example, the total number of teeth in man is 32. The basic total number of

teeth for mammal is 44 and the dental formula is $\frac{3\text{-}1\text{-}4\text{-}3}{3\text{-}1\text{-}4\text{-}3}$; This typical condition is found in the horse.

The dental formula for a few common mammals is given below:

dog $\frac{3\text{-}1\text{-}4\text{-}2}{3\text{-}1\text{-}4\text{-}3}$ = 42, cat $\frac{3\text{-}1\text{-}3\text{-}1}{3\text{-}1\text{-}2\text{-}1}$ = 30, cow $\frac{3\text{-}0\text{-}1\text{-}3}{3\text{-}0\text{-}1\text{-}3}$ = 28, Elephant $\frac{1\text{-}0\text{-}0\text{-}6}{0\text{-}0\text{-}0\text{-}6}$ = 26 In elephants all the 6 pairs of molar in each jaw, are not functional at the same time. Only one pair is active at a time.

In elephants the teeth are allowed to form high up in the skull, so that each tooth has a very great area, made up by the fusion of as many as twenty seven separate plates.

These plates develop as separate cones of dentine and enamel, each with its own pulp cavity. The three elements of teeth are exposed and they wear at slightly different rates leaving a rough surface. Each tooth is worn away gradually from infront backwards. The elephant molar is a horizontal shearing device, not a grinding one. During the course of evolution the number of plates has increased and they have become thinner and more closely packed so as to provide more shearing surfaces at each stroke (Fig. 4.33).

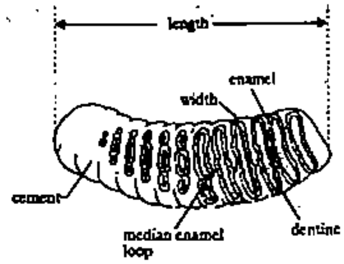


Fig.4.33: Molar of elephant showing its natural features.

The method of locomotion and the manner of use of limbs during locomotion varies among mammals. Most mammals are tetrapods and use all the four limbs for locomotion. Man is an exemption. Man uses only the hind pair of limbs for locomotion. This is to a great extent dependent on the habit and habitat and these together influence foot posture. The skeleton and limb muscles also show adaptive modifications depending on the type of locomotion. The ancestral basic type is the use of the entire sole of the feet (palm of the forelimb) being placed firmly and flat on the ground during locomotion. This posture is described as **plantigrade** (sole walking) type of locomotion. This provides better and firm footing. Man is plantigrade. Most carnivores walk/run on their digits. This is described as **digitigrade** (finger walking) type of locomotion. In this method only a small part of the digits come in contact with the ground. This lessons friction and help in more speed in movement. In this method the palm/foot and wrist/ankle are raised above the ground adding length to the limbs which in its turn provides longer stride and greater speed. The ultimate method in attaining higher speed is seen in hoofed mammals (Artiodactyla and Perissodactyla). The number of digits is reduced and the mammals move on the tip of their digits. They have developed cornified hoofs to stand wear and tear due to use. This type is described as **unguligrade** (hoof walking) type. This adds more to the length and consequently to greater speed. Horse is able to gallop at a greater speed because of this advantage. This method of locomotion is also described as **cursorial**. They can run faster and far. They are adapted for speed and endurance. Man can run at a speed of 22.3 mph, a cheeta at 70 mph, horse can run at 15 mph for 35 miles at a stretch. A jackrabbit at 40 mph, antelope at 60 mph, fox at 45 mph, a camel can run at 12 mph for 115 miles at a stretch. This should not be mistaken with the sustained speed of automobiles. This speed represents the attainable speed at some time during their running. They cannot run at the same speed for longer stretch of time.

Mammals are warm blooded animals. They are capable of maintaining their body temperature at constant levels in spite of changes of temperature in the surrounding environment. Oxidative processes in the cells of the body produce heat. Loss of this heat by radiation or evaporation is prevented by insulation provided by the hairy covering. Excess of heat is got rid off by evaporation. Sweating and heat used to evaporate sweat helps to cool the body and maintain body temperature at tolerable levels. There is profuse sweating on hot days. Because of this mechanism mammals are able to adapt themselves to excess heat of the summers and excessive cold of the winters. Desert mammals spend their days in shades or deep in the burrows without exposing themselves to hot sun. Most of them adapt nocturnal habit. They are active during nights. Mammals living in temperate zone countries or arctic regions where winters are very severe migrate to warmer regions and thus try to escape excess cold of winters. Seals, reindeer, bison, red bat and some species of whales migrate to warmer regions during winter. Mammals which cannot migrate spend winters in relative inactivity in warm caves or burrows. This method of spending winters in inactivity is called **hibernation** (winter sleep). Hibernation is a state of sleep when body metabolism slows down, heart beat becomes slower, blood circulation becomes sluggish, body temperature drops and animals spend time in sleeping and eating little or no food. Some animals accumulate fat to be utilized during hibernation. During hibernation animals can exist for a longer duration spending relatively little energy derived from the stored fats. With the onset of spring animals wake up and begin their normal activities. All hibernating animals are heterothermic. Chipmunks and ground squirrels spend cold winters in hibernation in underground nests and bats in caves. Bears of temperate regions are known to hibernate during winter in caves. Bats are known to hibernate in North India but not in South India.

As opposed to hibernation some mammals like ground squirrels spend their summers in deep burrows and sleep through the summer. This is called **aestivation**. This is summer sleep. They spend summers in relative inactivity very much like hibernation.

Feeding habits and the type of food consumed by mammals show variations. They may be **herbivorous, carnivorous, insectivorous or omnivorous.** Herbivorous animals feed on grass and other vegetation. Most domestic mammals, deer, rabbits, elephants, squirrels etc., are herbivorous. The cats (lion, tiger, leopard, wolf, fox), dogs etc., feed on herbivorous mammals. Omnivorous mammals like man, rat, bear etc., eat both plants and animals as their food. Insectivores like bats, moles, mice, shrews, pangolins, bears, racoons, ground squirrel etc., feed mostly on insects and may also eat other food. Some carnivores are known to eat fruits and grains also to supplement animal food. Some species of bat such as vampire specifically feed on blood of other mammals. They are described as sanguivorous. The different mammals show suitable adaptations to secure their respective food and consume them. One such adaptation is in the teeth. The bat has razor-sharp incisors which the animal uses to shave away the epidermis of its prey, exposing underlying capillaries. After infusing an anticoagulant to keep the blood flowing, it laps up its meal and stores it in a specially modified stomach. The other adaptations are with reference to their behavioural adjustments.

Mammals as a group of animals show some specialised behavioural patterns not found in others. They are capable of learning. Mammals are relatively more intelligent. They use their ability to produce sound to warn each other, scare the enemies, call their young, call the mates during mating seasons and call for help during times of distress. Many mothers keep their young with them for some time and teach them hunting, defending, searching food and discriminate good food from bad, etc.

4.3.1 Monotremata (Prototheria)

Monotremata (Gk Mono = single, tremos = hole) or Prototheria (Gk. Proto = first, theria = animals/mammals) are the most primitive of mammals. The name monotremata is used to designate the presence of a single exit opening for both excreta and urine and genital products. All other mammals are provided with separate openings for urinogenital ducts and the rectum. Prototheria are referred to as being the first mammals to evolve. They are today confined to and live in Australia and neighbouring islands (Tasmania & Newguinea). They represent a fascinating group of animals exhibiting both reptilian and mammalian features. The group is represented today by two genera only.

Example : Duckbill/Platypus (**Ornithorhynchus anatinus**), (Fig. 4.4)
Spiny ant eater/Echidna (**Tachyglossus aculeata**, Fig. 4.3)

Egg laying is a reptilian habit. But in these animals eggs are retained inside the mother's body and incubated. The young ones are fed by the mother. These animals exhibit some characters peculiar to them alone, like the presence of dorsal nostrils, short fur and absence of the external ear the **pinna.**

Platypus is adapted to an aquatic mode of life. It is found in the rivers and ponds of a restricted region of Australia. It has webbed feet and paddle like tail to help in swimming. It grows to a length of 45 cm. The mouth is drawn out in the form of duck bill, so the name duckbill and it is covered by a soft skin. These animals feed on freshwater invertebrates like insects and shell fish. The body is covered by a, thick fur. Teeth appear in the young and are absent in the adults. There are poisonous glands and horny spine connected to the poison glands on the hind feet of males. Females are provided with nippleless mammary glands. They lay 1 to 3 yolky eggs which are similar to the reptilian eggs. There is a cloacal opening through which both the urinogenital ducts and the rectum open out. They build nests in the burrows on the banks of rivers. Eggs are laid in the nests and they incubate and nourish the young. Eggs hatch within two weeks. Mammary glands produce milk which oozes out through the fur and is licked by the young.

Echidna is a terrestrial form. It grows to a length of 45 cm. The body is covered by coarse hair and spines. It is specialised for diet of termites. It is provided with powerful claws. The snout is narrow, long and beak like. It has a long sticky tongue with which it can poke into the termite nests. They feed on ants, so the name ant eater. Teeth have been lost. They protect themselves by digging themselves in until their sharp spines protrude above the surface of the ground. The female develops a pouch on the ventral surface of the abdomen afresh every breeding season. They lay single egg and carry the egg in the pouch until hatched. The young feeds on the milk which seeps out through the mother's hair. Two genera and two species are alive today; Tachyglossus found in Australia and a larger genus Glosses found in Newguinea.

4.3.2 Marsupialia

Marsupial means pouched mammals (Gk. Marsupion = pouch). Marsupials and Placentals represent two separate branches which diverged about 60 million years ago from a common ancestral group of mammals. So they have a common origin. Marsupials are confined to Australia and neighbouring islands with a lone exception, the opossum living in the American continent. In addition to mammalian characters they show some specialised features peculiar to the group. They are provided with a ventral pouch called marsupium. The gestation period is very short. In kangaroo it is only 13 days. The young born in an underdeveloped condition, are transferred to the pouch, protected and nourished until they are able to live by themselves. Placenta is not formed during embryonic development. Small amount of yolk is present in eggs and this is utilized by the developing embryo. The young when born are hairless, blind and deaf. But they are endowed with a keen sense of olfaction which helps them in finding their way from the urinogenital orifice to the pouch. In the pouch they attach themselves to the single nipple present in the pouch, suck the milk and grow safely in the protection of the pouch. After several weeks of development the young are able to leave the pouch, venture out to feed or play and dart back to the safety of the pouch at the first sign of danger. The female carries the young during its wanderings in search of food and such other activities. The forelimbs are better developed than the hind limbs at birth; because they are used to cling on to the mother's fur on the journey to the pouch (Fig. 4.34).

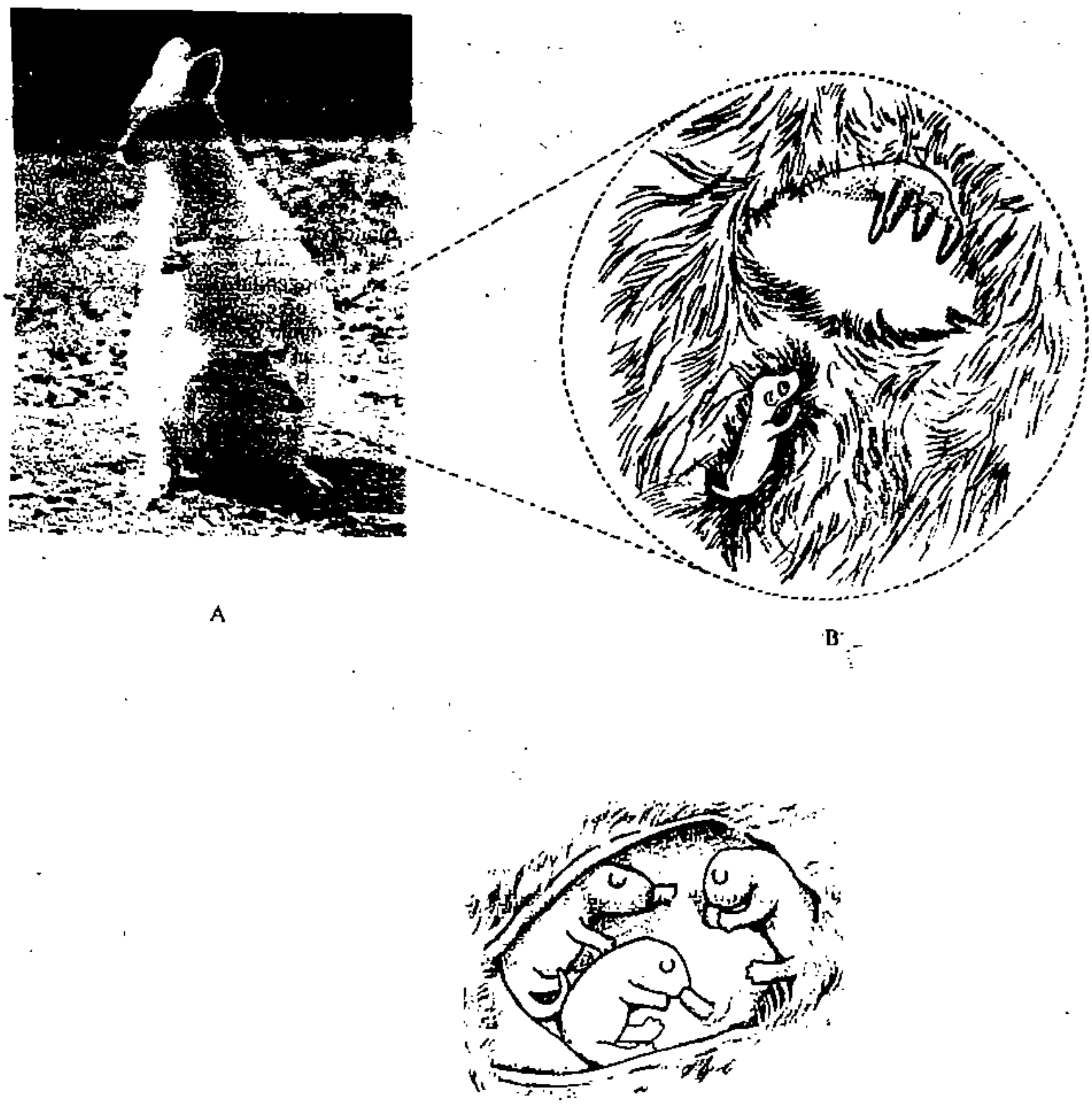


Fig.4.34: Kangaroo (*Macropus*) with her young.

Kangaroos (*Macropus*) live in Australia only, (Fig. 4.5). It is because of this that the members of the cricket team from Australia are some times referred to as Kangaroos. The forelimbs are shorter than the hind limbs. The tail is long and powerful. They sit on their hind limbs and tail which forms a third leg as it were. The tail provides a push a momentum when kangaroo takes a leap which is its normal method of locomotion. Kangaroos are bipedal and herbivorous.

Opossums are found in America. They are arboreal and insectivorous. They are provided with a prehensile tail which helps them to coil around branches during their movement through branches. A marsupium is absent. The young are carried on the back of the mother. There are two sub-species of opossums living in the central and southern states of north America. They represent the most primitive among the American mammalian fauna. They are, therefore, often called "living fossils". Opossums are hunted for their fur and meat.

4.3.3 Eutheria

Eutherians are often called Placentals as they are truly viviparous and highly advanced among mammals. A placenta is formed during the uterine development of the embryo. The placenta protects, nourishes and helps the embryo in excretion during embryonic development. Placenta is formed by the apposition of foetal and maternal tissues. Nourishments and oxygen reach the embryo and nitrogenous wastes, as well as carbon dioxide leave the embryo through placenta. Eutheria are at present the dominant animals on land. They are divided into 28 orders of which only 16 are represented by living examples. There has been a remarkable degree of adaptive radiation in Eutherians during the 60 million years of their existence. They burrow walk, run, swim and fly. They eat almost anything like grass, weeds, sea weeds, worms, insects, fruits, bark, squids, crustaceans, other animals and each others. They live on land, caves and burrows, on tropical tree tops (monkeys, and apes), live in open seas (whales, dolphins, porpoises), arctic ice floes (polar bear, seals), sandy deserts (camels, rats) and of course artificial dwellings like apartment houses (man).

Floe : sheet of floating ice.

Order Insectivora includes insect eating mammals, and represents the most primitive and most widely distributed eutherians. Insectivores are considered to be the ancestral stalk from which most placental mammals including man are said to have evolved. They are small and sharp snouted mammals. They are nocturnal in habit and spend most of their life underground. The body is covered by a soft fur except in hedgehogs where hairs on the dorsal surface are modified into spines. There are a few vibrissae and the animals are endowed with an acute sense of hearing. The eyes in moles are very small and rudimentary. Some Insectivores still retain a cloaca. They give birth to a large number of young at a time. Testes are abdominal in position. There are a large number of mammary glands arranged along an axis on the ventral surface of the abdomen and thorax. Limbs are pentadactyle and the digits are provided with claws that help in burrowing. They possess the primitive number of teeth (44) and show no differentiation. Placenta is discoidal and haemochorial type. Most insectivores, hibernate during winter.

Vibrissae : stiff coarse hairs near mouth of most mammals and in human nostril.

Discoidal placenta

As the embryo and chorion enlarge only those villi which are in contact with enometrium remain and others degnerate. The region still in contact with endometrium forms the disc shaped placenta. The manner in which the trophoblast interacts with the maternal tissue largely determies the morphology of placenta. Very intimate contact between the mother and embryo is achieved in the placenta found in the humans and rodents. Thus in the animals in which the villi are produced only from a part of allantochorion taking the form of a disc or plate the placenta is called discoid.

Rodentia far outnumber the other placentals in the number of species and individuals. Rodentia represents one of the largest and most important orders of Eutheria. It includes about 3000 living species. This group is of enormous economic importance. Rodents account for nearly 30% loss of food grains in India. They destroy both the standing crops and the stored food grains. They are very bad house pests. They also act as vectors transmitting diseases like plague. Teeth are modified for gnawing. Their dentition is characterised by the presence of strong chisel shaped incisors with persistent pulp. The incisors do not form roots, and continue to grow throughout the life. Canines are absent. Rodentia are mostly herbivorous. The order includes all types of rats, gerbils, mice, guinea pig, squirrel, beevers, porcupine etc. They are found everywhere. Some of them are amphibious but not completely aquatic. They are polyestrous and cycle throughout the year. They give birth to 10-12 young at a time. They are most harmful mammals. However, they are used as laboratory animals for research work.

Man is the most **intelligent** of all mammals. Man and his near relatives, the apes and monkeys are relatively more smart and intelligent, hence the name **Primate** (chief) given

Haemochorial placenta

The chorionic villi grow deep into uterine tissue and break down the maternal blood vessels until they are bathed in maternal blood. This kind of placenta is called **haemochorial** placenta in which a thin membrane separates the embryontic blood within the capillary of the chorionic villus from the maternal blood in the crypts of the endometrium. It is through this membrane that the exchange of gases takes place; oxygen and nutrients pass from blood to the embryo and CO_2 and other wastes from the foetal blood move across the membrane to mothers' blood.

Intelligence

(1) Intelligence is a quality of behaviour that demonstrates the degree to which an organism is able to learn quickly and to adopt responses rapidly and effectively when faced with new situations.

(2) The ability to manipulate symbols and to grasp abstract relationships in problem solving and to respond flexibly to changing demands within a given context. Human intelligence encompasses the collective repertory of cognitive powers possessed by an individual which can be brought to bear on the solution of difficult and complex problems such as reasons, insight, foresight, judgement or imagination.

to this order. However, it should be kept in mind that not all primates are equally intelligent. Primates have evolved from a primitive group of placentals, most probably the insectivores. The liberation of forelimbs from the function of locomotion is the most striking feature of Primates. Monkeys and other primitive primates, however, are quadripedal. Fore-limbs of man and apes are used as hands. This has given them the ability to handle and manipulate. They are able to coordinate their visual perceptions. Primates are the most unspecialised eutherian mammals. This seems to be an advantage rather than being a disadvantage. Having evolved from the most primitive placentals they have evolved highest degree of intelligence ever to have attained by any animal so far in evolution. Primates are widely distributed in all the continents except Australia.

Earliest Primates are the **Prosimians** (premonkeys). The Prosimians (ex. lemurs, tarsiers etc.,) are found in Africa, (Madagaskar and South Asia). Three major groups evolved from Prosimians 1) **Ceboidea** (new world monkeys) found in central and South America only, 2) **Cercopithecoidea** (old World monkeys) found in warmer parts of eastern hemisphere except Australia, 3) the top group **Hominidae** (man-like) includes different species and races of man (all extinct except **Homo sapiens**). The brain case of man is twice as big as those of apes. Man is bipedal, walks erect and has scanty hair covering on the body compared to other Primates. The greater toe is not opposable as the thumb in hands and as found in monkeys.

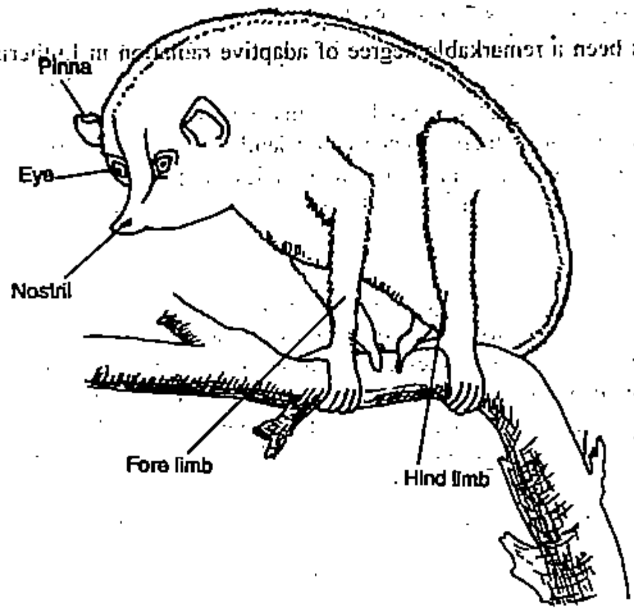


Fig.4.35: Loris.

Lemurs are found in Madagaskar. They have a long prehensible tail. **Loris**, (Fig. 4.35), does not possess a tail, is found in South India. Loris feeds on plant food and small animals, and exhibits oestrous cycle as opposed to menstrual cycle of all other Primates.

Tarsier another Prosimian is found in the Phillipines. It grows to the size of a cat. It has large eyes. It has pads on toes. Marmosets, another Prosimian lives in central America (Brazil). They grow to the size of a small squirrel. The body is covered by soft fur. All the digits are provided with claws except the great toes which have nails.

Ceboidea are confined to American continents. Both the great toe and the thumb are opposable. All digits are provided with nails. Tail is long and prehensible. It helps in climbing trees by curving round the branches. The two nostrils are set far apart. Example : squirrel monkey; spider monkey, howler monkey, etc.

Old world monkeys have a long tail but it is not prehensible. The two nostrils are close together. They possess cheek pouches. They live mostly in Africa and Asia. Examples : Baboons, Macaqua, rhesus monkey, (Fig. 4.31) etc.

Apes belong to the suborder Pongidae. Tail is absent, fore limbs are longer than the hind limbs and walk on two feet. Example : Gibbon (***Hylobates agilis***) lives in South East Asia and East Indies, (Fig. 4.32). They are arboreal and omnivorous in diet. They grow to a height of 3 ft. They swing from branch to branch with their fore limbs and walk on ground on their hind limbs.

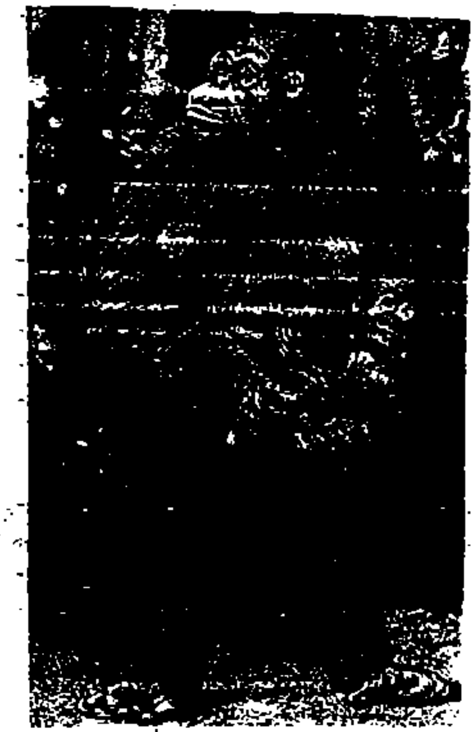


Fig.4.36: Orang-utan.

Orang utan (*Pongo pygmaeus*) lives in Borneo and Sumatra, (Fig. 4.36). They are herbivorous. They live on tree tops and grow to a height of 3 ft. Brain is smaller than that of man.

Fig.4.37: Gorilla.

Gorilla *(Gorilla gorilla)* is found in western Africa. (Fig. 4.37). It is the largest of the apes. It is vegetarian, large and bony, and grows to a height of 5.5 ft. and weigh about 500 lbs. It builds nests and lives in small groups.

Fig.4.38: Chimpanzee.

Chimpanzee (*Pan troglodytes*) is also found in western Africa, (Fig. 4.38). It resembles gorilla but, smaller in size with shorter arms and is relatively more intelligent.

Fig. 4.39 : *Pteropus* (Flying-fox).

Bats belonging to the order **Chiroptera** are adapted to a life of flight. The digits of the fore limbs are elongated. A stretch of leathery skin extends between the fingers, between the fore and the hind limbs and encircles the hind end of the animal often including the tail to form the wing. There are hooks on the toes with which they hang themselves from branches or from any perch, when not flying. They hang up side down. There are about 600 species of bats. The order is subdivided into two suborders based on size and diet. **Megachiroptera** includes large bats which are mostly fruit eaters, (Fig. 4.39). **Microchiroptera** includes small bats which are insectivorous. (Fig. 4.8). A few species of bats are sanguivorous and suck the blood of other animals like horses, cattle etc. These bats are called vampires. Vampires act as vectors transmitting diseases like rabies, yellow fever, chaga's disease and trypanosomes among horses. Bats are known for their special sense of **echolocation**. They move around and guide themselves by emitting high frequency sounds and then detecting these when they are reflected back off objects in the surrounding medium. This is a type of radar mechanism which bats seem to have invented long before man discovered it. They have eyes and can see well. Most of the bats are nocturnal and depend on echolocation to find their way, discover enemies prey/food and obstacles. The living mechanism of echolocation is said to be more efficient than man made radars. The sonar system of bats is millions times more efficient and more sensitive. Moreover, they have the advantage of millions of years of evolutionary experience. Bats can find their insect prey in complete darkness, even when the insect does not produce any sound that can be heard by man. Bats can get a complete picture of their surroundings through echo of the sound.

Echolocation : is the determination of the position of the object through the sound reflected by it. Bats use this mechanism to locate its surroundings.

Cetacea comprises mammals adapted for aquatic life. This order includes more than 100 species. Whales are the largest living animals. The fore limbs of whales are modified into flippers to help in swimming. Hind limbs have been lost. Tail is horizontally flattened into a fluke like structure with two lobes. It also helps in swimming. Eyes are small, external ears are absent, they have sparse hairs. But they have a thick subcutaneous layer of fat called blubber which provides insulation in the absence of hairs. Teeth have undergone degeneration and numerous in number. Whale bone whales have structures called whalebone on the sides of the upper jaw instead of teeth. Whalebone is made up of parallelly arranged horny plates. Whales feed on small animals of the sea. The whalebone helps as a sieve to drain water retaining only the animals in the mouth on which it feeds. Whales grow to a length of 105 ft. Blue whales are the largest. They weigh 125 tons.

Order Carnivora consists of mammals adapted for flesh eating. There are both land and aquatic forms. The teeth are modified for flesh eating. The well developed canines and the **carnassial** teeth help in capturing prey and tearing their flesh. The digits are provided with retractable claws as in cats. Incisors are small; Lion, tiger, cheetah, wolf, fox, leopard, dog, cat, mongoose, (Fig. 4.40) are examples of land forms, seals of marine forms, (Fig. 4.41); Otters and Dolphins of fresh water forms, (Fig. 4.42 & 4.43). Carnivores are adapted for digitigrade mode of locomotion. Bears (Fig. 4.44) are an exception which use plantigrade type of locomotion. Seals and walruses (sealion) are adapted to acquatic mode of life. Both pairs of limbs are webbed and help in swimming. The body is fish-like. Most of them are marine and a few are freshwater forms. Walruses are comparatively larger and have large canines in the upper jaws. The canines are used by Walruses to dig sand to search burried crustaceans and molluscs which form its food.

Walrus : large sea animal of the arctic regions with two long tusks.

4·40

Fig.4.40: *Herpestes* **(Mongoose).**

Fig.4.41: *Phoca* **(Seal).**

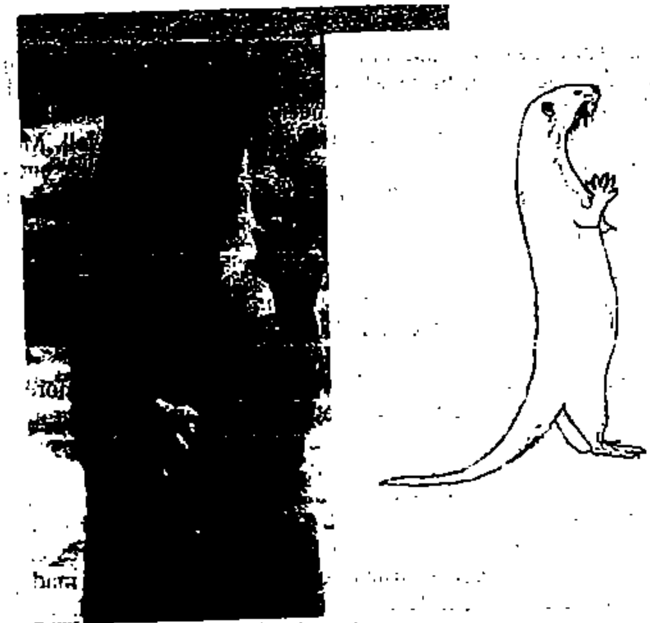


Fig.4.42: ***Lutra*** **(otter).**

Fig.4.43: Common Dolphin (*Delphinus delphis*).

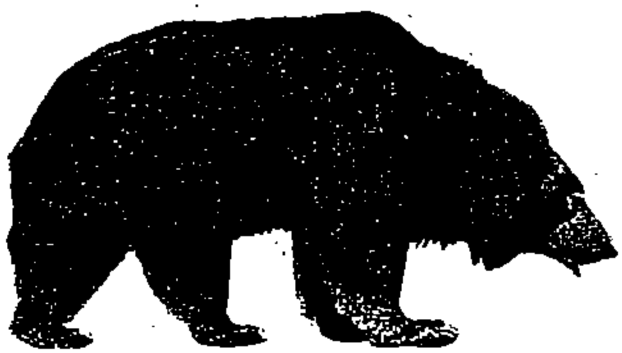


Fig.4.44: ***Malursus ursinus*** **(Sloth Bear).**

Elephants are members of the order **Proboscoidea** having the largest land dwelling animals today. They grow to a height of 16 ft and weigh nearly 1500 lbs. They are found in Africa and Asia. The hairy covering on the body is sparse, skin is loose and thick and is provided with large muscular proboscis (trunk). Nasal openings are present at the tip of the proboscis. Upper incisors of the male are modified into tusks. Canines are absent. There are 6 pairs of large grinding molar teeth on each jaw. But only one pair is functional at a time. Their skull is massive and has thick bones that have air spaces making the skull light. Elephants have the longest gestation period of 23 months.

Fig.4.45: Bison (Gaur)

Fig.4.46: *Deer* (Kashmiri stag or Hangul, *Cervus elaphus hanglu*).

Fig.4.47: Sambar *Cervus unicolor.*

Fig.4.48: Antelope (*Gazella gazella*)

Peccary : Kind of wild pig found in America.

Hoofed mammals (**Ungulata**) usually live in open grass lands. They are herbivorous and cursorial in habit. The group is called ungulata because of the presence of hoofs at the tip of their digits. There are two groups based on the number of digits on their feet; **Artiodactyla** with even number of digits (2 or 4 digits), e.g., pig, peccaries, hippopotamus, camel, llamas, cattle, buffalo, bison (Fig. 4.45), sheep, goat, deer (Figs. 4.46 & 4.47), giraffe, antelope (Fig. 4.48) etc., and **Perissodactyla** with odd number of digits (1 or 3) such as horse, tapirs, rhinoceros, donkey etc., Artiodactyla are called big game animals because they are hunted by both man and predators alike for food and sport respectively. Some of the artiodactyles like camel, deer, pronghorn antelope, cattle, buffalo are ruminants. This is an adaptation for life on open grass land habitat where security is not available. They have learnt to swallow as much food as possible in a short time as possible without wasting time on chewing and then move to a secure place, regurgitate the food from the stomach, chew it completely at leisure and reswallow it to be digested and assimilated. They have specially modified stomach to help in this habit (Fig. 4.49). The stomach is four chambered. It consists of **rumen**, the **reticulum**, the **psalterium** and then **abomassum**. Rumen is the largest chamber used for storing unmasticated food. This habit is called rumination.

Camel (one humped) lives in Arabia and Indian desert. Its another species (two humped) lives in Gobi desert north of Himalayas. They are beasts of burden. They possess splayed feet which help to spread their weight on sand or snow. The hump is a fat storing organ and the stomach stores water. This enables them to go long distances on small ration of food and water.

Mule is a **a man made Ungulate**. It has been in the service of man for over 3000 years. Very few man created animals have been as valuable and biologically as interesting as this mule. It assists man in transporting men and materials in the most inaccessible places. Mule is a hybrid obtained by crossing a male donkey with a female horse. Male mules are sterile, whereas female mule is capable of reproducing and give birth to foals (young horses). The hybrid between the male horse and the female donkey is called a **Ninny** and it is not as useful as a mule. The mule which served man for thousands of years faithfully is on the verge of disappearance under the impact of mechanisation. Mules have played a worthy role in human affairs and have helped create history. They really deserve a better fate as at present than an obscure drift towards oblivion.

The head gear of hoofed mammals is very interesting. They are provided with horns and antlers. They appear similar but are fundamentally different. These cephalic adornments appear in the members of five families of Ungulates : **Rhinocerotidae** (example, rhinoceros), **Bovidae** (example, cattle, antelope, goat), **Antilocapridae** (example, pronghorned antelope of America), **Cervidae** (example, moose, caribou, elk, deer) and **Giraffidae** (example giraffe). Horns and antlers generally occur in Artiodactyle ungulates with the sole exception of rhinoceros which is a Perissodactyle. Rhinoceros are provided with two (African species) or one (Asian species) permanent midline nasal horns. Bovidae are provided with horns which are symmetrical and permanent. Pronghorn antelopes possess a pair of symmetrical horns which are shed and renewed every year. Cervidae also possess a pair of annually renewable antlers. Giraffes have paired cephalic protruberances nature. Antlers occur in the males only. Antlers are complex in structure and ornate in shape. They have been coveted by people as trophies. But they have no utility value and some times are a nuisance and an encumberance to the animals. Antlers get entangled among the branches of trees or with the antlers of rivals and expose them to dangers of becoming easy prey to predators. Antlers are very delicate and they are used by males during mating season to win harems of females. Evolutionists describe antlers as an uneconomic experiment of nature. Horns on the other hand are permanent structures and present in both sexes. They do not regenerate as do the antlers. Horns serve animals as effective weapons of offence and defense. Horns are made of keratin and are supplied with blood capillaries and nerves. Horns are not ornamental structures. They may be curved, twisted, coiled, helical, zigzag and straight with pointed ends and may be used as spears to gore to death an enemy or a rival. The horns of rhinoceros are made up of hairs, a solid keratin structure. The horns of cattle are hollow and are mounted like a shoe on spike like structure called os cornua.

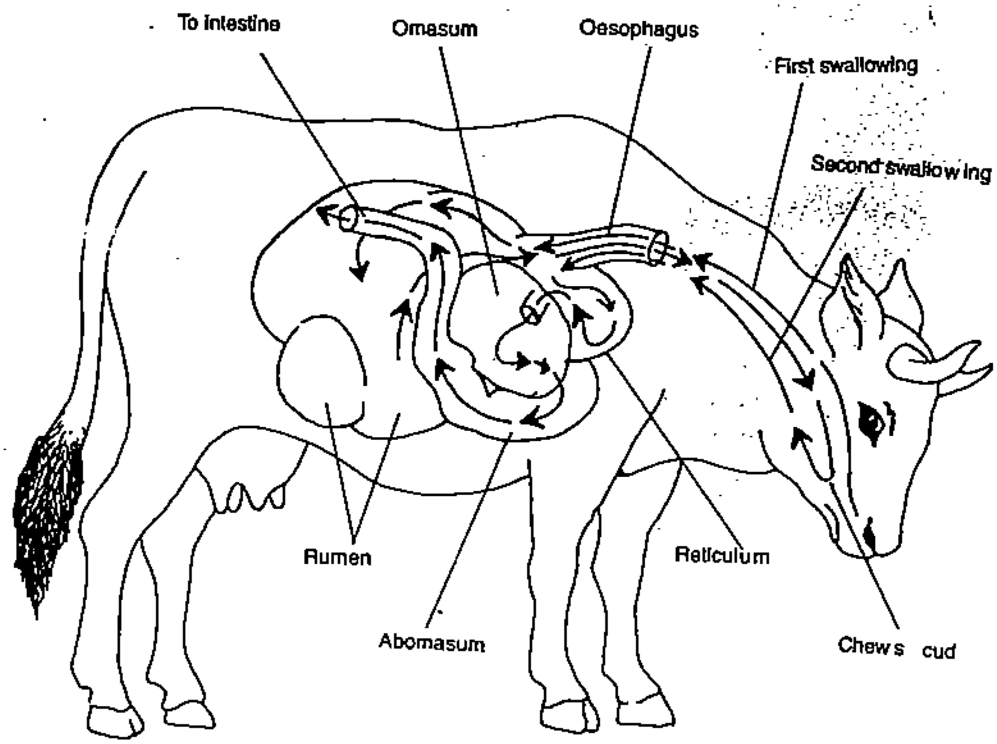


Fig.4.49: **Ruminants such as the cow have special digestive structures for the digestion of cellulose. Digestion of cellulose begins in the large rumen, where vast numbers of protozoans and bacteria begin the breakdown of cellulose under anaerobic conditions. The products are regurgitated as the cud, rechewed and swallowed, this time entering the reticulum (follow the arrow). The partially digested mass then enters the omasum and finally the abomasum (the true stomach) where digestion of the microorganisms themselves begins. Digestion is completed in the small intestine.**

Cradle : place where something is born or begins.

4.3.4 Economic Importance

Mammals formed the cradle for the evolution of man. Man belongs to the class Mammalia. They seem to have provided both material and opportunity for his physical, biological and cultural evolution. They have provided the biological environment. They have made his life possible and feasible. Man gets most of his food and clothing from mammals. Ancient man completely depended on them for his food and clothing. Flesh of cattle, buffalo (beef), sheep, goat (mutton), pig (pork) and camel are used as food by man. They also provide milk and milk products which form good nourishment. The hide of these and many other mammals is tanned and used in the manufacture of leather whose products like foot wear, belts, purses, bags, suit cases and warm wearing apparently are used by man. Buffaloes of North America sustained the civilization of

American native Indian populations. The thick blubber of whales and seals is used as fuel oil and in the manufacture of soap and detergents. The soft fur of minks, beavers, fox, musk rat, opossums are used in manufacturing warm garments coveted by the aristocrats and the rich. An industry to breed them has been started providing job opportunities to many people. Many mammals are hunted not only for food but also for recreation in the name of sports. That is why most wild populations of ungulates come to be called Game animals. The result is that many of them have become extinct or are on the verge of becoming extinct. Most of these rare species could now be seen today only in sanctuaries or zoos. Zoos are established to provide recreation to man in the name of education and in the garb of conserving many of them. Many wild animals provide man with precious material like ivory. Ivory is used in the manufacture of jewellery, articles of art and sports (Billiard balls, Carrom strikers, pens, combs, etc.,). Horns are used in preparing ornamental articles. Horn also is a source of protein. Antlers of deer, head and proboscis of elephants, legs of elephants are used to prepare ornamental articles and precious furniture. Many wild mammals are stuffed and exhibited at homes and museums. Many mammals like buffalo, cattle, donkey, camel, horse help man in transporting them and their material, draft and farming. Dogs are used for dragging wheel carts on snow. The wool and hair of many mammals like sheep, goat etc., are spun into yarn, woven into fabrics to provide warm clothing to people living in colder climates. Dogs, cats and otters are used as pets. Dogs are trained to help man in providing security and to guard house, farm and herds of sheep and goats. Many mammals are helpful as laboratory experimental animals (rats, guinea pigs, dogs, cat, cattle, horse etc.,). Horse and dog racing is a common sport and recreational activity which has developed into an industry by itself breeding them.

As many mammals are useful to man a number of them are harmful and injurious also. They cause physical menace, act as source of diseases like plague, typhus, rabbit fever, ...hosis and rabies. Many predators kill and feed on domestic mammals and many some ...ers posing danger to man.

... the mammal to which

.en in

words given in the brackets.

a. Horses possess.........at the end of their digits. (nails, claws, hoofs)

b. Man has.........on his digits. (hoofs, claws, nails)

c. Carnivores are provided with..........on their digits. (nails, claws, hoofs)

d. Some mammals spend their winters in ....in temperate zone climate. (aestivation, hibernation, circulation)

e. Nails, hair, claws and hoofs are the................exoskeleton of mammals. (endodermal, mesodermal, epidermal)

(iv) State in the box provided whether the following statements are True (T) or False (F) :

a. Rats are useful mammals. ☐

b. Elephants are the largest land animals. ☐

c. Blubber is found in monkeys. ☐

d. Carnivores are grass eating mammals. ☐

e. Mole is burrowing Insectivore. ☐

f. Whale lives in the sea. ☐

g. Kangaroos are natives of India. ☐

h. Cows provide milk. ☐

i. Horse is a ruminant mammal. ☐

(v) Match the common names of the following mammals in group A with their generic names in group B,

Group A		Group B	
a.	Duckbill	v.	Macropus
b.	Echindna	w.	Homo
c.	Kangaroo	x.	Ornithorhynchus
d.	Man	y.	Hylobates
e.	Gibbon	z.	Tachyglossus

4.4 EVOLUTION AND AFFINITIES

Mammals have evolved from mammal—like reptiles, the Synapsida, during late Triassic of early Jurassic period. These early ancestral forms showed both reptilian and mammalian characteristics. They were very small and were no match to the giant reptiles of the day. They evolved simultaneously with the flowering plants, crocodiles and turtles. Mammals represent the highly evolved vertebrates. Fossil record of early mammals is scanty. The earliest known mammal—like reptile was Cynognathus. It was of the size of a carnivorous dog. The rate of evolution in the beginning was very slow. This is attributed to the unavailability of habitats since most of them were already extensively occupied by reptiles. The reptiles were well adapted and could not be easily dislodged. Some amount of diversification in evolution of mammals appears by late Jurassic. Mammals of Cretacious were very small, about the size of mice. The fossils available are few and far between and only parts of skeletons are available. Examination of the dentition which has been well preserved indicates evolution of mammals along three lines. This shows diversification in their feeding habits. There were herbivores feeding on fruits and seeds, carnivores feeding on other animals and insectivores feeding on insects and small animals. Mesozoic has been described as the golden age of reptiles. The mammals living in that time appear like specialised descendants of reptiles. Mammals managed to live through Jurassic and Cretaceous inspite of the fierce competition of reptiles of the day. Better and efficient physiology and reproductive strategy seems to have helped the mammals to survive. Cenozoic period, the next geological age was characterised by continental drift and wide spread erosion. Consequently not many fossils of the period are available. Some fossils of Paleocene are found, mostly from north American continent. By late Paleocene mammalian fossils become available in Asia, Europe and South American continents. By this time radiation of mammals had started. Thus Paleocene was a period of transition in the history of earth, from the age of reptiles to the age of mammals. Dinosaurs surprisingly disappeared by the dawn of Paleocene and suddenly the continental fauna became dominated by mammals. The Paleocene mammals are mostly represented by Marsupials and Insectivorous mammals. Herbivorous ungulates, Carnivorous predators and small monkey like forms, rodents and other forms of mammals appeared by the end of Paleocene. By this period it looks as though mammals had inherited the earth. Disappearance of most mesozoic reptiles vacated many habitats and mammals were quick to grasp the opportunity and occupy them. Paleocene was a period of extensive radiation and divergence of mammals. In the end mammals outran the reptiles by occupying all the available niches. At this point you should remember that mammals did not cause the extinction of reptiles. Actually extinction of reptiles provided opportunity for mammals to diverge and to expand. At about this time one of the most important and striking changes in the evolution of mammals occurred. viz., increase in the size of brain as evident from the cranium size in the fossils available.

Plancenta : Organ lining the womb during pregnancy by which the foetus is nourished. It is expelled with the foetus and the umbilical cord following birth. Mammals having placenta are called **placentals.**

Marsupial : Animal of the class of mammals the females of which have a pouch in which to carry their young. which are born before developing completely e.g. Kangaroos.

Both marsupials and placentals seem to have evolved independently from a common ancestor during the cretacious period. In the course of evolution. Placentals became dominant because of their superior intelligence. Insectivores represent the hypothetical eutherian ancestor. They are small in size with plantigrade type of locomotion. They come nearest to the placental ancestor with primitive generalised characters. Living reptiles of today that show many specialisations cannot be the stem reptiles from which insectivores may have evolved. Presently at what point mammal-like reptiles - **Therapsids** - ceased and mammals began, it is impossible to say as there was no sudden transformation of reptiles into mammal, and no dramatic event took place to mark the appearance of the first member of our class.

More moderate placentals appeared in Eocene and continued their diversification during the Oligocene. By Oligocene most of the modern placentals were already in existence. By Eocene and Oligocene the fauna of the earth, particularly the mammalian fauna had an exotic look. It is during this time that ancestral carnivore—like Sabre tooth, the ancestral forms of hoofed mammals like the **protylopus**, the ancestral camel, **Eohippus**, the ancestral horse, the **Moeritherium**, the ancestral elephant appeared. Insectivores are the ancestral forms of all eutherian mammals and a large numbers of modern descendants who we hardly recognise as our relative. Insectivores, therefore, include four rather different types. Firstly then typical living forms comprise such as shrews, moles and hedgehogs. The second form includes the living tree shrews perhaps the most primitive of living eutherians and fossils so generalised that they can not be put in any other placental order. The other two forms of insectivores include small divergent offshoots from the insectivores stocks, the elephant shrews and flying lemurs.

Luckily a complete list of fossils depicting the evolutionary history of camel, elephant and horse is available. It is possible to trace their evolution step by step with changes in the nature of habitats that were responsible for the changes. North American continent was the stage for these dramatic events. Evolution of camel and horse occurred in north America and their fossils are available in abundance there throughout Cenozoic era. But ironically they disappeared in the late Pliocene from the north America (Fig. 4.50). Surprisingly no native camel and horse occur in north America today. The evolution of horse has taken place from **Eohippus** through different geological ages and stages to the modern horse **Equus.** Similarly **Protylopus** from Eocene, **Poebrotherium** from Oligocene and **Procamelus** from Miocene and Pliocene have been found. **Moeritherium** from late Eocene measuring just 2 ft in height was the ancestor of elephants. It gave rise to

... measuring about 6 ft, growing to a size of 11ft of the modern elephant, the **Loxodonta** of Africa and **Elephas** of Asia. The history of the evolution of these herbivores spans a period of 60 million years and 350 recognisable species in between.

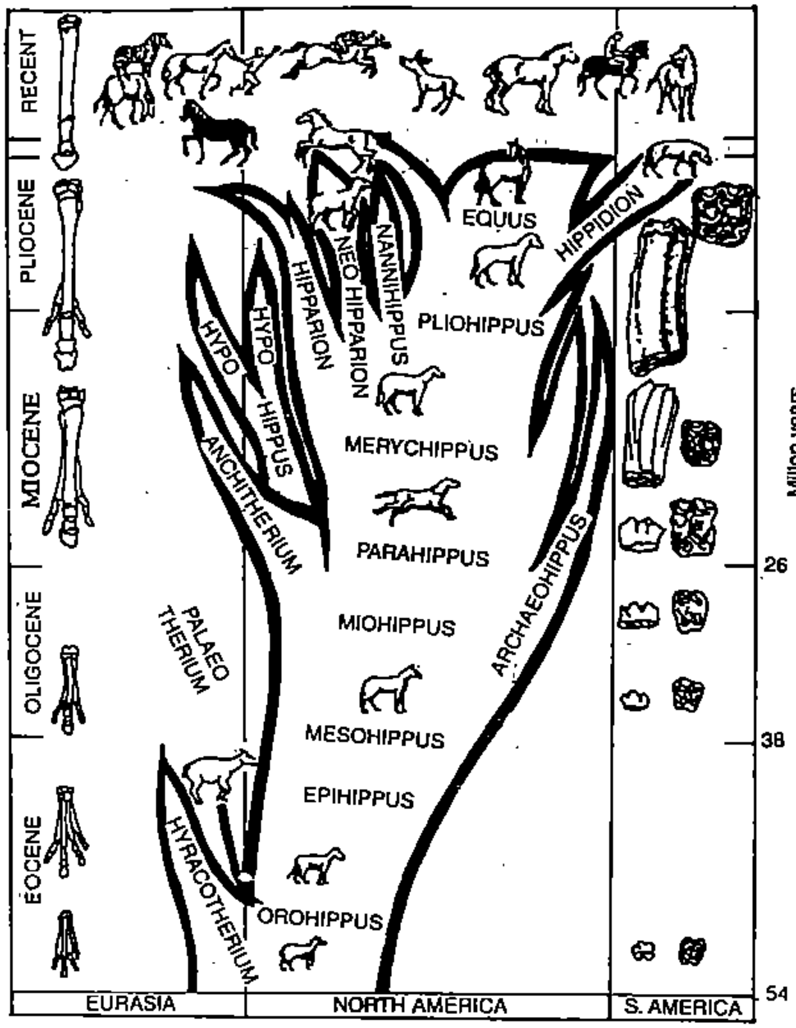


Fig.4.50: Table to show the evolution of horses. Then approximate condition of the limbs and teeth during each epoch are shown respectively to the left and right.

It is not so easy to trace the evolution of man. Man and apes seem to have had a common origin and they diverged early to evolve on different lines about 25 million years ago. All the seemingly similar ancestors who are on the direct line of evolution of man are grouped into a single family, the **Hominidae.** The mammals included in this family are commonly called the hominids. The important feature in the evolution of hominids is the development of upright posture and life on the ground. Apes are the nearest relatives of man. They are adapted for a life in forests. So they had to develop long muscular arms to help for a life among the trees; climbing and swinging from branch to branch.

The oldest known common ancestor of man and apes is **Proconsul.** He lived about 25 million years ago. A series of fossils found in different parts of the world have helped in reconstructing the possible lines of evolution of man. **Ramapithecus** discovered in India represents a fossil man. He is recognised as the next in line in the evolution of man. He is believed to have lived about 10 to 15 million years ago (Fig. 4.51). There is evidence from Africa which shows several distinct lines of creature resembling man. The bones of **Australopithecus** (southern ape) probably represent three species. None of them actually contained our ancestors, but evolve paralled to them. The first specimen found from Africa was a juvenile skull and was named **Australopithecus africanus.** Other fossils ferred to the genus Australopithecus which have been found in East Africa date back at 450-500 ml, little larger to body size of an ape. These fossils have been found in East Africa associated with stone tools. There is an evidence that they walked on two legs.

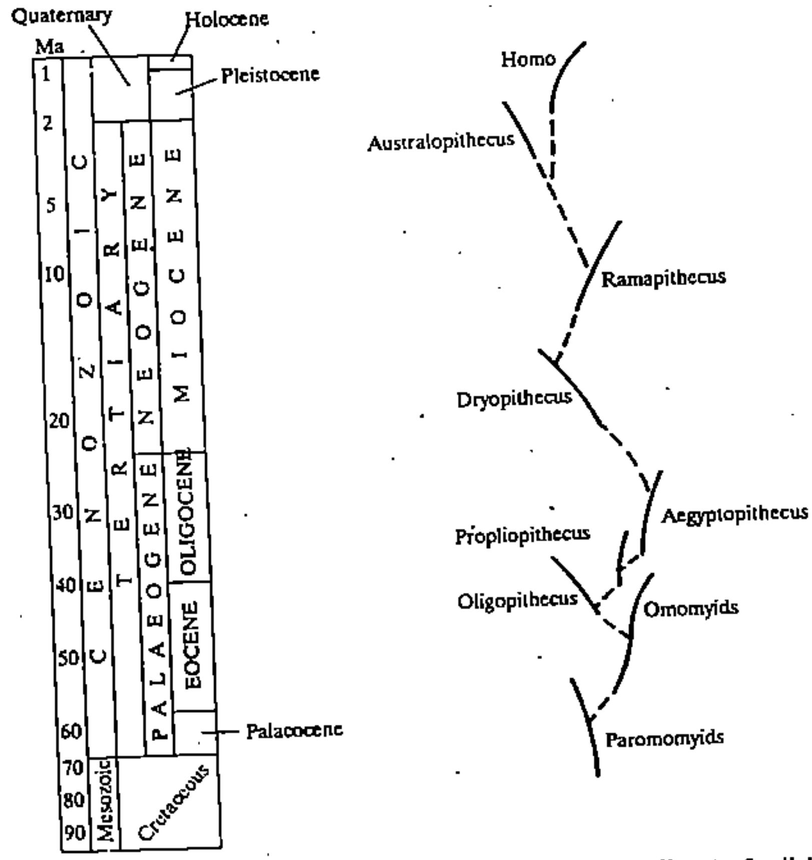


Fig.4.51: Distribution and hypothetical phylogenetic tree of taxa leading to fossil hominids.

The area at the back of skull for attachment of neck muscle was smaller than in apes while mastoid process was larger. The foramen magnum is at the centre of the skull. These features indicate that the head was balanced on the neck rather than hanging forward like apes. The mandibles were larger than in modern man but teeth form a rounded arcade. The incisors are vertical and the canines spatulate and smaller than in apes but larger than the man. The molars are relatively larger than in man but the pattern of replacement was like that of man. Some workers are of the view that **Australopithecus** may have run rather than walked, because the iliac blade faces dorsally and the middle metatarsal was thickened rather than the first as in Homo. Other workers believe that bone of these fossils be within the human range. However, fossils record show that a considerable variety of almost human creatures existed in Africa. The first true hominids found in fossil records are usually assigned to the genus **Australopithecus** (from **Australis**, Southern and **pithecus**, "ape" southern because the first specimens were found in south Africa). The origin of erect posture is recognised to be an important feature in the evolution of man. Erect posture is in fact biologically disadvantageous. It exposes underbelly to dangers and hinders fast and easy movement. However there is one great advantage; it liberates fore limbs from the shackles of being used in locomotion. It provided the opportunity for the evolution of a species with free hands. The hands could now be put to other uses like defending himself against enemies. Free hands made possible holding of articles like tools and weapons. **Australopithecus** seem to have been tool makers and tool users. Remains which can be recognised as tools have been found with these fossils. The ability to hold articles seems to have contributed greatly to the rapid evolution of brain. Erect posture bestowed another advantage of looking from a greater height and to look longer distances. Tight grip allowed use of tools and/or of weapons. They could defend effectively, and could pick flower, fruits and leaves from plants, dig roots and kill other animals for food. Therefore, development of erect posture and free hands are recognised as the most important events in the evolution of man. Modern man is included in the genus **Homo**. The genus **Homo** evolved about 500,000 years ago. Java man was the first fossil of **Homo** to be discovered in Java.

Java man may be classified as **Homo erectus** (originally described as **Pithecanthropus erectus**). Specimens of these fossils have been found in Asia, Africa and Europe. Later similar fossils were found in Africa and Beijing (old Peking). All these fossils have been included under one single species **Homo erectus. Homo erectus** stood erect, a little taller than **Australopithecus**, about 5 ft in height. Brain case of java mass was larger: The recent ancestor of man has been identified as **Neanderthal** man. He lived throughout most of Europe, and also in parts of Asia and Africa, about 1,60,000 to 60,000 years ago. He must have been a member of a race of **H.erectus** or a new species of the genus **Homo**. He seems to have lived and flourished in cold harsh environments (Fig.4.52). Evidences indicate that he used weapons to kill animals for food. He had developed some sort of culture and seems to have burried his dead relatives with ceremony as indicated by the evidences at the burial site. Brain was larger than that of the modern man, and seems to have been intelligent. Suddenly disappeared some 30-40,000 years ago. Neanderthal man is considered by some authors as a separate species intermediate between **H.erectus** and **H.sapiens** the modern man. It is considered to be next in the evolution of **H.sapiens**. Neanderthal man was succeeded by Cromagnon man. **Cromagnon** man resembled modern man in size and his general body build. He seemed to have been a great hunter. He used stone weapons and tools like spear, arrow heads and knives. He had developed the art of painting. He has left many evidences of his painting ability in the form of pictures of animals in the cave walls all over France and Spain.

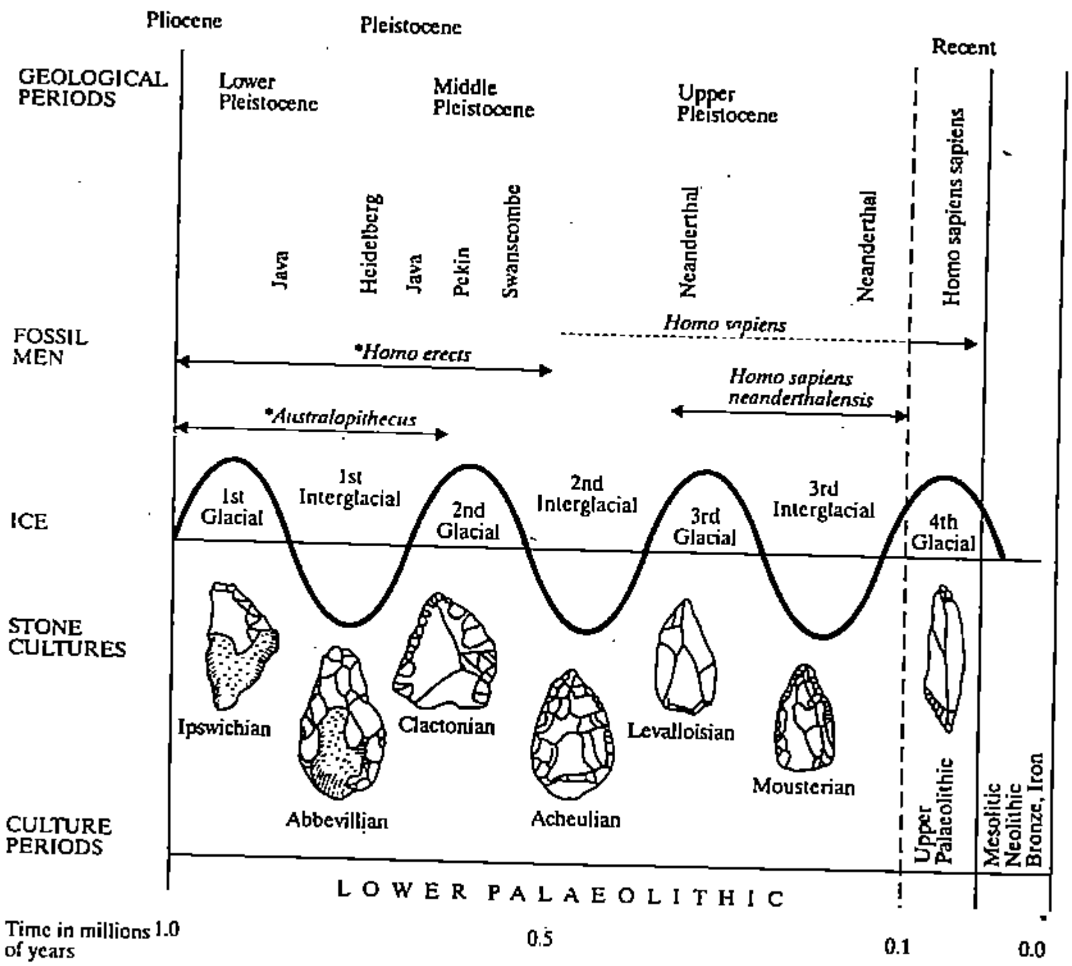


Fig.4.52: Diagram of Pleistocene time and some stages of human cultural evolution.

Cromagnon the cave dwelling hunter evolved into a village dwelling agriculturist, the modern man. This in brief is the evolution of man. The evidences are scanty. Full skeletal fossils have not been found. Pieces of jaw, cranium, teeth and other evidences found as fossils have been pieced together in reconstructing fossil individuals and trace the possible lines of evolution of man. From these studies it becomes evident that the EVOLUTION OF MAN IS NOT ONLY AN ACHIEVEMENT OF THE PAST BUT ALSO A PROMISE FOR THE FUTURE. It has to be seen whether man will keep this promise or will perish as other animals did before his making way for a better species.

The early history of man is thus not complete. It is half evidence and half conjecture. He seems to have lived in the beginning in Africa in groups as do some of the natives even today in Africa as tribes. They spread to other continents in search of better opportunities.

It is estimated that about one million years ago total human population may have been just 12,500. By the dawn of civilization by about 10,000 years back the concept of family seems to have taken root. Four distinct races of **Homo** sapiens are recognised today though population biologist Dr. Dobzonsky recognises seventeen races. The four races are **Australoid, Caucasoid, Mangoloid** and Negroid: Australoid with curly hair, moderately broad nose, and brown skin; Caucasoid with wavy hair, narrow nose and white skin; Mongoloid with straight hair, moderately broad nose and yellow-brown skin; Negroid with wooly hair, broad nose and black skin. So the races of man have been identified on the basis of their skin colour, hair texture and facial structures:

The human species is still young. If the life span of the planet earth is measured in hours and assumed to be 24 hours man has appeared just five minutes ago. Man seems to have been well adapted to his environment. This shows amazing speed of his evolution He has developed the capacity to reason and his greatest asset is curiosity. These qualities should stand by him today to help controlling mass destructive weapon environment polluting industries, uncontrolled population growth and unabated destruction of nature, too much interference with his surroundings all in conflict with nature. If he is not cautious he may be doomed to extinction.

If a species of animal has to survive it must get adequate food, protection against enemies and competition. In the case of man the immediate need is to control galloping population growth, to produce more food, control nuclear weapons and disease producing organisms which are threatening to destroy not only the very existence of human organism but all other organisms on the earth. He must learn to live in harmony with the environment. Man must learn to allow other organisms to live. He must realise that other living beings also have equal rights if not more to live. The philosophy of peaceful coexistence among people should extend to include all other living organisms.

SAQ 3

1. Match the names of mammals given in group A with the names of their earliest ancesters given in group B.

Group A		Group B	
a.	Man	w.	Eohippus
b.	Camel	x.	Proconsul
c.	Horse	y.	Protylopus
d.	Elephant	z.	Moeritherium

2. The various fossil ancestors of man are given below. Rearrange them in the order of their appearance in the evolution of man.

   Homo sapiens

   Homo erectus

   Ramapithecus

   Australopithecus

   Proconsul

   Cromangnon man

   Neanderthal man.

3. What is the probable reptilian group from which mammals have evolved? Select the correct one from the names given in the brackets. (Crocodilia, Lacertilia, Synapsida).

....

4. Mention the name of the earliest known mammal-like reptile by selecting one from the lists given in the parenthesis. (Ornithorhynchus, Eohippus, Cynognathus).

....

5. Tick mark (✓) the primitive group of mammals which show both reptilian as well as mammalian characters (Metatheria, Eutheria, Prototheria).

....

4.5 THREATENED SPECIES IN INDIA

Planet earth has plenty of resources like soil, forests, water, wild life, minerals etc., This has helped the origin, evolution and growth of life on this planet. Most organisms have tended to use these natural resources for their existence, survival and perpetuation. But after the appearance of man on the earth all this has changed. There has been over exploitation of these natural resources to feed, house and clothe the ever increasing millions of people. There is an inverse correlation in the increase of human population and development of natural resources. Human population is increasing unabated. There is wide spread destruction of habitat and pollution of whatever remains. Forests are not only a source of materials and home for the wild life, it is also the life and breath of nature. Forests constitute the major part of our environment other than the vast mass of water. Forest is a wealth. It regulates rain fall and thus indirectly the water resources of earth. It helps to hold the soil intact and prevents erosion. Besides increase in human population density dependent factors such as overpopulation of species (reproductivity) emigration, competition for resources, predation, parasites and diseases regulate the populations and cause threat to the existence of a species size. Competition can be between individuals of the same species or between individuals of different species. Factors causing threat to wild life have been discussed in Ecology course and for detailed information students are advised to refer to Block 4, Unit 14 of LSE-02.

The major constituent of wild life is the species of mammals; the predators, the game animals and some rare species like elephants, rhinoceros, slendor loris, otters etc., They add colour and grandeur to life on the earth and make life worth living. They provide variety and meaning to life on the earth. They help us understand ourselves. The natural resources are classified into two types; (1) the renewable resources like the flora and the fauna which constitute the biotic factors, soil and water which constitute the physical factors and (2) the non-renewable such as minerals.

The renewable resources are intricately interrelated and form ecological webs and chains or pyramids of numbers, energy, producers and consumers. A disturbance at one level would disturb the whole chain and dissociate the pyramids. Most organisms have tended to use these natural resources for their existence, survival and perpetuation. The able management of renewable resources is to use them prudently within the level of continuous renewal.

After the advent of man there has been a thorough change, a change for the worse. Forests constitute the primary renewable resources. These forests were the habitats of rare precious species of animals and plants. They constitute major part of our environment other than the vast mass of water.

There has been continuous encroachment of forests to make way for farm lands, urban expansion and development. In India these two human activities are posing danger to the very existence of wild life and in a way to the existence of man himself. This is the condition in the world everywhere. This has created habitat destruction, disturbances in climate. There has been either increased or decreased rain fall causing floods or famines. The recurring floods in the north eastern part of India and coastal south India are eroding forests in addition to destroying agricultural crops. The recurring famines resulting in death of millions of people in north Africa is a result of this. The main reason in India is deforestation and denudation of Himalayas foot hills and Western Ghats. Monsoons are failing or erratic causing famines, and unavoidable hardship on the wild life and is threatening their very existence. Elephants are killed by the poachers for their precious ivory and by the hunters in the name of sport. Rhinoceros are killed for their horns and slender loris for their eyes which are said to have aphrodisiac (exciting sexual desire and activity) powers. Predators are hunted and killed in the name of sports for recreation. With all laws on paper poaching continues unabated. Many species have become extinct in the near past and many more are on the verge of extinction. The wild life is a natural wealth, source of joy and happiness for a nature lover. Once upon a time wild life was in all its glory in India. They roamed the forests. They were admired and appreciated by natives and visitors alike. Rudyard Kipling was so fascinated that he has written profusely about wild life. Indians should be proud of them. Alas! we have lost all feeling and do not care what happens to our wild life. Kings and Princes hunted them down in the name of sports for their own recreation and probably also to please the British rulers during pre-independence era. Under the garb of promoting tourism habitat disturbance continues even today. Sanctuaries and safaries have been established to secure natural homes for the wild life. But it has not solved the problem. It has intensified and has caused disturbance in their reproductive physiology causing induced sterility. The result is dwindling numbers of wild animals. Conservation today is conservation of what little is left after all this human activity. It should aim to promote natural increase of their numbers and to provide protection to all of them.

Following is a short list of a few important endangered species of mammals in India (Red Data Book, issued by the International Union for Conservation of Nature (IUCN) located in Morges. Switzerland).

Carnivores :

1. Clouded Leopard (*Neofelis nebulosa*)
2. Snow leopard

   Both of Himalayan habitat and kashmir, once found in plenties, now being reduced to a few.
3. Tiger (*Panthera tigris*), Project tiger seems to have improved their strain.
4. Lion (*Panther leo*) today confined to Gir forests in Gujarat.
5. Civet cat (Viverridae family), caught and killed for the scent glands to improve aromatic industry.

Ungulates :

1. Rhinoceros (*Rhinoceros unicornis*). The single horned rhinoceros is today confined to Kaziranga Sanctuary in Assam. It faces hardships in the perennial floods every year.
2. Great Indian wild ass (*Equus heminous*) once plentiful in Kutch near Indo-Pakistan border in Gujarat.
3. Hangul, Kashmir stag (*Cervus elaphus*) confined to Dachigram-Kashmir.
4. Brow-antlered deer (*Sangai*) confined today to a 14 sq. km. marshy patch of land in Manipur sprawling Logtake lake.
5. Black buck (*Antilope cervicapra*) found in the planes of south India.
6. Musk deer (*Moschus moschiferus*) of the Himalayas.
7. Nilgiri Tahr (*Hemitragus hylocrius*), found in the tandra of Kerala; Evavikolum reserve.
8. Himalayan Tahr (*Hemitragus jemlahicus*) once widely distributed from Kashmir to Bhutan.
9. Swamp deer (*Cervus duvauceli*) found in Nepal, Dhudwa reserve in Uttar Pradesh and Kaziranga sanctuaries in upper Assam.
10. Himalayan markhor (*Capra falconeri*) distributed in north west Himalayas, a mountain goat.

Great Indian water buffalo (*Bubalus bubalis*), once plentiful in Assam, part of Orissa, Madhya Pradesh swamps.

12. Indian bison Gaur (*Bos gaurus*) also called white socks because of the presence of white ankle patches. Once plentiful in western ghats.

Others:

1. Pangolins the scaly ant earter, widely distributed.
2. Lion tailed Macaque found in Western ghats.
3. Malabar flying squirrel inhabits Kerala and Western ghats.
4. Slender loris restricted to South India.

SAQ 4

(i) Mention the two types of natural resources.

....

....

(ii) Tick mark (✓) which among the list of mammals given below are threatened species.

a.	ox	e.	slender loris
b.	camel	f.	sheep
c.	tiger	g.	dog
d.	rhinoceros	h.	black buck

4.6 SUMMARY

Mammals represent the highly evolved group of vertebrates. They are viviparous. They give birth to young ones and nourish them with milk a secretion by a special group of glands, the mammary glands hence the name Mammalia. They are warm blooded. The body is covered by hairs which form epidermal exoskeleton. There are sweat glands and sebaceous glands in the skin. Sweat glands secrete sweat. It is both a method of excretion and a method of keeping the body cool during hot weather. The feet are variously modified for walking, running, swimming and flying. They are widely distributed and found in all the continents and all the seas. The teeth of mammals are heterodont, thecodont and diphyodont type. The skull is bicondylar. The lower jaw is made of only one bone and is directly articulated with the skull. There are three pairs of ear ossicles in the middle ear. Heart is four chambered and consists of bicuspid and tricuspid valves preventing backward flow of blood from left and right ventricles to corresponding auricles respectively. There is only one aortic, the left aortic arch. Prototheria are the most primitive and primate the most highly advanced groups of mammals. Whales are the largest living water animals and elephants the largest living land animals. Man's arbitrary and dictatorial behaviour have caused untold miseries to many animals and disturbed the environment with the result that many species have become extinct and many more are on verge of extinction. Unless man mends his ways man himself is facing the threat of extinction.

4.7 TERMINAL QUESTIONS

A. 1) Mention the characters of mammals with reference to the structure of heart, and skull.

....

....

....

....

....

....

....

....

....

....

2) Describe the structure of a mammalian tooth and its mammalian characters.

....

....

....

....

....

....

3) Name a few mammals you see in your every day life and mention the orders which they belong to.

....

....

....

....

....

....

....

....

....

4) Explain the adaptation in bats to flying.

....

....

....

....

....

....

5) Match the name of the mammal in Group A with a character in Group B.

Group A		Group B	
A.	Camel	a.	diastema
B.	Rabbit	b.	cloaca
C.	Echidna	c.	echolocation
D.	Bat	d.	wool
E.	Sheep	e.	hump
F.	Chimpanzee	f.	fur
G.	Mink	g.	blubber
H.	Whale	h.	brachiation

6. Mention, what for the following mammals are useful to man?

a.	whale	b.	elephant
c.	sheep	d.	cow
e.	horse	f.	camel
g.	guinea pigs	h.	rhinoceros

....

....

....

....

....

....

....

....

7. Explain with examples the process of hibernation.

....

....

....

8. Mention the names of any four threatened species of mammals.

....

....

....

....

4.8 ANSWERS

Self Assessment Questions

1. (i) a. Body being covered by hairs.
   b. Heterodont, thecodont and diphyodont dentitition.
   c. Presence of left aortic arch.
   d. Formation of placenta during embryonic development.

(ii) 1. Australia 2. America
3. Assam/India 4 Africa

(iii) 1. Chiroptera 2. Rodentia
3. Carnivora 4. Artiodactyla

(iv) 1. Bat 2. Whale
3. Chimpanzee 4. Man

(v) Subsclass I Prototheria. Example. Echidna and Platypus
II Metatheria. Example. Kangaroo and Opossum

2. (i) a: man, b: dog. c: cat,
d: horse, e: cow. f: elephant

(ii) a: y b: z c: x

(iii) a: hoofs, b: nails. c: claws,
d: hibernation e: epidermal

(iv) a: false. b: true. c: false,
d: false, e: true. f: true,
g: false, h: true, i: false

(v) a: x, b: y, c: w,
d: z,

3. 1. a: x, b: y, c: w and d: z.
2. *Proconsul*
Ramapithecus
Austriopthecus
Homo erectus
Neanderthal man
Cromagnon man
Homo sapiens.
3. Synapside
4. Cyanognathus
5. Prototheria

4. (i) a) Renewable resources; biotic and physical factors.

b) Nonrenewable resources like minerals.

(ii) d, e, and h.

Terminal Questions

1. Heart; both auricle and ventricle are completely divided. Therefore, the mammalian heart is four chambered. The opening between the left auricle and the left ventricle is guarded by the bicuspid valve and the opening between the right auricle and the right ventricle is guarded by the tricuspid valve. Only one aortic arch, the left one takes its origin from the heart.

   Endoskeleton : Skull bicondylar, only one bone forming the lower jaw, the dentary, presence of three ear ossicles in the middle ear, the upper jaw is fused with the skull and the lower jaw articulates directly with the skull, presence of an external ear opening.

2. A typical mammalian tooth consists of two parts; part protruding out of the jaw, the crown and the part embedded in the pit of the jaw, called the root. The tooth is made of dentine. On the crown portion it is covered by enamel and on the root part it is covered by cement. In the centre of the tooth is the pulp cavity containing blood capillaries, nerves and connective tissue.

   The teeth of mammals are heterodont, thecodont and diphyodont. The mammalian teeth are modified according to the food and feeding habits.

3. Cattle, Buffalo, Sheep, Goat } Artiodactyla

   Horse, Donkey } Perissodactyla

   Cat & dog - Carnivora

   Rats - Rodentia

   Monkey - Primate

   Bats - Chiroptera

4. Bats have wings made by the leathery skin spread between the fingers, between the fore and hind limbs and between the hind limbs encircling the hind end. It may or may not include the tail. The wing helps in flying. The bats have developed echolocation by which they learn about their surroundings and catch the prey and avoid obstacles while flying.

5. A : e, B : a, c : b,

   D: c, E: d, F: h,

   G: f, H: g.

6. a : useful, blubber;

   b : useful, ivory;

   c : useful, wool;

   d : useful, milk;

   e : useful, carrying men and materials

   f : useful, transport in desert;

   g : useful, experimental animal

   h : useful, horn.

7. Hibernation is spending the cold winter in relative inactivity. Example. bats and squirrel in temperate zone.

8. Clouded leopard; *Neofelis nebulosa*

   Rhinoceros; *Rhinoceros unicornis*

   Black buck; *Antilope cervicapra*

   Slender loris;

Alveolus (plural, alveoli) : a small cavity such as the tiny air sac in the lung or sac of a compound gland, or the socket for a tooth.

Allantois : one of the extra embryonic membranes of the amniotes that function in respiration and excretion in birds and reptiles and plays an important role in the development of the placenta in most mammals.

Amnion : the innermost extra embryonic membrane forming a fluid filled sac around the embryo in amniotes.

Anus : the terminal opening of the gut.

Atrium : any main chamber; the principal receiving chamber of the heart; the large cavity containing the pharynx in tunicates and cephalochordates.

Autostyly : a type of jaw suspension in which hyomandibular is non functional as a supporting structure and the upper jaw region is entirely responsible for its own suspension, seen in Dipnoi.

Auricularia larva : larva found in holothuriodea of Echinoderms.

Brachiation : a form of locomotion in which the arms are used to swing the body from branch to branch among trees; a special type of suspensory locomotion; arm swinging locomotion.

Bipinnaria larva : free swimming ciliated larva of the asteriod echinoderm.

Canine : a pointed tooth between incisors and premolars.

Chorion : outer of the double membrane that surrounds the embryo of reptiles, birds and mammals. In mammals it contributes to the placenta.

Cloaca : the common chamber into which the gut, excretory tubes and reproductive tubes empty their contents.

Dentine : a bonelike tissue of teeth that is secreted by odontoblasts; dentin.

Diaphragm : the domelike muscular partition between the abdominal and thoracic cavities in mammals which functions in gentle inspiration and in defecation.

Diastema (plural, diastemata) : a gap especially the toothless interval between canine and premolars in mammals.

Echolocation : the location of objects by detecting echoes reflected from them; echo ranging.

Enamel : the hard, crystalline material produced by epidermal cells and deposited over dentine of tooth in tetrapods and their immediate ancestors.

Eocene : the second epoch of the Tertiary period of the cenozoic era.

Esophagus : the part of the gut tube that lies between pharynx and stomach, oesophagus.

Fenestra (plural fenestral) : large opening or window, usually in a bone or between bones.

Heterocercal tail : the type of tail fin found in cartilaginous fishes (sharks and rays) in which the lobes of the fin are asymmetrical; this is caused by the lengthening of some of the fin rays.

Holostyly : a type of jaw suspension in which there is support both from hyomandibular and a direct articulation of upper jaw of braincase seen in Holocephali.

Homeotherms : warm blooded animals having a constant body temperature that is invariant with the surroundings.

Homocercal tail : the type of tail fin found in most living bony fishes. The two lobes of the tail are symmetrical and supported only by dermal fin rays.

Hyostyly : a type of jaw suspension in which the upper jaw has no direct connection with the brain case and the jaw joint is braced entirely by hyomandibular bone. Seen in most modern fishes.

Gestation : the period of time from fertilization to birth in embryos that develop within the body of a parent.

Genealogy : account of descent from ancestor; investigation of pedigree; plants or animal's line of development from earlier forms.

Incisor : any tooth of a mammal that is located anterior to the canines and is used for cutting. Upper incisors are lodged in the premaxilla whereas lower incisors are fixed in dentary.

Labyrinthodont : one of a group of extinct amphibians derived from crossopterygians that have complexly infolded tooth dentine; of 'like' or pertaining to that group of amphibians.

Lateral line receptors : a line of mechanical receptor cells lying along the sides of certain fishes and amphibians, and sensitive to sound and wave action in water.

Larynx : a complex of cartilaginous elements, muscles, and fibers at the pharyngeal openings of the trachea that functions to protect the opening and in some forms permits vocalization, voice box especially in humans.

Lophophore : ciliated tentacle used to collect food.

Mammal : any animal belonging to the class Mammalia. Mammals have mammary glands, hair, warm bodies and three ear ossicles i.e, incus, malleus and stapes.

Marsupial : any individual of the mammalian order Marsupialia which includes opossums, kangaroos, and wallabies.

Marsupium : an abdominal brood pouch on most marsupials in which the young ones develop.

Monophyletic : group of species having all been derived from a common ancestor or single parent stock.

Neoteny : a condition in which an organism attains sexual maturity while certain larval or juvenile characters are retained permanently.

Nocturnal : of or pertaining to the night.

Occipital condyle : one of the joint surfaces from the occipital region of the skull that articulates with the atlas.

Ossification : deposition of mineral salts, calcium phosphate and calcium carbonate around collagen fibres in tissues so that the tissue becomes hardened or ossified.

Polyphyletic : derived from more than one ancestral source; opposed to monophyletic.

Poikilotherms : cold blooded animals having a body temperature that varies with that of their surroundings.

Taxonomic clade : a taxon or other group consisting of a single species and all of its descendents forming a distinct branch on a phylogenetic tree.

Tornaria larva : a free swimming larva of Enteropneusta that rotates as it swims.

Viviparity : the condition of producing young of considerable development within the adult body.

Wing : any appendage which serves as a major aerofoil especially the forelimbs of birds, bats and pterosaurs.

Further Reading

1. The Life of Vertebrates J.Z. Young (Third Edition) ELBS. Oxford University Press.
2. The Vertebrate Body A.S. Romer and T.S. Parson (Sixth Edition). CBS College Publishing.
3. Chordata Anatomy and Evolution D. Jacob, A. Sharma and K. Nandchahal (1994). Ramesh Book Depot, Jaipur.

APPENDIX – I

GEOLOGICAL TIME TABLE

Era	Period	Epoch	Biologic events	Years before present (B.P.)
CENOZOIC	Quaternary	Recent	Modern humans	11 thousand
		Pleistocene	Early humans	1.7 million
	Tertiary	Pliocene	Large carnivores	5 million
		Miocene	Abundant grazing mammals	23 million
		Oligocene	Apes, monkeys, whales	38 million
		Eocene	Radiation of placentals	54 million
		Paleocene	First placental mammals	65 million
MESOZOIC	Cretaceous		Climax of giant land and marine reptiles, followed by extinction; flowering plants; decline of gymnosperms	135 million
	Jurassic		First birds; first mammals; dinosaurs abundant	192 million
	Triassic		First dinosaurs; mammal like reptiles; conifers dominate plants	230 million
PALEOZOIC	Permian		Radiation of reptiles; displacement of amphibians; extinction of many marine invertebrates	280 million
	Carboniferous	Pennsylvanian	First reptiles; giant insects; great conifer forests	320 million
		Mississippian	Radiation of amphibians; abundant sharks; scale trees and seed ferns	345 million
	Devonian		First amphibians freshwater fishes abundant; bryozoans and corals	405 million
	Silurian		First jawed fishes	430 million
	Ordovician		Ostracoderms (first vertebrates): abundant marine invertebrates; first land plants	500 million
	Cambrian		Origin of many invertebrate phyla and classes; trilobites dominant; marine algae	570-600 million
PRECAMBRIAN	Precambrian		Fossil algae; other fossils extremely rare; evidence of sponges and worm burrows	

CLASSIFICATION OF CHORDATES

In this scheme of classification of chordates we give only the living phyla and their classification.

PHYLUM	–	CHORDATA
SUBPHYLUM	–	UROCHORDATA (= Tunicata)
SUBPHYLUM	–	CEPHALOCHORDATA (= Acrania)
SUBPHYLUM	–	VERTEBRATA (= Craniata)
SUPERCLASS	–	AGNATHA (= Cyclostomata)
GROUP	–	GNATHOSTOMATA
SUPERCLASS	–	PISCES
CLASS	–	AMPHIBIA
CLASS	–	REPTILIA
CLASS	–	AVES
CLASS	–	MAMMALIA

CLASSIFICATION OF FISHES

Super class	–	Agnatha	
Class	–	Myxini	(hagfishes)
Class	–	Cephalaspidomorphi	(lampreys)
Super class	–	Pisces	
Class	–	Chondrichthyes	
Sub class	–	Elasmob...	
Orde...			

)
s)
nes)
nes)
paddlefish)
eels)
gue)
& anchovies)
& minnows)
pikes)
es)
ish)
suckerfish)

Superorder	–	Acanthopterygii	(modern fishes – perches, mullet, flying fish etc.)

CLASSIFICATION OF AMPHIBIANS

Class	–	Amphibia	
Order	–	Anura (= Salientia)	(frogs, toads)
Order	–	Gymnophiona (= Apoda)	(caecilians)
Order	–	Caudata (= Urodela)	(salamanders)

CLASSIFICATION OF REPTILES

Class	–	Reptilia	
Subclass	–	Anapsida	
Order	–	Testudines (= Chelonia)	(Tortoises & Turtles)
Subclass	–	Diapsida	
Superorder	–	Lepidosauria	
Order	–	Sphenodonta	(*Sphenodon*)
Order	–	Squamata	(snakes and lizards)
Superorder	–	Archosauria	
Order	–	Crocodilia	(alligators, gharial, crocodiles, caimans)

CLASSIFICATION OF BIRDS

Class	–	Aves	
Subclass	–	Archaeornithes (Extinct)	(*Archaeopteryx*)
Subclass	–	Neornithes	
Superorder	–	Paleognathae	
Order	–	Struthioniformes	(ostriches)
Order	–	Rheiformes	(rheas)
Order	–	Casuariiformes	(cassowaries, emus)
Order	–	Apterygiformes	(kiwis)
Order	–	Tinamiformes	(tinamou)
Superorder	–	Neognathae	
Order	–	Cuculiformes	(cuckoos, roadrunners)
Order	–	Falconiformes	(eagles, hawks, vultures, condors, buzzards)
Order	–	Galliformes	(fowl, quail, turkey, pheasants)
Order	–	Columbiformes	(pigeons, doves)
Order	–	Psittaciformes	(parrots parakeets)
Order	–	Coliiformes	(mousebirds)
Order	–	Coraciiformes	(kingfisher, hornbill)
Order	–	Strigiformes	(owls)
Order	–	Caprimulgiformes	(goatsuckers, nighthawks, whippoorwills)
Order	–	Apodiformes	(swifts, hummingbirds)
Order	–	Trogoniformes	(trogons)

Order	–	Piciformes	(wood peckers, toucans, puffbirds)
Order	–	Passeriformes	(songbirds)
Order	–	Gruiformes	(cranes, rails, coots)
Order	–	Podicipediformes	(grebes)
Order	–	Charadriiformes	(gulls, oyster catches, plovers, Terns etc.
Order	–	Phoenicopteriformes	
Order	–	Anseriformes	(swans, ducks, geese)
Order	–	Ciconiiformes	(herons, bitterns, storks, ibises, spoonbill, flamingos)
Order	–	Pelecaniformes	(pelicans, cormorants, gannets etc.)
Order	–	Procellariiformes	(albatross, petrel)
Order	–	Gaviiformes	(loons)
Order	–	Sphenisciformes	(penguins)

CLASSIFICATION OF MAMMALS

Class		–	Mammalia	
Subclass		–	Prototheria (= Monotermata)	(*Echidna*)
Subclass		–	Metatheria (=Marsupialia)	(platypus and other marsupialia)
Subclass		–	Eutheria (= Placentalia)	
	Order	–	Insectivora	(shrews & moles)
	Order	–	Macroscelidea	(elephant shrews)
	Order	–	Dermoptera	(flying lemurs)
	Order	–	Chiroptera	(bats)
	Order	–	Edentata	(armadillo)
	Order	–	Pholidota	(pangolins)
	Order	–	Tubulidentata	(aardvark)
	Order	–	Lagomorpha	(hares & rabbits)
	Order	–	Rodentia	(rats & squirrels)
	Order	–	Cetacea	(whales, dolphins, porpoises)
	Order	–	Proboscidea	(elephants)
	Order	–	Sirenia	(sea cows, dugongs, manatees)
	Order	–	Hyracoidea	(hyracoids)
	Order	–	Carnivora	(cats, dogs, lions, bears, weasals)
	Order	–	Artiodactyla	(hoofed mammals, cattle, deer, goat etc.)
	Order	–	Perissodactyla	(horses, zebra, rhinoceros, donkeys)
	Order	–	Primates	(monkeys, man)

UGZY -02
Animal Diversity – II

Block

2

FUNCTIONAL ANATOMY OF CHORDATES -I

BLOCK 2 FUNCTIONAL ANATOMY OF CHORDATES – I

All living animals depend for their life on the fulfilment of several crucial needs. Nutrients, hormones, and wastes must be carried to from and among the body's cells. The animals must move in search of food, shelter, and mate. The food must be digested and assimilated. The functioning of cells and tissues and organs must be co-ordinated. The environment responded to and enemies avoided or fought off. None of these needs is easy to meet. Each requires special organs and cells with special function. Alone they cannot survive but together they ensure life. Block 2 and Block 3 describe the functional anatomy of chordates using a comparative approach. This block discusses the integument and digestive, respiratory and circulatory systems.

Unit 5 **Integument** begins a systematic treatment of vertebrate morphology. The unit tells you about the embryonic origin of integument, structure of epidermis and dermis. Derivatives of epidermis and dermis have also been explained. You will learn that the integument is far more complex than a first impression may suggest. Features of fish and tetrapod integument are explained in detail and specialisation of integument of mammals is discussed at length.

In Unit 6 **Digestive System**, you will learn that because of the constant need for energy and raw materials, all animals including vertebrates give a high priority to obtaining and processing food. Vertebrates meet this need with the help of a digestive system. This unit describes the dentition pattern and feeding adaptations in different groups of chordates. You will study about the evolution of alimentary canal and its organisational variations related to the different dietary habits of mammalian vertebrates.

In Unit 7 **Respiratory System**, you will learn that animals need oxygen to process foodstuff and to obtain energy. In the process, carbon dioxide is produced which must be removed. In lower chordates and fishes, this exchange system is seen in gills. In animals that live on land and those that fly in air, this exchange system is the lung. We also describe the various accessory respiratory organs for air breathing in fishes and for buccal respiration in frogs.

Unit 8 **Circulatory System**, is the last unit in this block and deals with the circulation of body fluids in chordates. Blood circulates through the body. Heart pumps it through blood vessels, which branch and rebranch to pass near every cell in the body. You will learn how the vertebrate heart has evolved, and that blood vessels form two circuits, the pulmonary circuit and the systemic circuit. Apart from this, an extensive network of thin walled dead end channels forms the lymphatic system and scattered extensively in the body are the lymph nodes that form an important part of the immune system.

Objectives

After studying this block you will be able to:

- Give a comparative account of the organ systems in vertebrates,
- Give a comparative account of the structure of heart in vertebrates along with the circulation of fluids in the body,
- Describe the feeding adaptations in chordates and give an account of their digestive systems, and
- Describe the various water and air breathing respiratory structures along with their accessory respiratory organs in vertebrates.

UNIT 5. INTEGUMENT

Structure

5.1 INTRODUCTION

The integument (or skin) is a composite organ. On the surface is the **epidermis**, below it is the **dermis** and between them lies the **basement membrane**.

The integument is one of the largest organs of the body, making up some 15 per cent of the human body weight. Epidermis and dermis together form some of the most varied structures found within vertebrates. The epidermis produces hair, feather, baleen, claws, nails, horns, beak and some types of scales. The dermis gives rise to dermal bones and osteoderms of reptiles. Collectively epidermis and dermis form teeth, denticles and skin of fish.

As the critical border between the organism and its environment, the integument has a variety of specialized functions. It forms part of the exoskeleton and thickens to resist mechanical injury. The integument helps hold the shape of an organism. Osmotic regulation and movement of gases and ions to and from the circulation are aided by the integument in conjunction with other systems. Skin gathers needed heat or radiates the excess and houses sensory receptors. It holds feathers for locomotion, hair, for insulation and horns for defense. Skin pigment blocks full sunlight.

Let us begin by examining the embryonic orgin and development of skin.

Objectives

After studying this unit, you would be able to :

- understand the structure of integument,
- explain the integument of tetrapods,
- discuss the specialized derivatives of integument.

5.2 EMBRYONIC ORIGIN

By the end of neurulation in the embryo, most skin precursors are delineated. The single layered surface ectoderm proliferates to give rise to the multilayered epidermis. The deep layer of the epidermis, the **stratum basale** rests upon the basement membrane. Through active cell division, the basement membrane replenishes the single layer of outer cells called the **periderm** (Fig. 5.1a).

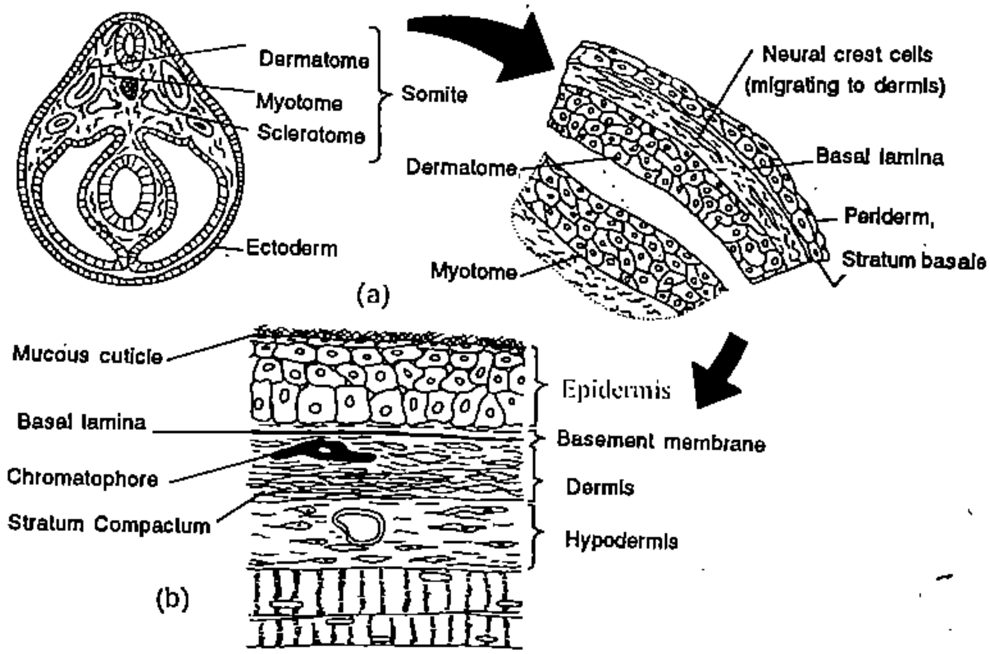


Fig. 5.1: Embryonic development of the skin. (a) Cross section of a representative vertebrate embryo. (b) The epidermis differentiates into a stratified layer that has cuticle on the surface.

The dermis arises from several sources, principally from the dermatome. Fundamentally, the integument is composed of two layers, epidermis and dermis, separated by the basement membrane. Vascularization and innervation are added, alongwith contributions from the neural crest. Interaction between epidermis and dermis stimulates specializations such as teeth, feathers, hair and scales of several varieties (Fig. 5.2).

5.3 GENERAL FEATURES OF THE INTEGUMENT

5.3.1 Dermis

The dermis of many vertebrates produces plates of bone directly through intramembranous ossification. Because of their embryonic source and initial position within the dermis, these bones are called **dermal bones**. They are prominent in ostracoderm fishes but appear secondarily even in derived groups, such as in some species of mammals.

The most conspicuous component of dermis is the fibrous connective tissue composed mostly of collagen fibres. Collagen fibres may be woven into distinct layers called **plies** The dermis of the protochordate amphioxus exhibits an especially ordered arrangement of collagen within each ply (Fig. 5.3). These plies are laminated together in very regular, but alternating orientation.

These alternating layers act like warp and weft threads of cloth fabric giving some

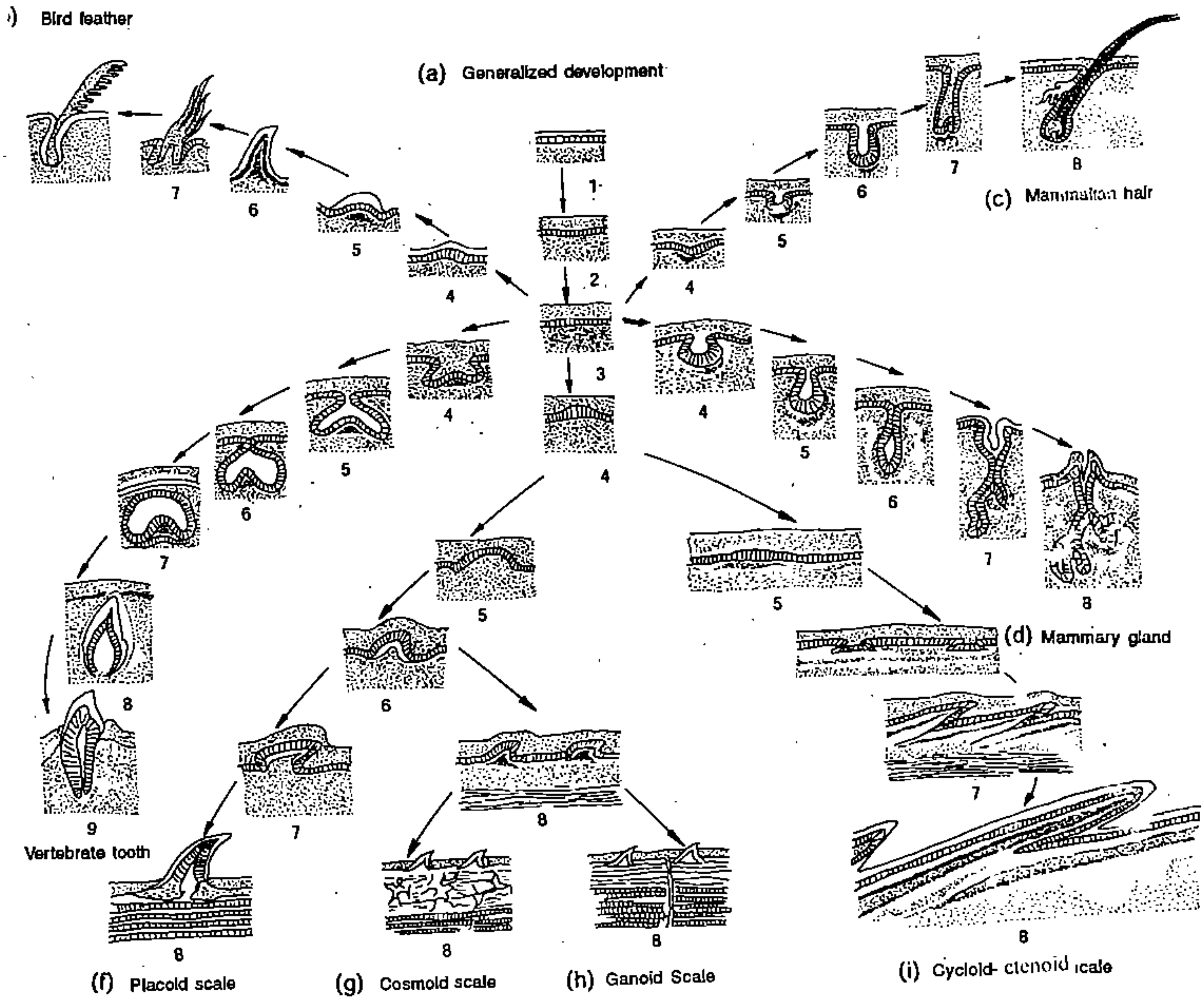


Fig. 5.2: Skin derivatives. (a) Out of the simple arran...m at of epidermis and dermis, with a basement membrane, a great variety of vert... ate integuments develop. Interaction of epidermis and dermis gives rise to feathers in birds. (b) Hair and mammary glands in mammals (c&d) teeth in vertebrates (e) placoid scales in chondrichthyans (f) and cosmoid, ganoid scales in bony fishes (g-i).

shape to the skin and preventing it from sagging. In aquatic vertebrates such as shark, the bundles of collagen lie at angles to each other, giving the skin a bias; like cloth. That is, the skin stretches when it is pulled at an angle oblique to the direction of the bundles. For example, if you take a piece of cloth, like a handkerchief and pull it along either warp or weft threads, the cloth extends very little under this parallel tension. But if you pull at opposite corners, tension is applied obliquely at 45° angle to the threads, and the cloth stretches considerably (Fig. 5.4 a, b). This principle seems to govern the tightly woven collagen of shark skin. The skin of shark stretches without wrinkling. Because it does not wrinkle, water flows smoothly and without turbulence across the surface of the body (Fig. 5.4 d).

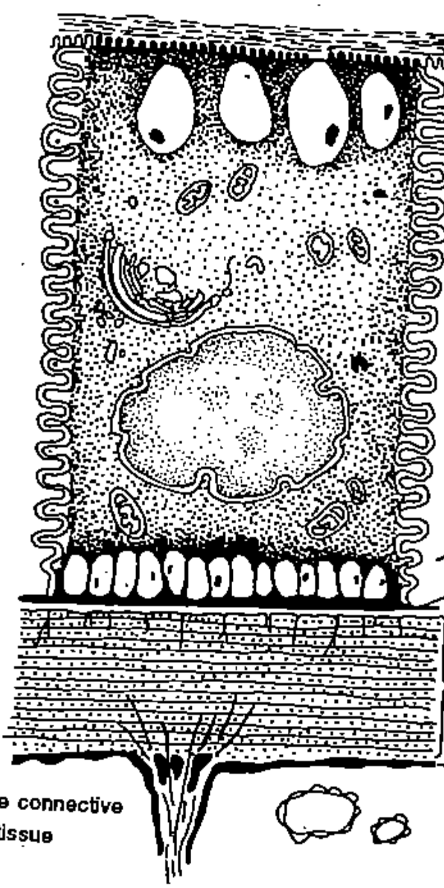


Fig. 5.3: Protochordate, skin of amphioxus. The epidermis is a single layer of cuboidal or columnar cells that secrete mucus that coats the surface and rests upon basal lamina. The dermis consists of highly ordered collagen arranged in plies to form 'fabric'.

In fishes and aquatic vertebrates, including cetaceans and aquatic squamates, collagen fibres of dermis are usually arranged in orderly plies that form a recognizable *stratum compactum*.

5.3.2 Epidermis

The epidermis of many vertebrates produces mucus to moisten the surface of the skin. In fishes, mucus seems to afford some protection from bacterial infection and helps ensure the laminar flow of water across the body surface. In amphibians, mucus probably serves similar roles and additionally keeps the skin from drying during the animal's **sorties** onto land.

In terrestrial vertebrates the epidermis covering the body often forms an outer **keratinized** or **cornified** layer, the **stratum corneum**. New epidermal cells are formed by mitotic division, primarily in the deep **stratum basale**. These cells push more superficial ones towards the surface, where they tend to self destruct in an orderly fashion. During this process, various protein products accumulate and collectively form **keratin** in a process called **keratinization**.

Keratinisation and formation of **stratum corneum** also occur when friction or direct mechanical abrasion insult the epithelium. For example, the epidermis in the oral cavity of layer, especially if the food eaten is unusually sharp or abrasive. The stratum corneum may be differentiated into hair, hooves, horn sheaths or other specialized confined structures.

Scales form within the integument of many aquatic and terrestrial vertebrates. Scales are basically folds in the integument. If dermal contributions predominate, the fold is called a **dermal** scale. An epidermal fold produces an **epidermal scale**.

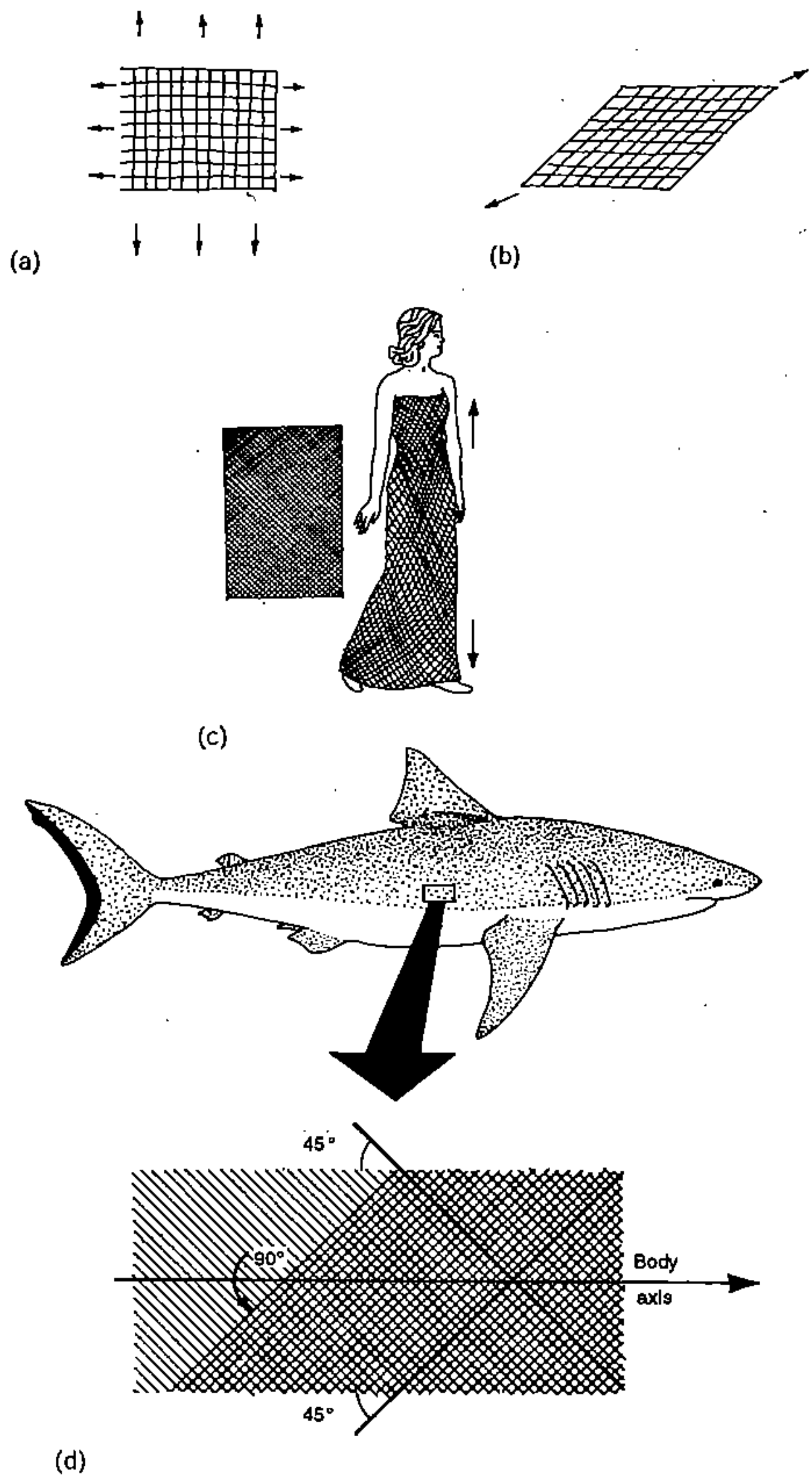


Fig. 5.4: Bias in woven material. a) Warp and weft compose the fibres of fabric. If the tensile force is parallel with the thread, little distortion of fabric occurs. b) However, tension along the bias at 45° to the threads results in substantial change. c) Fashion designers take advantage of the features of fabric when designing clothes. d) Plies of collagen of stratum compactum of fish skin act in a similar way. The flexible bias of the skin is oriented 45° to body length.

5.4 PHYLOGENY

5.4.1 Integument of Fishes

With few exceptions, the skin of most living fishes is nonkeratinized and covered instead by mucus. Exceptions include keratinized specializations in a few groups. The "teeth" lining the oral disc of lampreys, the jaw coverings of some herbivorous minnows, and the friction surface on belly skin of some semiterrestrial fish are all kerantinized derivatives. However, in most living fishes, the epidermis is alive and active on the body surface, and there is no prominent superficial layer of dead, keratinized cells.

Two types of cells occur within the epidermis of fishes; **epidermal** cells and specialized **unicellular glands**. In living fishes, including cyclostomes, prevalent epidermal cells make up the stratified epidermis. Epidermal cells are tightly connected through cell junctions and contain numerous secretory vesicles that are released to the surface where they contribute to the mucous cuticle.

Unicellular glands are single, specialized and interspersed among the epidermal cell population. There are several types of unicellular glands. The club cell is an elongate, sometimes binucleate unicellular gland (Fig. 5.5).

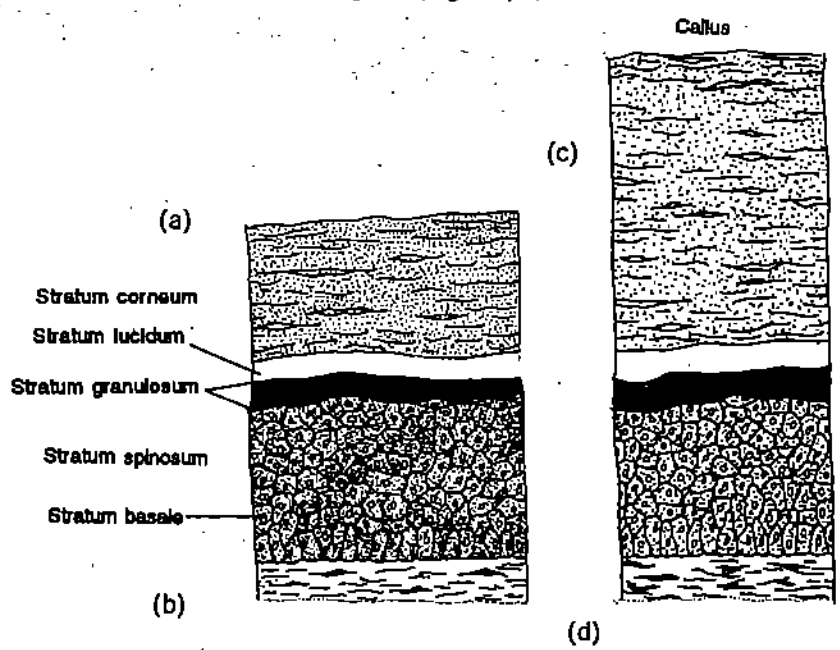


Fig. 5.5: Keratinization. In places where mechanical friction increases, the integument responds by increasing production of protective callus and s. corneum thickens as a result.

Collagen within the stratum compactum is regularly organized into plies that spiral around the body of the fish, allowing the skin to bend without wrinkling. In some fishes, the dermis has elastic properties. When a swimming fish bends its body, the skin on the stretched side stores energy that helps unbent the body. The fish dermis often gives rise to dermal bone, and dermal bone gives rise to dermal scales. In addition, the surface of fish scales is sometimes coated with a hard, acellular **enamel** of epidermal origin and a deeper **dentin** layer of dermal origin.

Primitive Fishes : In ostracoderms and placoderms, the integument produced prominent body plates of dermal armor that encased their bodies in an exoskeleton. Dermal bones of the cranial region were large, forming the head shields, but more posteriorly along the body, the dermal bones tended to be broken up into smaller pieces, the dermal scales. The surface of these scales was often ornamented with tiny, mushroom shaped tubercles. These tubercles consisted of a surface layer of enamel or an enamel like substance over an inner layer of dentin (Fig. 5.6).

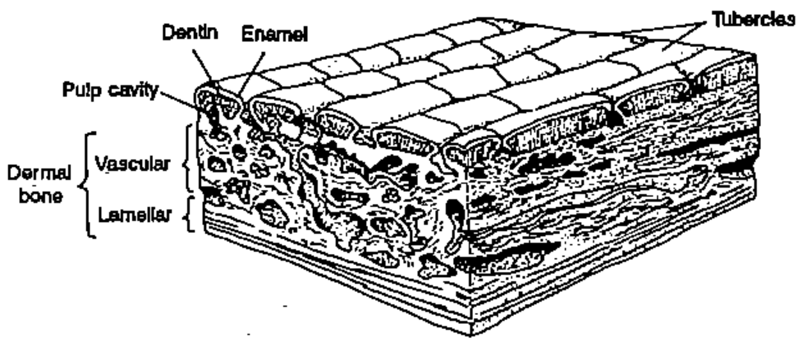


Fig. 5.6: Section through an enlarged ostracoderm scale. The scale consists of tubercles capped with dentin and enamel.

The skin of living hagfishes and lampreys departs considerably from that of primitive fossil fishes. Dermal bone is lost, and the skin surface is smooth and without scales. The epidermis is composed of stacked layers of numerous living epidermal cells throughout. Interspersed among them are unicellular glands, namely, the large granular cells and elongate club cells. In addition, the skin of hagfishes includes **thread cells** that discharge thick cords of mucus to the skin surface when the fish is irritated. The dermis is highly organized into regular layers of fibrous connective tissue. Within the dermis, hagfishes also possess multicellular slime **glands** that release their products through ducts to the surface.

Chondrichthyes: In cartilagenous fishes, dermal bone is absent, but surface denticles, termed **placoid scales**, persist. These scales give the rough feel to the surface of the skin (Fig. 5.7 a).

Recent evidence suggests that these tiny placoid scales favourably affect the water flowing across the skin as the fish swim forward to reduce friction drag. Numerous secondary cells are present in the epidermis as well as stratified epidermal cells. The dermis is composed of fibrous connective tissue, especially elastic and collagen fibres, whose regular arrangement forms a fabric like warp and weft in the dermis (Fig. 5.4 d). This gives the skin strength and prevents wrinkling during swimming.

The placoid scale develops in the dermis but projects through the epidermis to reach the surface. A cap of enamel forms the tip, dentin lies beneath and pulp cavity resides within (Fig. 5.7 a,b).

Bony Fishes: The dermis of bony fish is subdivided into a superficial layer of loose connective tissue and a deeper layer of dense fibrous connective tissue. Chromatophores are found within the dermis. The most important structural product of the dermis is the scale. In bony fishes, dermal scales do not actually pierce the epidermis, but they are so close to the surface they give the impression that the skin is hard (Fig. 5.8 a,b).

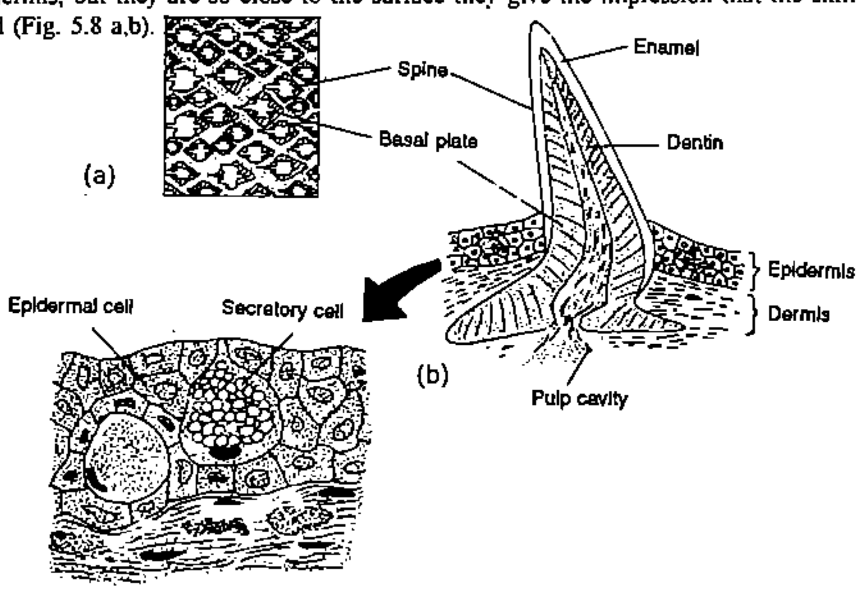


Fig. 5.7: Shark skin. (a) Surface view of the skin showing regular arrangement of projecting placoid scales. (b) Section through a placoid scale of shark.

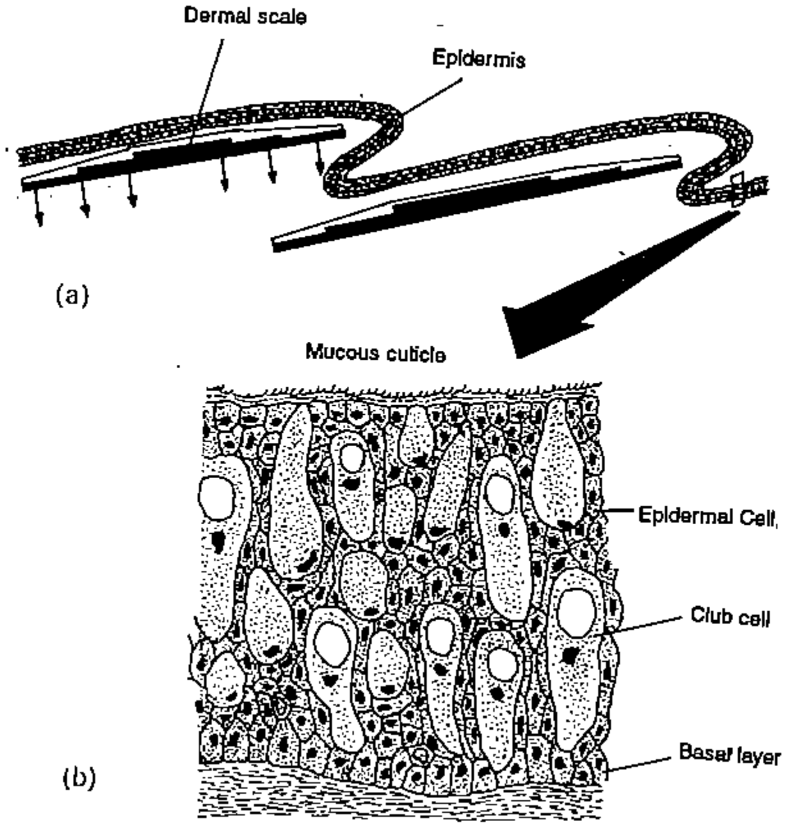


Fig. 5.8: Bony fish skin. (a) Arrangement of dermal scales within the skin of teleost fish. (b) Enlargement of epidermis.

On the basis of their appearance, several types of scales are recognized among bony fishes. The **cosmoid** scale, seen in primitive sarcopterygians resides upon a double layer of bone, one layer of which is vascular and the other lamellar. On the outer surface of this bone is a layer that is now recognized as dentin and spread superficially on the dentin is a layer now recognized as enamel (Fig. 5.9)

The ganoid scale is characterized by the prevalence of a thick surface coat of enamel, without an underlying layer of dentin (Fig. 5.9 b). Dermal bone forms the foundation of the ganoid scale, appearing as a double layer of vascular and lameller bone or single layer of lamellar bone. Ganoid scales are shiny, overlapping and interlocking.

The **teleost** scale lacks enamel; dentin and vascular bone layer. Only lamellar bone remains, which is acellular and mostly noncalcified (Fig. 5.9 c). Two kinds of teleost scales are recognized. One is **cycloid** scale, composed of **circuli**. The other is **ctenoid** scale with a fringe of projections along to posterior margin (Fig. 5.9 d).

5.4.2 Integument of Tetrapods

Keratinization is a major feature of integument among terrestrial vertebrates. Extensive keratinization produces a prominent outer cornified layer, the stratum corneum, that resists mechanical abrasion. Lipids are often added during the process of karatinization or spread across the surface from specialized glands. The cornified layer alongwith these lipids increases the resistance of the tetrapod skin to desiccation. Multicellular glands are more common in the skin of tetrapods than in the skin of fishes. In fishes, the mucous cuticle and secretion of the unicellular gland at or near the surface of the skin coat it. In contrast, among tetrapods, multicellular glands usually reside in the dermis and reach the surface through common ducts that pierce the cornified layer.

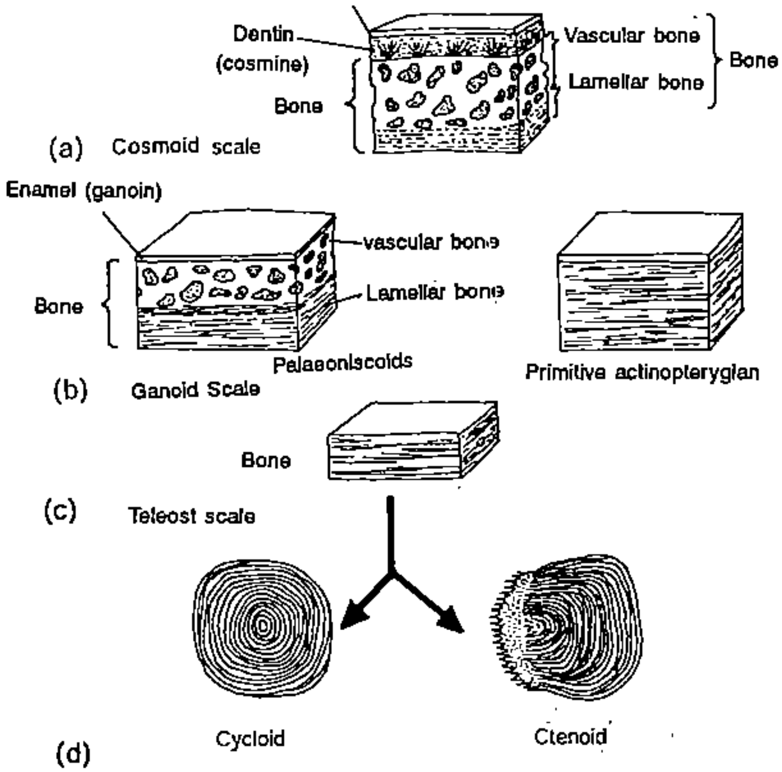


Fig. 5.9: Scale types of bony fishes. Cross section of a comsoid (a), a ganoid scale (b), and a teleost scale (c). Surface views of the two types of teleost scale, cycloid and ctenoid scales (d).

Amphibians

Amphibians are of special interest because during their lives they usually metamorphose from an aquatic form to a terrestrial form. Phylogenetically, amphibians are also transitional between aquatic and terrestrial vertebrates. In most modern amphibians, the skin is also specialized as a respiratory surface across which gas exchange occurs with the capillary beds in the lower epidermis and deeper dermis. In fact, some salamanders lack lungs and depend entirely on **cutaneous respiration** through the skin to meet their metabolic needs.

The most primitive amphibians had scales like the fishes from which they arose. Dermal scales are present only as vestiges in some species of tropical caecilians. Frogs and salmanders lack all traces of dermal scales (Fig. 5.10 a). In salamanders, the skin of the aquatic larvae includes a dermis of fibrous connective tissue. Scattered throughout are large Leydig cells to secrete substances that resist entry of bacteria or viruses (Fig. 5.10 b). In terrestrial adults, the dermis is similarly composed of fibrous connective tissue. During the breeding season **nuptial pads** may form on digits of limbs of male salamanders or frogs. Nuptial pads are raised calluses of cornified epidermis that help the male hold the female during mating.

Generally, the skin of frogs and salamanders usually includes two types of multicellular glands, **mucus** and **poison glands** (Fig. 5.10 b). Chromatophores may occassionally be found in amphibian epidermis but most reside in the dermis.

Box 5.1 : Poison Arrows and Poison Frogs.

The skin of most amphibians contains glands that secrete products that are distasteful or even toxic to predators. In tropical region of the New World lives a group of frogs, the poison arrow frogs, with especially toxin secretions. Native people of the region will often gather these frogs, hold them on sticks over a fire to stimulate release of these secretions and then collect the secretions on the tips of their arrows. Game shot with these toxin-laced arrows are quickly tranquilized or killed.

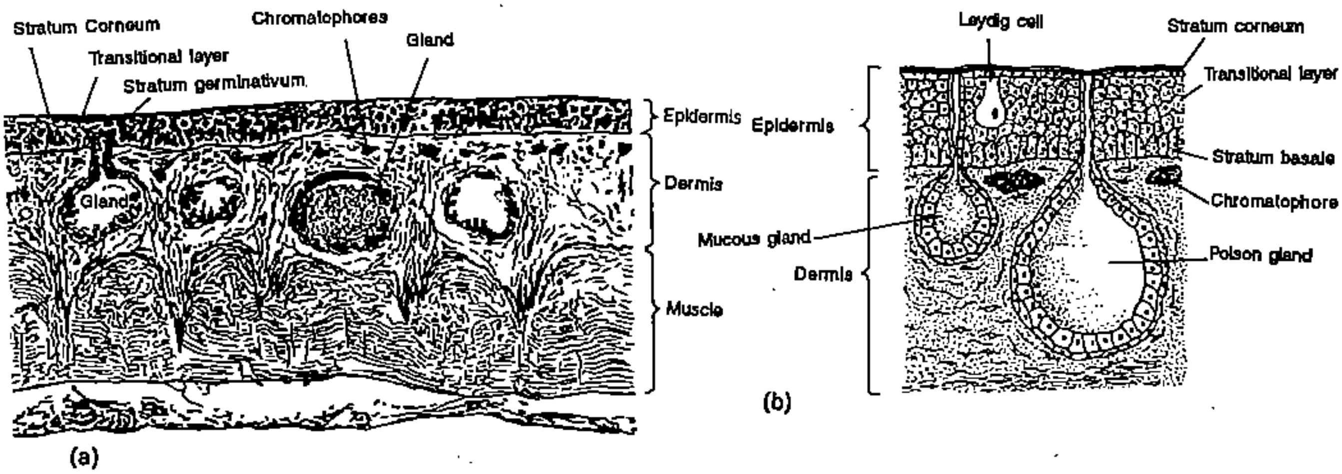


Fig. 5.10: Amphibian skin. a) Section through an adult frog skin. A basal stratum basale and a thin, stratum corneum are present. b) Diagrammatic view of amphibian skin showing mucous and poison glands that empty their secretions through short ducts to the surface of the epidermis.

Reptiles

The skin of reptiles reflects their greater commitment to a terrestrial existence. Keratinization is much more extensive, the skin glands are fewer than in amphibians. Scales are present, but these are fundamentally different from the dermal scales of fishes, which are built around bone of dermal origin. The reptilian scale usually lacks the bony undersupport or any significant structural contribution from the dermis. Instead it is a fold in the surface epidermis, hence it is an epidermal scale (Fig. 5.11 a). If the epidermal scale is large and platelike, it is termed **scute**. Additionally, epidermal scale may be modified into crests, spines or hornlike processes.

Dermal bone is present in many reptiles. Where dermal bones support the epidermis, they are called **osteoderms**, plates of dermal bone located under the epidermal scales. Osteoderms are found in crocodilians, and some lizards. The dermis of reptilian skin is composed of fibrous connective tissue. In turtles and crocodiles, sloughing of skin is modest, comparable to birds and mammals, in whom small flakes fall off at irregular intervals. But in lizards and in snakes, shedding of cornified layer, termed **molting or** ecdysis results in removal of extensive sections of epidermis (Fig. 5.11 b).

Integumental glands of reptiles are restricted to certain areas of the body. Many lizards possess rows of **femoral glands** along the underside of the hindlimb in the thigh region. Crocodiles and turtles have **scent glands**. Most integumental glands of reptiles play a role in reproductive behaviour.

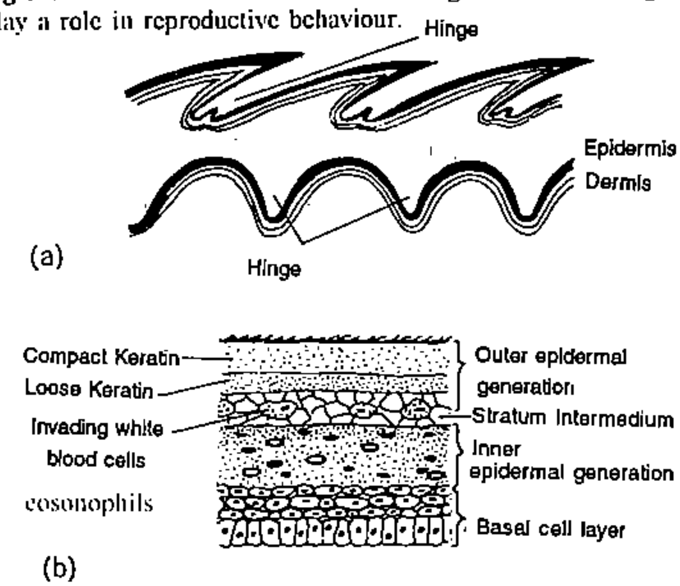


Fig. 5.11 : Reptile skin. a) Epidermal skin scales. Extent of projection and overlap of epidermal scales varies among reptiles and even along the body of same individual. b) Skin sheddin

Birds

Basic Structure : The feathers of birds have been called nothing more than reptilian scales. This oversimplifies the homology but probably not very much. The dermis of bird skin, especially near the feather follicles, is richly supplied with blood vessels, sensory nerve endings. During brooding the dermis in the breast of some birds becomes vascularized, forming a **brood patch** in which warm blood can come in close association with incubated eggs.

The epidermis comprises the stratum basale and stratum corneum. Between them is the transitional layer of cells transformed into the keratinized surface of stratum corneum (Fig. 5.12 a,b).

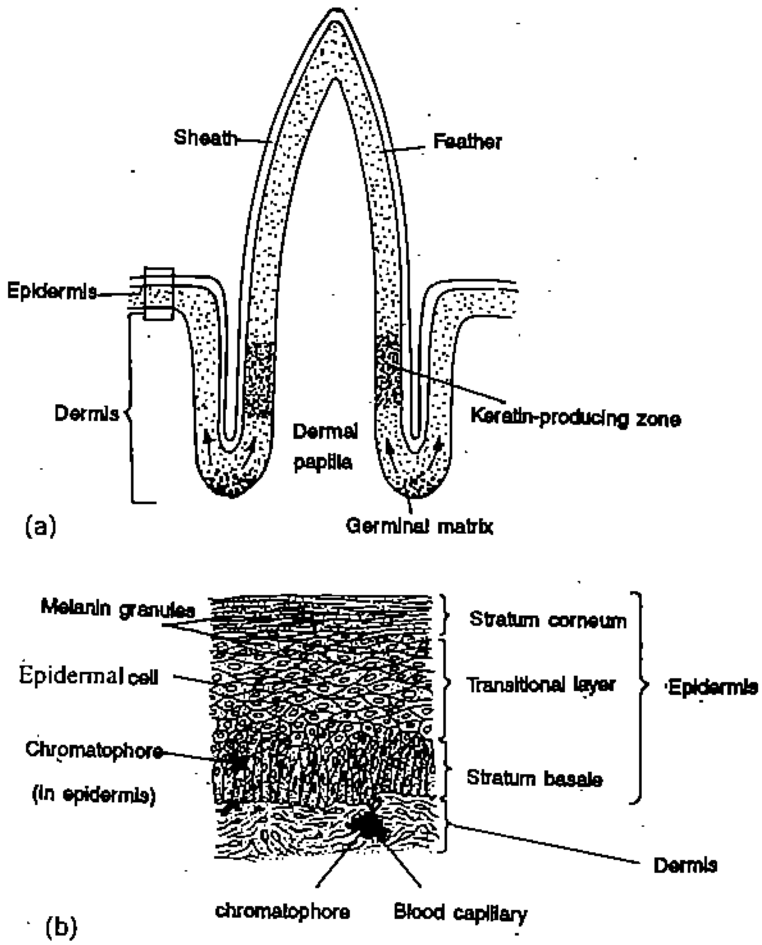


Fig. 5.12 : Bird skin. (a) Growth of a feather follicle. The feather forms within a sheath, that is a keratinised derivative of epidermis. (b) Section of skin showing the stratum basale and keratinised surface layer, stratum corneum.

Bird skin has few glands. The **uropygial gland**, located at the base of the tail (Fig. 5.13 a) secretes a lipid and protein product that birds collect on the sides of their beak and then smear on their feathers. The other gland located on the head of some birds, **salt gland**, is well developed in marine birds. Salt glands eject excess salt obtained when these birds ingest marine foods and sea water.

Feathers distinguish birds from all other vertebrates. Feathers can be structually elaborate and come in a variety of forms. Yet feathers are nonvascular and non-nervous products of the skin, principally of the epidermis and the keratinizing system. They are laid out along distinctive tracts, termed pterylae, on the surface of the body (Fig. 5.13). Feathers develop embryologically from *feather follicles*, invaginations of the epidermis that dip into the underlying dermis.

At least one bird has feathers and skin lightly coated with a toxin thought to deter predators. The brightly coloured bird, called a **hooded pitohui**, lives in New Guinea and is about the size of a blue jay. The poison works by repelling snakes, hawks, or other predators tasting one of the feathers. The bright plumage of the pitohui may represent a warning colouration to predators.

The feather itself grows outward in the sheathed case. Within the sheath, the central axis is divided into a distal *rachis* that *bears* barbs with interlocking connections, termed *barbules* and a proximal *calamus* that attaches to the body.

There are several types of feathers (Fig. 5.13). *Contour feathers* lie close to skin as thermal insulation. *Filoplumes* are often specialized for display and *flight feathers* constitute the major aerodynamic surface.

Flight feathers are characterised by a long *rachis* and prominent *vane* (Fig. 5.13 c). Their primary function is locomotion. Most feathers receive sensory stimuli and carry colours for display or courtship. Chromatophores occur within the epidermis, and their pigments are carried into the feathers to give them colour.

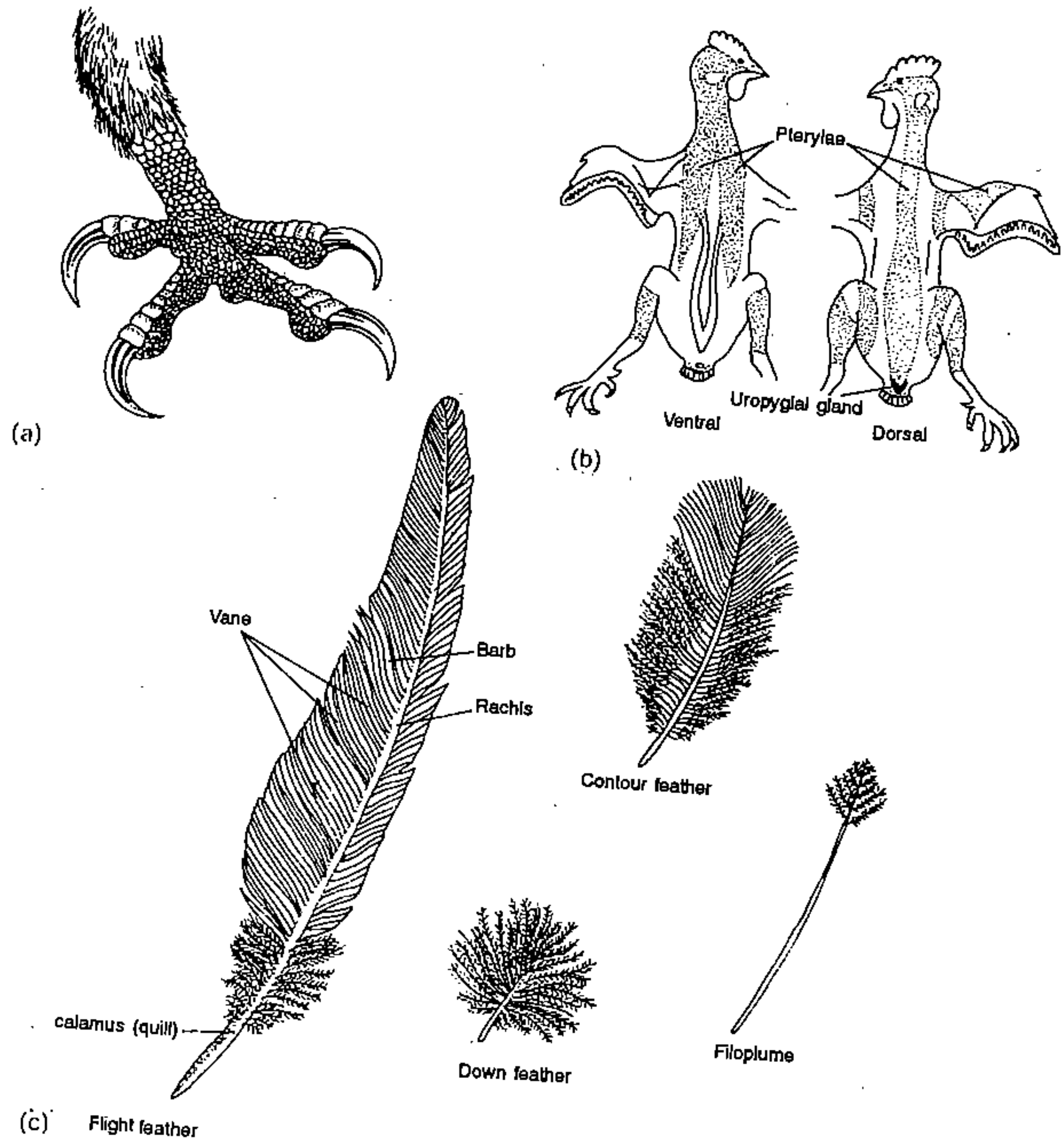


Fig. 5.13 : Epidermal derivatives in the bird. (a) Epidermal scales are present on the feet and legs on birds. (b) Feathers arise along specific pterylae tracts. (c) Feather types.

Mammals : As in other vertebrates, the two main layes of mammalian skin are epidermis and dermis which join and interface through the basement membrane. Beneath lies the hypodermis, composed of *connective tissue* and fat.

Epidermis : The epidermis may be locally specialized as hair, nails or glands. Epithelial cells of the epidermis are keratinocytes and belong to the keratinizing system that forms the dead superficial cornified layer of the skin. The surface kerantinized cells are replaced by cells arising primarily from the *stratum basale* cells. Cells within the basale divide mitotically. As they are displaced to higher levels, they pass through keratinization stages exhibited as distinct, successive layers *stratum spinosum, stratum granulosum, stratum lucidum* and *stratum corneum* (Fig. 5.14).

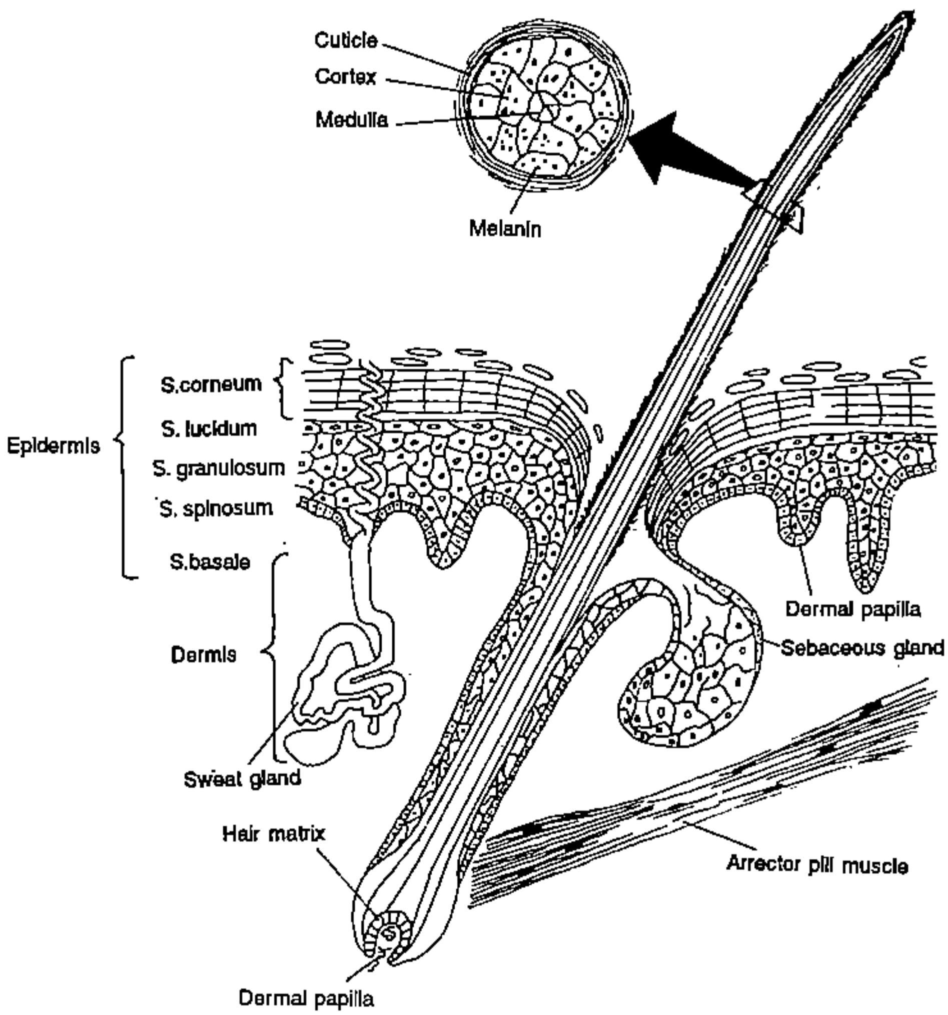


Fig. 5.14 : Mammalian skin. The epidermis is differentiated into distinct layers. As in other vertebrates, the deepest is stratum basale. The dermis pokes up dermal papillae that give the overlying epidermis an undulating appearance. Sweat glands, hair follicles and sensory receptors lie within the epidermis.

The process of keratinization is most distinct in the regions of the body where the skin is thickest, as the soles of the feet. Elsewhere, these layers may be less apparent.

Keratinocytes are the most prominent cell type of the epidermis, but others are recognised although their functions are less clearly known. The *Langerhans Cells* are stellate cells dispersed throughout the upper part of *stratum spinosum*. These cells play a role in cell mediated action of immune system. The *Merkel cells*, originating from neural crest and associated with nearby sensory nerves, respond to stimulation. *Chromatophores* arise from embryonic neural crest cells. These secrete granules of the pigment *melanin*, which are passed directly to epithelial cells. Skin colour arises from a combination of yellow *stratum corneum*, the red underlying blood vessels and dark pigment granules secreted by chramatophores.

Dermis : The mammalian dermis is double layered. The outer *papillary layer* pushes finger like projections, called *dermal papillae* into the overlying epidermis. The deeper *reticular* layer includes irregularly arranged fibres, connective tissue, blood vessels, nerves and smooth muscles occupy the dermis but do not reach the epidermis. The mammalian dermis produces dermal bones, but these contribute to the skull and pectoral girdle and rarely form dermal scales in the skin.

Blood vessels and nerves enter the epidermis. Hair follicles and glands project inward from the epidermis (Fig. 5.14). The dermis is usually composed of irregularly arranged fibrous connective tissue that is often impregnated with elastic fibres to give it some stretch but return it to its original shape. As a person ages, this elasticity is lost and the skin sags.

Hair : Hair are slender, keratinous filaments. The base of a hair is the root. Its remaining length, constitutes the *shaft*. The outer surface of the shaft often forms a *cuticle*. Beneath this is the *hair cortex* and at its core is the *hair medulla* (Fig. 5.14).

The hair shaft projects above the surface of the skin but it is produced within an epidermal hair *follicle* rooted in the dermis.

At its expanded base, the follicle receives a small tuft of the dermis, *hair papilla*. Chromatophores in the follicle contribute pigment granules to the hair shaft to give it further colour. The *arrector pili* muscle, a thin band of smooth muscle anchored in the dermis, is attached to the follicle and makes the hair stand erect in response to cold, fear or anger.

Some hair are specialized. Sensitive nerves are associated with the roots of *vibrissae* or *whiskers* around the snouts of many mammals. These are common in nocturnal mammals and in mammals that live in burrows with limited light. The quills of porcupines are stiff, coarse hairs specialized for defense.

Glands : Principally, there are two main types of glands in mammals, *sebaceous* and *sweat* glands. Derived from them are *scent* and *mammary glands*.

The *sebaceous glands* produce an oily secretion *sebum*, that is released into hair follicles in order to condition and help waterproof fur. Sebaceous glands are absent from the palms of hands and soles of feet, but they are present without associated hair, at the angle of the mouth, on the penis, near vagina and next to mammary nipples. The *wax glands* of outer ear canal, which secrete ear wax and *Meibomian glands* of the eye lid, which secrete on oily film over the surface of the eye ball.

The *sweat glands* produce a watery product called perspiration or *sweat*. Two types are usually recognized by the viscosiy of their sweat (viscous or thin) by their association (with or without hair follicles) and by their functional onset (at puberty or before). One type produces thin sweat, is not associated with hair follicles and functions before puberty. Its products function in regulation of body temperature. The other produces viscous sweat, is associated with hair follicles, and begins functioning at puberty. It is responsible for body odor.

Sweat glands are not found in all mammals, and their distribution varies. Chimpanzees and humans have the greatest number of sweat glands, including some on the palms and soles. In the duckbill platypus, sweat glands are limited to the snout. In deer, they are present at the base of tail. In elephants, sweat and sebaceous glands are absent entirely.

The *scent glands* are derived from sweat glands and produce secretions that play a part in social communication. Secretions of these glands are used to mark territory, identify the individual and communicate during courtship.

The *mammary glands* are also thought to be derived from sweat glands or perhaps from sebaceous glands. Functional only in the female, they produce milk and watery mixture of fats, carbohydrates and proteins that nourishes the young. The number of mammary glands varies among species. Release of milk to suckling is *lactation*. Mammary glands consist of numerous lobules. Each lobule is a cluster of secretory alveoli on which milk is produced. The alveoli open into a common duct that, in turn, opens to the surface through a raised epidermal papilla or *nipple*. The nipple is surrounded by circular pigmented area of skin called *aerola*. Alveolar ducts open into a common chamber or cistern within a long collar of epidermis called *teat* (5.15 a,c). Adipose tissue can build up beneath the mammary glands to produce *breasts*.

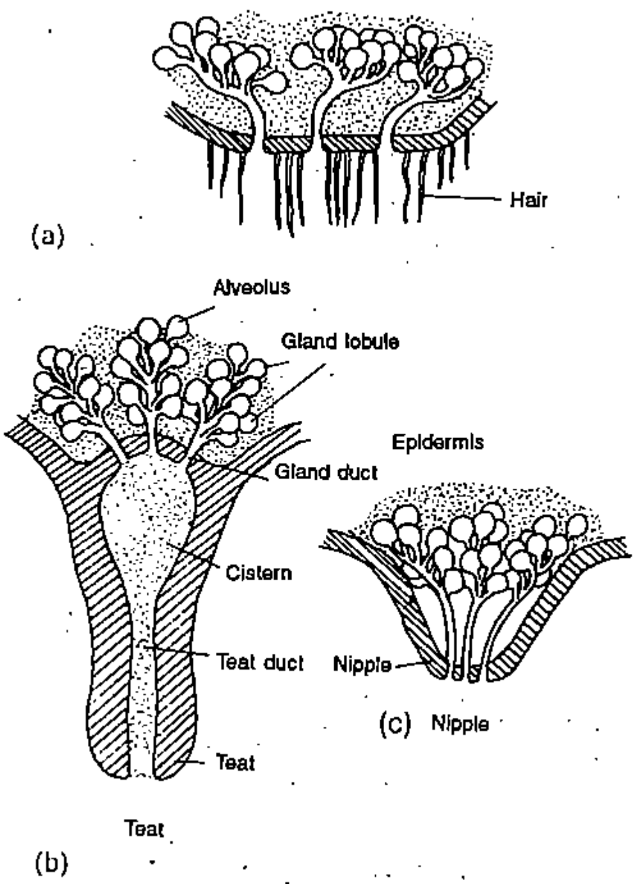


Fig. 5.15 : Mammary glands. a) In monotremes, the mammary glands open to the unspecialized skin surface, and the young press their snout to skin where these glands open. b) In some marsupials, the mammary ducts open through specializations of the integument, c) The nipple is a raised epidermal papilla around which the supple lips of the infant fit to drink the milk.

In *monotremes*, *nipples* and *teats* are absent and breasts do not form. Milk is released from ducts into the flattened milk patch or aerola on the surface of the skin (Fig. 5.15 a). The point of infant's snout is shaped to fit the surface, permitting vigorous sucking. At sexual maturity adipose tissue builds up under the mammary glands to produce breast from which milk is released. In common language, this is termed *let down*.

SAQ 1

Fill in the blanks.

a) Dermal bones are most prominent in ________.

b) In fishes and aquatic vertebrates, collagen fibres of the dermis are arranged to form ________ layer of the integument.

c) In terrestrial vertebrates, the epidermis covering the body often form a keratinized layer called as ________.

d) Epidermal fold, in the form of thickened keratinized layer produces ________.

e) *Stratum basale*, the deepest layer of epidermis rests upon ________.

SAQ 2

Match the following:

i) Femoral glands	a) Birds
ii) Uropygial glands	b) Crocodiles
iii) Scent glands	c) Lizards
iv) Mammary glands	d) Eye lids of mammals
v) Meibomian glands	e) Female mammals
vi) Sebaceous glands	f) Mammals

SAQ 3

Answer the following in one or two words :

a) Two types of cells present within the epidermis of fishes.

....

b) Surface denticles present in chondrichthyes.

....

c) Scales, characterized by prevalence of thick enamel, present in bony fishes.

....

d) Skin is specialized as a respiratory surface in these tetrapods.

....

e) In these reptiles, osteoderms are found.

....

f) The presence of major structure which distinguishes birds from all other vertebrates.

....

5.6 SPECIALISED DERIVATIVES OF THE INTEGUMENT

5.6.1 Nails, Claws, Hooves

Nails are plates of tightly compacted, cornified epithelial cells on the surface of fingers and toes, thus, they are products of the keratinizing system of the skin. The nail matrix forms new nail at the nail base by pushing the existing nail forward to replace that worn or broken at the free edge. Nails protect the tips of digits from inadvertent mechanical injury. They also help stabilize the skin at the tips of the fingers and toes, so that on the opposite side the skin can establish a secure friction grip on objects grasped.

Only primates have nails (Fig. 5.16 a). In other vertebrates, the keratinizing system at the terminus of each digit produces claws or hooves (Fig. 5.16 b, c). *Claws* or *talons* are curved, laterally compressed keratinized projections from the tips of digits. They are seen in some amphibians and in most birds, reptiles and mammals. *Hooves* are large keratinized plates on the tips of the ungulate digits.

5.6.2 Horns and Antlers

Horned lizards have processes extending from behind the head that look like horns but are specialized, pointed epidermal scales. Mammals are the only vertebrates with true horns or antlers.

The skin, together with the underlying bone contributes to both true horns and antlers. As these structures take shape, the underlying bone rises up, carrying the overlying integument with it. In horns, the associated integument produces a tough, cornified sheath that fits over the bony core (Fig. 5.17 a). In antlers, the overlying living skin (called 'velvet') apparently shapes and provides vascular supply to the growing bone. Eventually the velvet falls away to unsheath the base bone, the actual material of the finished antlers (Fig. 5.17 b).

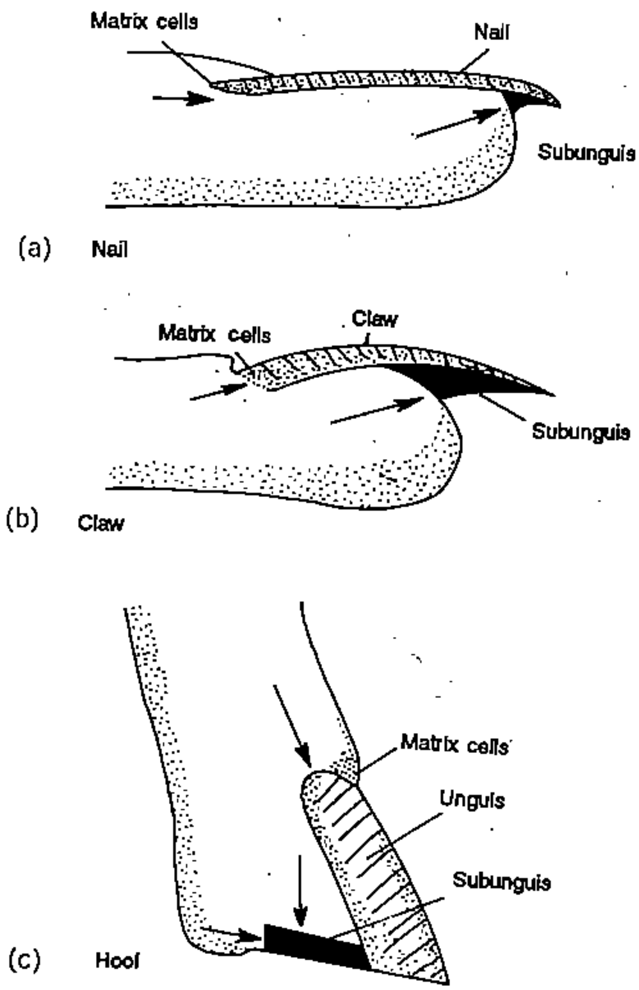


Fig. 5.16: Epidermal derivatives. (a) The nail is a plate of cornified epithelium growing outward (arrows) from proliferating matrix cells at its base and from subunguis. (b) Claw (c) Hoof.

True antlers occur only in members of the *Cervidae* (e.g. deer, elk, moose). Typically, only males have antlers, which are branched and shed annually. There are notable exceptions. In deer, the antler usually consists of a main beam from which branch shorter points.

The annual cycle of antler growth and loss in the white-tail deer for example, is under hormonal control. In spring, increasing length of daylight stimulates the pituitary gland to release hormones that stimulate antlers to sprout from sites on the skull bones. By late spring, the growing antlers are covered by velvet. By fall, hormones produced by the testes inhibit the pituitary and the velvet dries.

Among mammals, true horns are found among members of the family bovidae (e.g. cattle, antelope, sheep, goats, bison). Commonly horns occur both in males and females, are retained year round, and continue to grow throughout the life of the individual. The horn is unbranched and formed of a bony core and a keratinized sheath.

Unlike true horns of bovids, horns of the pronghorn, family Antilocapridae, are forked in adult males. The rhino horn does not include a bony core, so it is exclusively a product of the integument. It forms from compacted keratinous fibre.

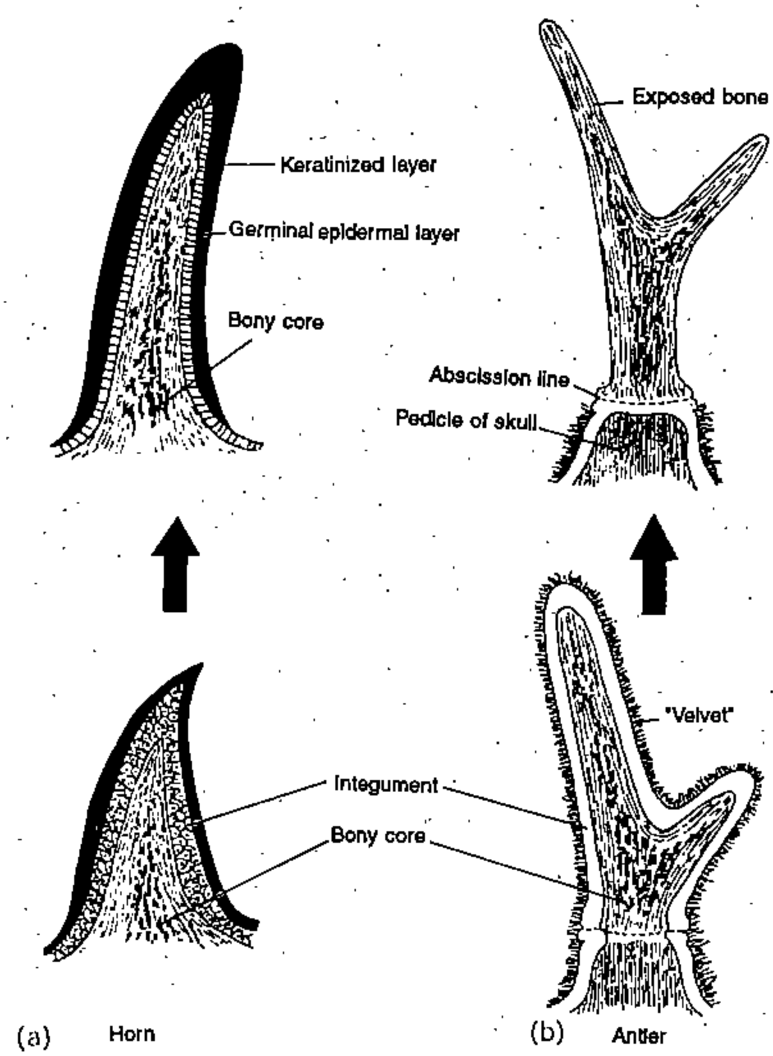


Fig. 5.17: Horns and Antlers. (a) Horns appear as outgrowth of skull beneath the integument, which forms a keratinized sheath. b) Antlers also appear as outgrowth of the skull beneath the overlying integument, which is referred to as 'velvet' because of its appearance.

5.6.3 Baleen

The integument within the mouths of mysticete whales forms plates of *baleen* that act as stainers to extract krill from water gulped in the distended mouth. Although, it is sometimes referred to as "whalebone", baleen contains no bone. It is a series of keratinized plates that arise from the integument. During its formation, groups of dermal papillae extend and lengthen outward, carrying the overlying epidermis. The epidermis forms a cornified layer over the surface of these projecting papillae. Collectively, these papillae and their covering of epidermis constitute the plates of baleen (Fig. 5.18).

5.6.4 Scales

Scales have many functions. Both epidermal and dermal scales are hard, so when they receive mechanical insult and surface abrasion, they prevent damage to soft tissues beneath. The density of scales also makes them a barrier against invasion of foreign pathogens, and they retard water loss from the body. In sharks and fishes, scales dampen the boundary layer turbulence to increase swimming efficiency. Some reptiles regulate the amount of surface heat they absorb by turning their bodies forward or away from the sun.

Epidermal scales compose the major component of the skin of reptiles. They are also present in birds along their legs and in some mammals, such as the beaver, they cover the tail.

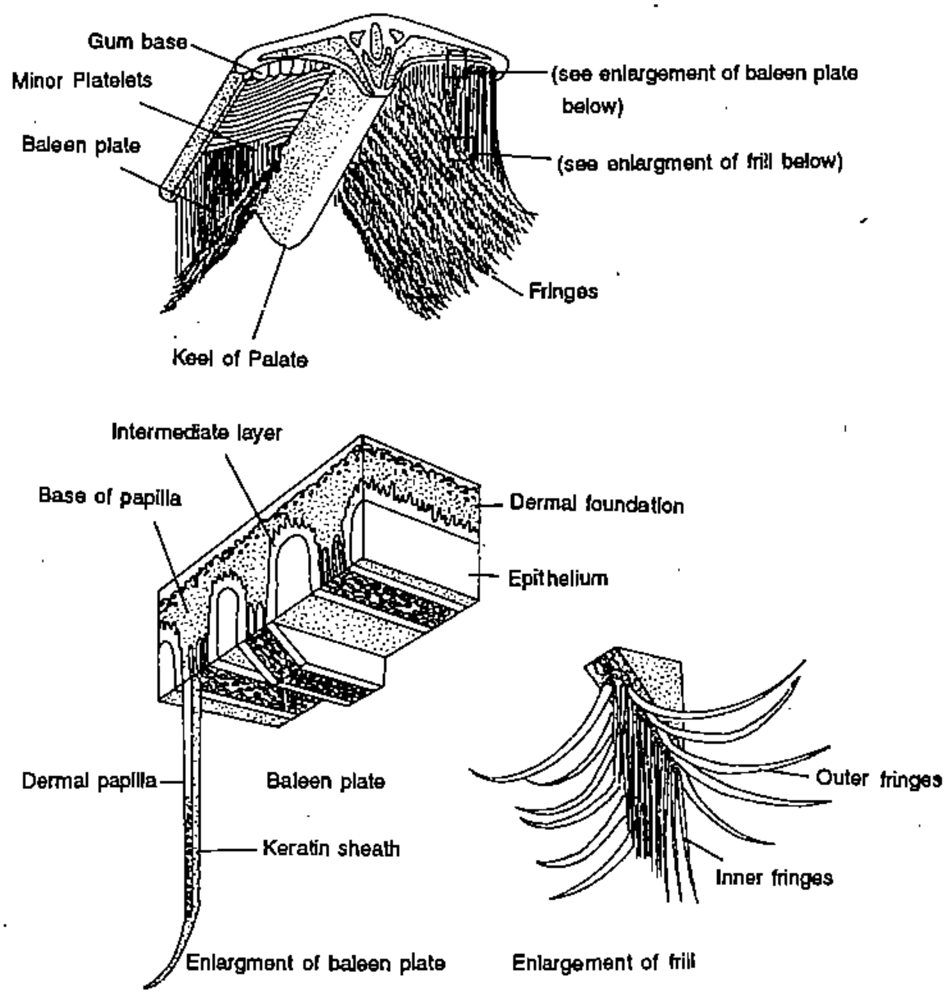


Fig. 5.18: Baleen from a whale. The lining to the mouth includes an epithelium with the ability to form keratinized structures. Groups of outgrowing epithelium become keratinized and frilly to form the baleen.

5.6.5 Dermal Armor

Dermal bone forms the armor of ostracoderm and placoderm fishes. Being a product of the dermis, dermal bone finds its way with a great variety of structures. Dermal bone supports the scales of bony fishes but tends to be lost in tetrapods. It is absent in the skin of birds and most mammals. Exceptions have been noted earlier, namely, in the fossil mammal *Glyptodon* and in the skin of the living armadillo. However, selected dermal bones take up residence in the fish skull and pectoral girdle.

The shell of turtles is a composite structure. The dorsal half of the shell is the *carapace* formed by fusion of dermal bone with expanded ribs and vertebrae. Ventrally the *plastron* represents fused dermal bones along the belly. On the surface of both carapace and plastron, keratinized plates of epidermis cover this underlying bone.

5.6.6 Mucus

Mucus produced by the skin serves several functions. In aquatic vertebrates, it inhibits entrance of pathogens and may even have slight antibacterial action. In terrestrial amphibians, mucus keeps the integument moist, allowing it to function in gas exchange. Although cutaneous respiration is prominent in amphibians, it occurs in many vertebrates as well. For example,many turtles rely on cutaneous gas exchange as they hibernate submerged in ice-covered ponds during winter. Sea snakes may depend on cutaneous respiration for up to 30 per cent of their oxygen uptake. Similarily fishes such as the plaice, European eel and mudskipper may depend on some cutaneous gas exchange to meet their metabolic requirement.

Mucus is also involved in aquatic locomotion. As a surface coat, it smoothes the irregularities and rough surface features on the epidermis to reduce the friction met by a vertebrate swimming through relatively viscous water.

5.6.7 Colour

Skin colour results from complex interactions between physical, chemical and structural properties of the integument. Changes in blood supply can redden the skin, as in blushing. The *differential scattering* of the light, referred to as *Tyndall scattering*, is the basis of much colour is nature. This is the phenomenon that makes the clear day sky appear blue. In birds, air-filled cavities within feather barbs take advantage of this scattering phenomenon to produce blue feathers of kingfishers, blue jays, and blue-birds. Many black, brown, red, orange and yellow colours result from pigments. Pigments produce colour by selective light reflection. Interference phenomena are responsible for *iridescent colours.*

Many of the pigments producing colours by this variety of physical phenomena are synthesized by and held in specialized chromatophores. Most chromatophores arise from embryonic neural crest and can take up residence almost anywhere within the body.

On the basis of form, composition and function, four groups of chromatophores are currently recognized. The most well known of these is the melanophore that contains the pigment melanin. There are two types of *melanophores*. The dermal melanophore is broad, flat cell that changes colour rapidly and is found only in ectotherms. The *epidermal melanophore* is a thin, elongated cell prominent in endotherms but present in all vertebrates.

A second type of chromatophore is the *iridophore* which contains light reflecting, crystalline guanine platelets. It is found in ectothermic vertebrates and in the iris of the eye of some birds. Two other types of chromatophores are the *xanthophores*, containing yellow pigments and the *erythrophore*, so called because of the red pigments.

Sunlight can influence physiological changes in chromatophore activity. Increased exposure stimulates increased production of pigment granules, resulting in darker skin over a period of days.

Box 5.2 : Skin Colour

In humans, the conversion of the dehydrocholestrol to vitamin D, which is necessary for normal bone metabolism requires small amounts of UV radiation. If vitamin D is insufficient, bones become soft and deformed. On the other hand, too much ultraviolet radiation can be very damaging to deep living tissues. Skin alone is not especially effective in reflecting or safely absorbing these wavelengths of solar radiation. This task falls to the chromatophores and the pigment.

Only a few minutes of exposure to sunlight each day is necessary to convert enough precursor (dehydrocholestrol) into Vitamin D to meet an individual's metabolic needs. In tropical regions near the equator, sunlight passes directly through the absorbing layers of the atmosphere to strike the surface of the earth. Terrestrial vertebrates covered with hair, feathers or scales have some external protection against sun exposure. Too much UV radiation can produce harmful amounts of vitamin D, sunburn and a higher incidence of skin cancer.

The number of chromatophores in the skin is evolutionary adaptation to the level of exposure to ultraviolet radiation.

SAQ 4

a) Which are the four successive layers present in the integument of mammals?

....

....

b) Which muscle is attached to the hair follicle of human beings and makes hair stand erect?

....

....

SAQ 5

a) Which pigment in human beings causes skin colouration?

....

....

b) Though misleadingly referred to as 'whale-bone', it contains no bone. What is it?

....

....

5.6 SUMMARY

- Integument is a composite organ. Fundamentally it is composed of epidermis. and dermis, separated by the basement membrane.
- The dermis of many vertebrates produces *dermal bones*, prominent in fishes. The epidermis of terrestrial vertebrates form *keratinized* layer, called as *stratum corneum*.
- In cartiliginous fishes, *placoid scales* are present. Bony fishes are characterised by *cosmoid scales* and *ganoid scales*. Teleosts are characterised by two types of scales: *cycloid scales* and *ctenoid scales*.
- Skin of amphibians is specialized for respiration i.e. *cutaneous respiration*, *Mucous glands* and *poison glands* are main characteristics of amphibians. Chromatophores may occasionally be found in the amphibian epidermis.
- In reptiles keratinization is much more extensive. Integumental glands of reptiles are restricted to certain areas of the body. Many lizards possess *femoral glands* in the thighs. Crocodiles and turtles have *scent glands*.
- Feathers distinguish birds from all other vertebrates. Bird skin has *uropygial glands* at the base of tail and *salt gland* on the head.
- The epidermis of mammals is specialized as *hair, nails or glands*. Keratinocytes are the most prominent cell types of epidermis. Skin colour of mammals is due to pigment *melanin*. Principally there are two main types of glands in mammals i.e. *sebaceous* and *sweat glands*. Derived from them are *scent* and *mammary* glands.
- Baleen, claws, hooves, horns, antlers and dermal armor are specialized derivatives of the integument.

5.7 TERMINAL QUESTIONS

1. What is the difference between cycloid scale and ctenoid scale of teleosts?

....

....

....

....

2. Write two important differences between scales of reptiles and fishes?

....

....

....

....

3. What are the different types of feathers? What are their functions?

....

....

....

....

....

4. What is the function of sebaceous glands? Write the various types of sebaceous glands present in mammals?

....

....

....

....

....

5. Explain keratinization in terrestrial vertebrates.

....

....

....

....

....

5.8 ANSWERS

Self Assessment Questions

1. a) ostracoderm fishes
   b) *stratum compactum*
   c) *stratum corneum*
   d) epidermal scale
   e) basement membrane

2. i - c   ii - a   iii - b
   iv - e   v - d   vi - f

3. a) epidermal cells and unicellular glands
   b) placoid scales
   c) ganoid scales
   d) amphibians
   e) crocodiles and some lizards
   f) feathers

4. a) i) *stratum spinosum*
   ii) *stratum granulosum*
   iii) *stratum lucidum*
   iv) *stratum corneum*
   b) Arrector pili

5. a) Melanin   b) Baleen

Terminal Questions

1. Cycloid scale is composed of concentric rings or **circuli** and ctenoid scale has a fringe of projections along its posterior margin.

2. The scales of fishes are of dermal origin. But reptilian scales lack bony undersupport or any significant structural contribution from the dermis. It is a fold in the surface epidermis.

3. There are four main types of feathers in birds : Contour feathers, down feathers, filoplumes and flight feathers. Contour feathers aerodynamically shape the surface of the bird. Down feathers lie close to the skin as thermal insulation. Filoplumes are often specialized for display and flight feathers constitute the major aerodynamic surface.

4. Sebaceous glands produce an oily secretion called sebum. The **wax glands** of outer ear canal, which secrete wax and **meibomian glands** of eyelid, which secrete an oily film on the surface of eyeball are derived from sebaceous glands.

5. Keratinocytes of epidermis form the dead, superficial cornified layer of the skin. The surface of keratinized cells are continually exfoliated and replaced by cells of stratum corneum.

UNIT 6 DIGESTIVE SYSTEM

Structure

6.1 INTRODUCTION

In the previous unit you have studied that nearly all the vertrebrates consist of bony or horny desposits in the skin, that may be either epidermal or dermal or both; but never cuticular, like the armour of an arthropod or the shell of a mollusc. You have also studied about functional modifications of skin in different vertebrates groups. In this unit you will study that all vertebrates possess alimentary canal as an organ for digestion and absorption of food materials. Digestion does not occur in a particular region of the alimentary canal but takes place in different regions so that digestion of food materials may be completed. We shall discuss here the feeding mechanism in different groups of chordates such as fishes, amphibians, reptiles, birds and mammals as well. We will deal with a comparative account of dental formula and digestive system at length in different mammalian groups like herbivores and carnivores.

Objectives

After reading this unit you should be able to:

- describe the dentition pattern in vertebrates,
- describe the feeding adaptations in chordates,
- trace the evolution of alimentary canal in mammalian vertebrates, and
- detail the organisation of alimentary canal of herbivores, carnivores and omnivores.

6.2 DENTITION

In unit 4(Section 4.3) of this course you studied briefly about dentition in mammals. Now you will read about mammalian dentition in greater detail.

Teeth are present in nearly all mammals, but in some they do not occur in adults such as in Whalebone whales. In *Ornithorhynchus* and *Tachyglossus* (Echidna) teeth are absent throughout life. In some ant-eaters like Echidna teeth are developed in foetus and are discarded in uterus resulting in adults being devoid of them.

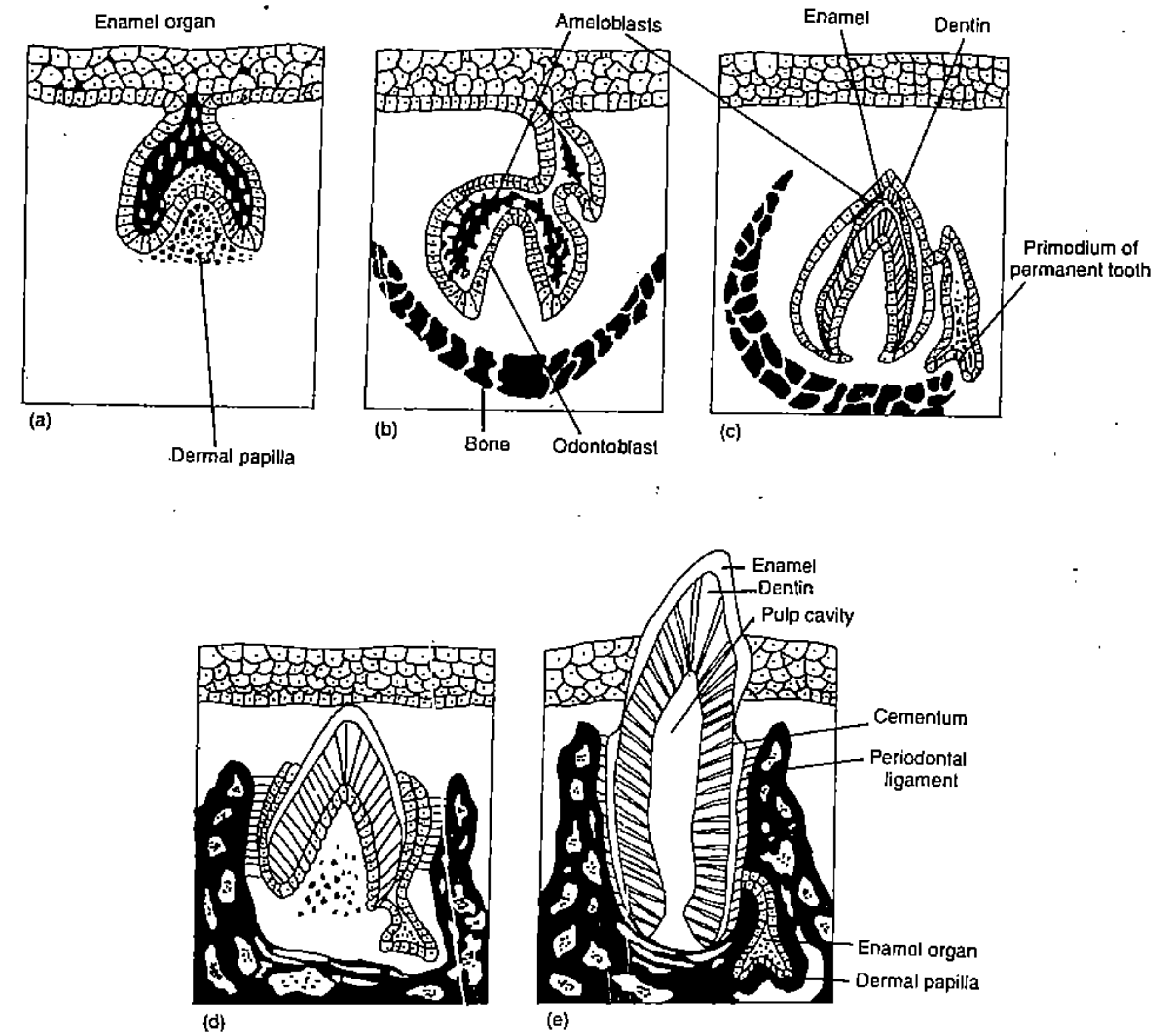


Fig. 6.1: Mammalian tooth development. (a) Enamel organ (from the epiderms) and dermal papilla (from the dermis) appear, (b) Ameloblasts are the source of tooth enamel and form the enamel organ. Odontoblasts are the source of dentin and form from the dermal papilla. Bone appears and begins to delineate the socket in which the tooth will reside, (c) The primordium of the permanent tooth appears, (d) Tooth growth continues, (e) The deciduous tooth erupts and is anchored in the socket by a well-established periodontal ligament. The enamel organ and dermal papilla of the permanent tooth primordium will not begin to form the tooth until shortly before the deciduous tooth is lost.

Teeth develop partly from the epidermis and partly from the underlying dermis, (Fig. 6.1). In mammals each tooth is lodged in a socket called alveolus in the jaw. The part of tooth developed from epidermis is **enamel**. The remainder of tooth – **dentine, cement** and **pulp** – is formed from the subadjacent **mesodermal** tissue.

Along the oral surface of the jaw is formed a ridge-like ingrowth of the ectoderm–the dental lamina – and from it a bud is given off in the position to be occupied by each of the teeth. The bud becomes constricted off as a conical cap of cells – the enamel organ which remains in continuity with the dental lamina by a narrow isthmus. The cap-like form of the enamel organ is brought about by its growth over a concentration of dermal tissue, the **dental papilla**. The dental papilla has a rich blood supply. On the surface of this papilla, in contact with the enamel organ, a layer of cells called **odontoblast** becomes arranged rather like an epithelium. This layer of odontoblast is the dentine forming layer. The cells of the enamel-organ which are in contact with the dental papilla become long and cylindrical to form **ameloblasts**. The layer of ameloblasts forms the **inner enamel epithelium**. The cells on that part of the surface of the enamel organ which is not in contact with the dental papilla form a layer of cuboidal cells called the **outer enamel epithelium**. Between these two layers the remaining cells of the enamel organ become modified: those in contact with the inner enamel-epithelium form a distinct layer called the **stratum intermedium**, while the remainder become vacuolated and form a loose tissue called the **stellate reticulum**. Around the enamel organ and dental papilla there develops a layer of connective tissue called **dental follicle**. This contains many blood vessels.

The hard part of tooth begins to develop by the formation of a cap of predentine produced by the odontoblasts; and of a layer of enamel matrix which is laid down on the surface of this (produced by the ameloblasts). The predentine and enamel matrix calcify to form **dentine** and **enamel**. Additional layers are added until crown of the tooth is complete. The enamel organ then degenerates, but dental papilla remains as the pulp of the fully developed tooth. Roots are formed and the crown of the tooth then erupts into the mouth cavity. The roots of a tooth consist of dentine over which a layer of cement is deposited. This is formed by the cells of the dental follicle. There is no enamel on the roots. In some mammals cement is also formed on the surface of the enamel on the crown, e.g. modern horses, rabbits, some rodents, some artiodactyles and the elephants. In mammals the roots of teeth generally open at their bases by small foramina through which nerves and blood vessels enter the pulp (Fig. 6.2). However, in some (e.g. the molar teeth of modern horses and elephants) formation of roots is delayed, and the enamel organ which persists around the sides and within the folds of the crown continues to add to height of the tooth long after it has erupted and come into use. In other mammalian teeth (e.g. the incisors of rodents and elephants, and all the teeth of rabbits) roots are never formed and the crowns of the teeth continue to grow throughout life. Such teeth are said to have persistent pulps.

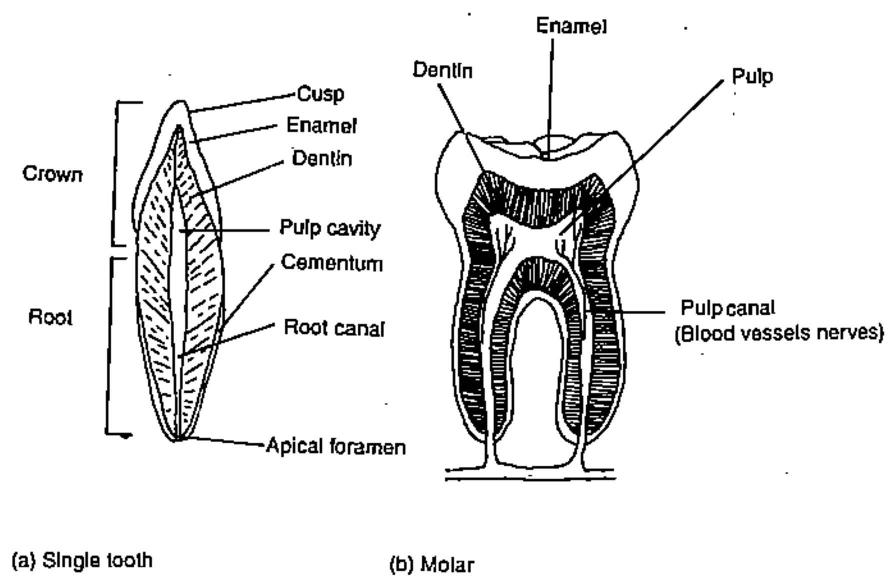


Fig. 6.2 : Tooth structure, (a) Tooth with single root, (b) Molar tooth with roots.

Usually mammals develop two distinct sets of teeth the deciduous (milk) and the permanent dentitions (Fig. 6.3). Sometimes there is only one set present. Accordingly **diphyodont and monophyodont** dentitions are distinguished. In nearly all of the latte· however, another set is developed, though the teeth may be absorbed early or remain as functionless vestiges. The milk teeth in mammals with typical diphyodont dentition sometimes disappesr at an early stage (e.g. seal), and sometimes persist and do not become replaced by the permanent teeth till long after birth (e.g.Man). In lower vertebrates teeth are usually homodont, similar in general appearance throughout the mouth. Modern turtles and birds lack teeth altogether but mammals have **heterodont** teeth which differ in general appearance throughout the mouth. In some mammals the number of teeth is not definite, e.g., dolphins and porpoises. Such teeth are uniform in which means their teeth are continuously replaced. A polyphyodont pattern of replacement ensures rejuvination of teeth if wear or breakage diminishes their function. However, most mammals are diphyodont with just two sets of teeth.

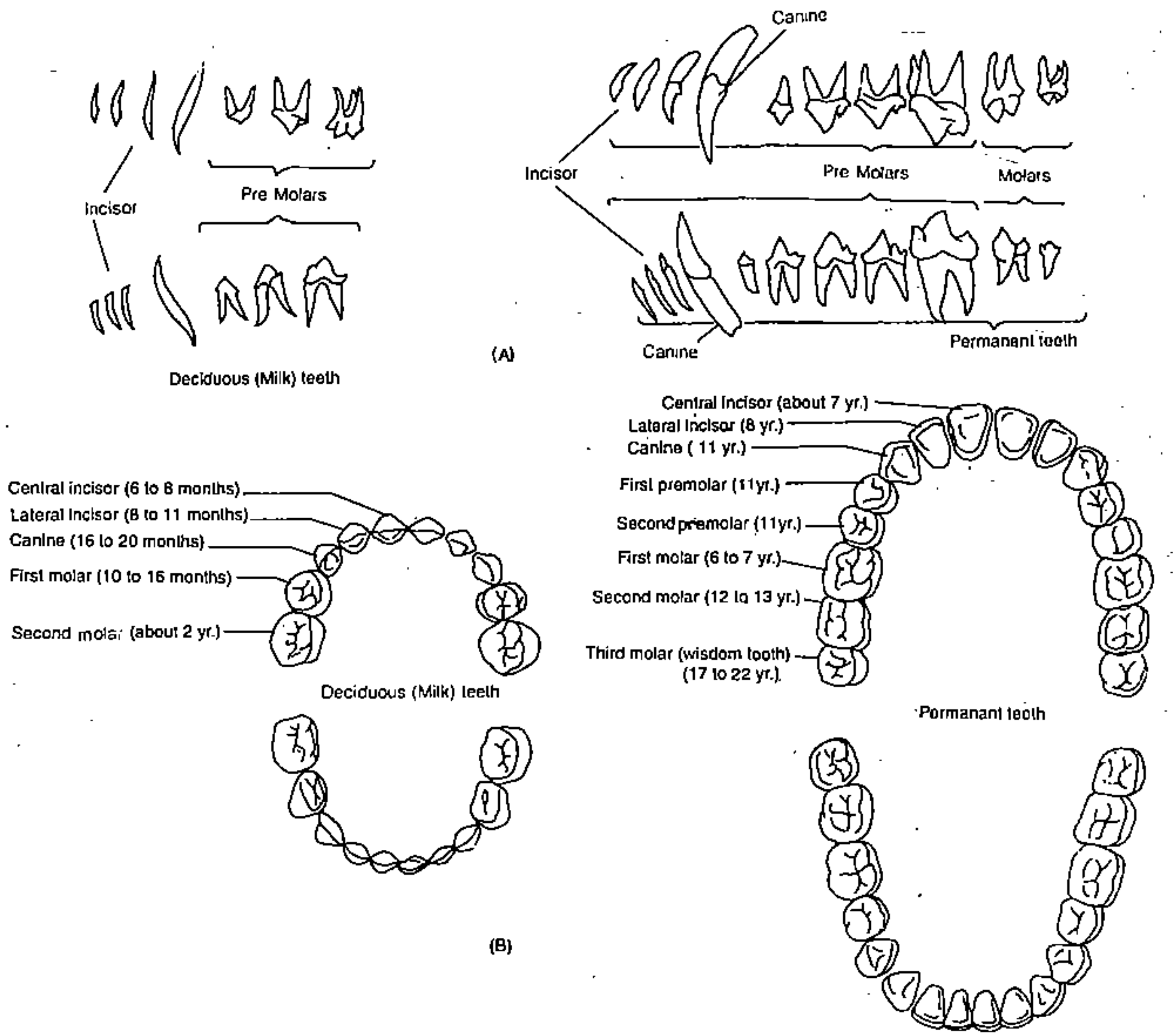


Fig. 6.3: A, Canis: Deciduous and permanent dentition. Upper (I) and lower (II) jaws of dog. B, Human deciduous and permanent teeth. (a) Deciduous teeth. Approximate time of eruption is shown in parentheses. (b) Permanent teeth.

Specialized teeth in Mammals:

In mammals, the teeth are not only specialized to capture or clip food, but they are also specialized to chew it. Infact, the dentition is so distinctive in different groups that it often becomes the basis for identifying living animals and fossil species.

The heterodont dentition of mammals includes four types of teeth within the mouth – i.e. **incisor** at the front, **canine** next to them, **premolars** along the sides of the mouth, and **molars** at the back. The number of each type differs among groups of mammals. The dental formula is shorthand expression of the number of each kind of tooth on one side of the jaw for a taxonomic group. For example, the dental formula of Coyote *(Canis latrans)* is:

$$I.\frac{3}{3},\ C.\frac{1}{1},\ Pm.\frac{4}{4},\ M.\frac{2}{3}$$

This means that there are three upper and three lower incisors (I), one upper and one lower canine (C), four upper and four lower premolars (Pm), and two upper and three lower molar (M), 21 per side or 42 total. Sometimes, the dental formula is written as 3-1-4-2/3-1-4-3, the first four numbers indicating the upper teeth and the second four lower teeth of the coyote. The dental formula for the mule deer *(Odocoileus hemionus)* is 0-0-3-3/3-1-3-3. You notice that the missing upper incisors and canines are indicated by zeros.

Incisors are generally used at the front of the mouth for cutting or clipping; canines for puncturing and holding; premolars and molars for crushing or grinding food. It is often hard to distinguish premolars from molars visually. The collective term used for both is cheek or molariform teeth. Cheek teeth may be quite diverse, a reflection of their many specialized functions. In human and pigs crowns are low or **brachyodont** (Fig.6.4). In horses, crowns are high or **hypsodont** (Fig.6.4).

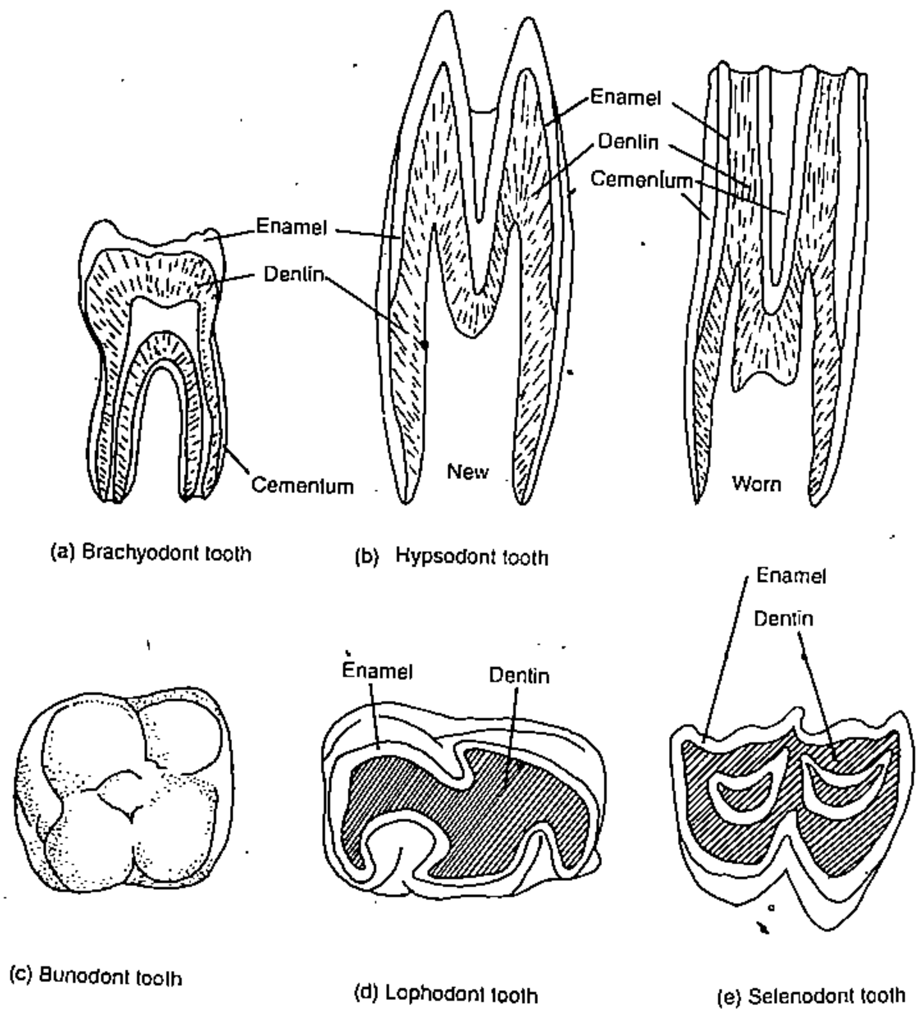


Fig. 6.4: Crown height and occlusal surfaces. Tooth height:(a) Brachyodont tooth. (b) Hypsodont tooth. When the occlusal surface of a newly erupted hypsodont tooth (left) becomes worn, alternating layers of dentin and enamel are exposed (right). The alternating layers of varying hardness ensure that ridges and depressions will form, producing a rough surface that does not become smooth after prolonged use. In mammalian teeth, various occlusal surfaces occur(c) Bunodont tooth, (d) Lophodont teeth, (e) Selenodont tooth.

If the cusps form peaks as in Omnivores the teeth are **bunodont** (Fig. 6.4). In perissodactyls and rodents, drawn out into ridges produce **lophodont** teeth (fig. 6.4). In artiodactyls, crescent-shaped cusps characterise **selenodont** teeth (Fig. 6.4). Hypsodont teeth are typically found in herbivores that grind plant material to break tough cell walls. Their occlusal surface is worn unevenly because the minerals which form the surface-enamel, dentin and cementum-differ in hardness. Occlusal surfaces are functionally important because they ensure that ridges and depressions persist throughout life, thereby maintaining a rough grinding surface which does not become smooth with continued use (Fig.6.4).

Mammals possess a variety of specialized teeth. In some, **sectorial teeth** are modified so that ridges on opposing teeth slice by one another to cut tissue. In some primates, cutting edges form on the upper canine and lower first permolar, the sectorial teeth. These teeth are deployed in fights between individuals or in defense. In carnivores, the upper last premolar and lower first molar form carnassials, specialized sectorial teeth which slice against each other like a scissors to cut sinew and muscle. Tusks arise from different teeth in different species. In elephants, the tusks are elongate incisors (Fig. 6.5) and in walruses, the paired tusks are upper canines that protrude downward (Fig. 6.5). In carnivorous mammals canine teeth together with powerful jaws are used to kill preys. Sometimes these teeth are used to puncture major blood vessels in the neck, causing the victim to bleed profusely and weaken. A carnivore such as an adult lion is more likely to bite into the neck and collapse the trachea to suffocate its prey. Some mammals such as anteaters and baleen whales lack teeth altogether (Fig. 6.5).

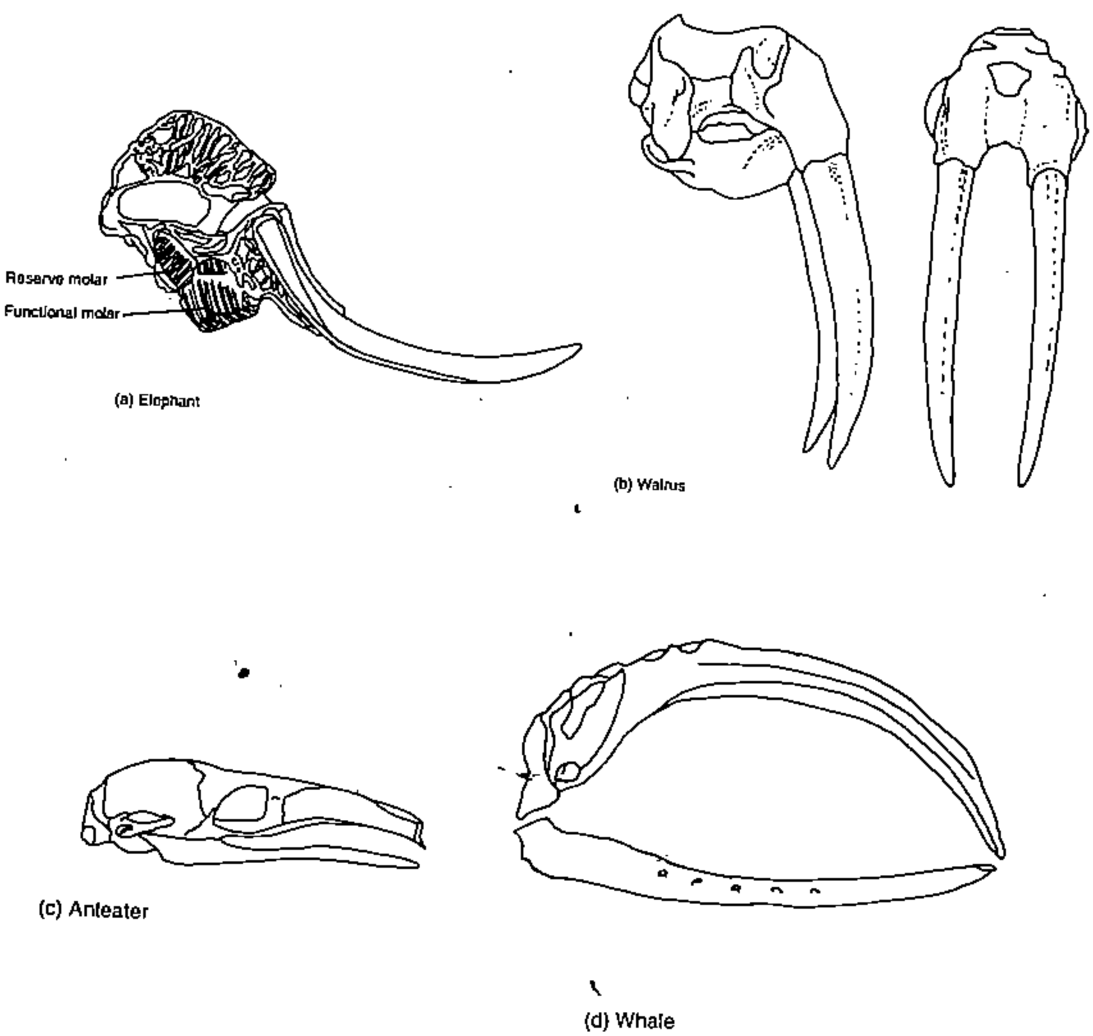


Fig. 6.5: Specialized mammalian teeth. Tusks arise from both upper incisors in the elephant (a) Elephant, and from canines in walruses, (b) Walrus, The teeth are absent in adult anteaters, (c) Anteater, and baleen whales, (d) Whale.

SAQ 1

In the following statements, put a tick mark (√) on the correct ones and a cross (X) mark on the incorrect ones in the given boxes.

i) The part of the tooth developed from the epidermis is the enamel. ☐

ii) The predentine and enamel matrix do not calcify to form dentine and enamel. ☐

iii) The enamel organ degenerates but dental papilla remains as the pulp of the fully developed tooth. ☐

iv) Some mammals have indefinite number of teeth e.g. elephant and monkey. ☐

v) Elephants have extremely specialised teeth because they do not have canines and lower incisors. ☐

vi) In insectivorous chiroptora molars are devoid of pointed cusp while in frugivorous forms molars are longitudinally grooved or excavated. ☐

6.3 FEEDING MECHANISMS

In Unit 7 of Physiology Course (LSE-05) the feeding mechanism have been discussed at length; however, for making a comparative study of feeding mechanisms in Chordates, various feeding devices are described here in a systematic evolutionary sequence. Obtaining nutritional essentials is clearly a key to the success of any animal/species. Much of the routine functioning of an animal is directed towards this purpose. The complexity and sophistication of the nervous system, for example, are due largely to the selective pressure brought to bear on obtaining of sufficient food and on avoidance of becoming someone else's meal. Animals use various strategies to feed. Some species search, stalk, pounce, capture, and kill. Sessile animals, unable to move about, resort to more subtle means, such as surface absorption, filter feeding or trapping. We will now discuss various devices employed by various groups of chordate animals.

6.3.1 Fishes and Amphibians

(i) Fishes: Lower vertebrates like cyclostomes, elasmobranchs, teleosts, amphibians use variety of feeding mechanisms. For any fish feeding is one of the main concerns of day-to-day living. Most of the fishes are carnivores. They prey on a variety of animal food from zooplankton and insect larvae to large vertebrates. Some deep sea fishes are capable of eating prey nearly twice their own size. This is an adaptation for life in a world where meals are infrequent. Most advanced ray-finned fishes can not masticate their food. Some such as the wolf eel have molar like teeth in the jaws for crushing their prey, that may include hard bodied crustaceans. Others grind their food using powerful pharyngeal teeth in the mouth to sieze their prey. The incompressibility of water makes the task even easier for many large mouthed predators. When the mouth is opened, a negative pressure is created which sweeps the prey inside.

A second group of fishes are herbivores eating flowering plants, algae and grasses. Although plant eaters are relatively few in number, they are crucial intermediates in the food chain specially in fresh water rivers, lakes, and ponds which contain very little plankton.

The filter feeders which crop the abundant microorganisms of the sea form a third and diverse group of fishes ranging from fish larvae to basking shark. One of the most important, successful and widely employd methods for feeding is to have evolved filter feeding (Fig. 6.6). Majority of filter feeders use ciliated surfaces to produce currents which can draw drifting food particles into their mouths. Free-swimming filter feeders have the advantage of being able to swim through their food and thus can be more selective in their feeding. Filter feeding has frequently evolved as a secondary modification among representatives of groups that are primarily selective feeders such as fishes, basking shark etc. A fourth group of fishes are **omnivores** feeding on both plant and animal food. Finally there are scavengers which feed on organic debris and the parasites that suck the body fluids of other fishes.

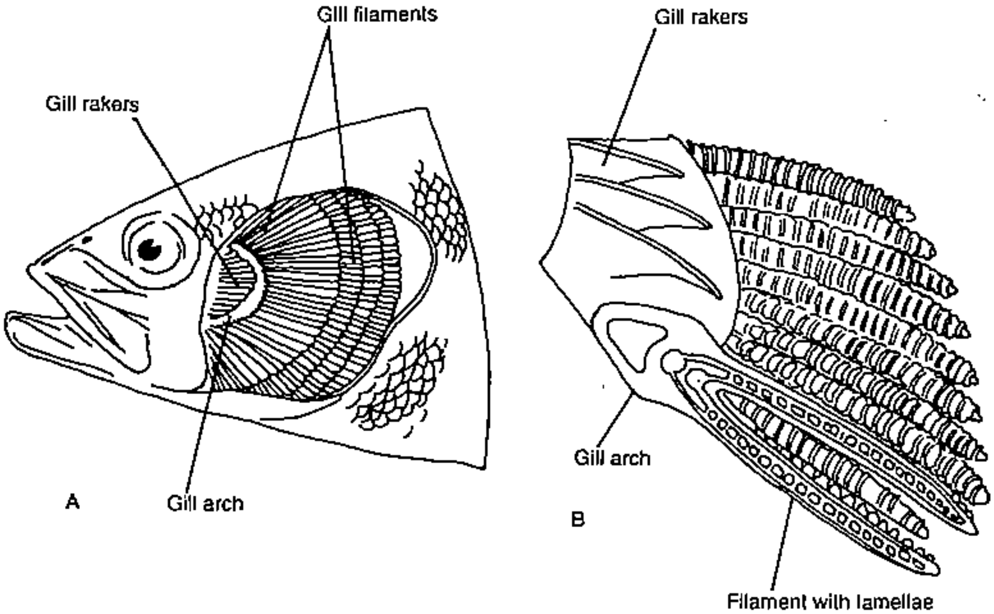


Fig. 6.6: Herring and other filter-feeding fishes (class Osteichthyes, phylum Chordata) use gill rakers, which project forward from the gill bars into the pharyngeal cavity to strain out planktons. Herring swim almost constantly, forcing water and suspended food into the mouth, food is strained out by gill rakers, and water passes out of the gill openings.

Lower vertebrates such as cyclostomes, elasmobranchs, and teleosts have pointed teeth, mounted on jaws or palate, which aid in holding, tearing and/or swallowing prey. Among the lower vertebrates it is common to swallow prey as a whole.

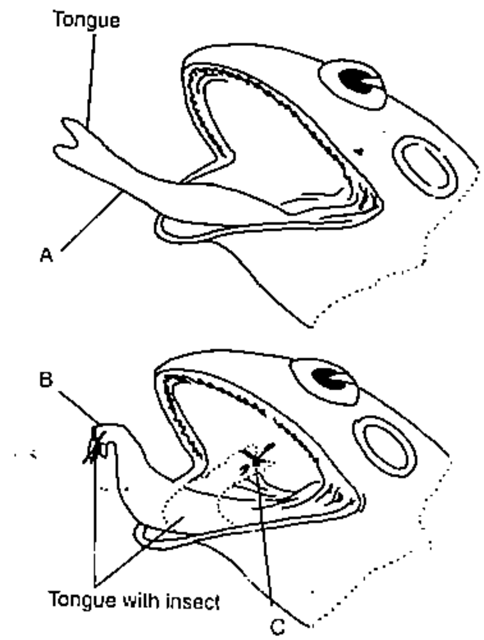


Fig. 6.7: Frog. Position of tongue in catching an insect. A-Tongue shot out. B-Insect sticks to it. C-tongue returned. The tongue in frog is highly movable. Infact, frogs use their tongue to capture insects. The tongue is attached to the front of the mouth permitting the sticky organ to be flicked far out with considerable speed and accuracy compared one whose tongue is fixed at the back. The prey is then crushed against a peculiar patch of teeth on the roof of the mouth and swallowed whole because amphibians cannot chew either.

(ii) Amphibians : Frogs are carnivores like most other adult amphibians. They feed on insects, spiders, worms, slugs, snails, millipedes or any thing else which moves and is small enough to be swallowed whole. They snap at moving prey with their protrusible tongue (Fig. 6.7) which is attached to the front of the mouth and is free behind. The free end of the tongue is highly glandular and produces a sticky secretion, that adheres to the prey. Teeth present on pre-maxillae, and vomers are used to prevent escape of prey but not for biting or chewing them. The larval stages of anurans (tadpoles) are herbivores, feeding on pond algae and other vegetable matter.

6.3.2 Reptiles and Birds

(i) Reptiles : You will come across with wide variety of feeding devices used by reptiles. When a chameleon snares a dragonfly, it anchors its tail and feet to a branch and then after few second it launches its sticky tipped foot-long tongue to trap the prey.

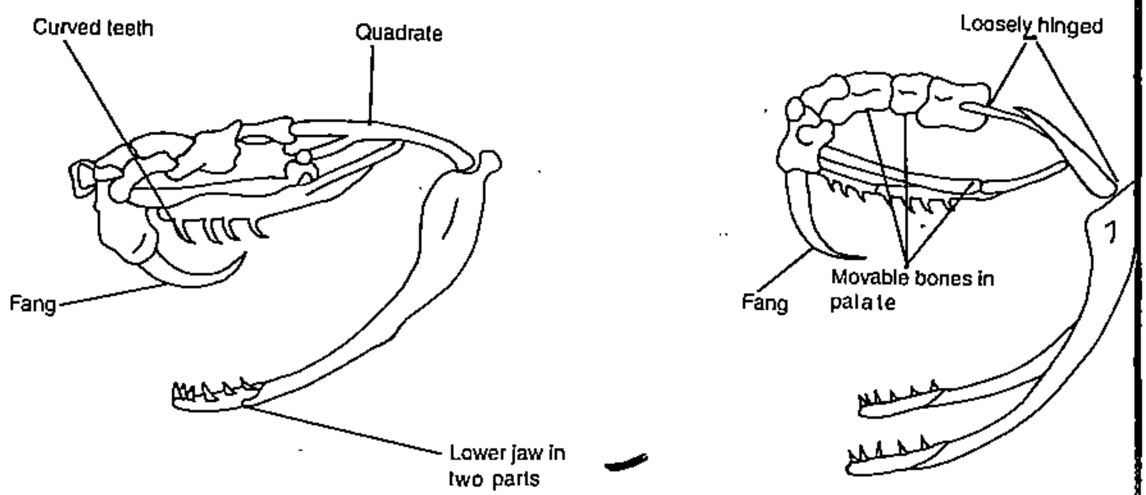


Fig. 6.8: Rattlesnake skull in a side view. (A) Partly open. (B) Open for striking. The fangs are tubular for delivery of toxin and are hinged to facilitate their storage between strikes.

Reptilian jaws or palate are provided with pointed teeth that help these animals in holding, tearing or swallowing their prey. Submammalian teeth are generally poorly differentiated from one another. One exception is found among the poisonous snakes, such as vipers, cobras and rattle snakes, which have modified teeth, called fangs which are used to inject Venom (Fig. 6.8). These fangs are either equipped with a groove or are hollow, very much like a syringe needle to deliver venom at the site of bite. In rattle snakes, fangs fold back against the roof of the mouth, but extend perpendicularly when the mouth is opened to strike. Snakes cannot tear or chew their food. Captured prey is swallowed whole, a surprising feat since the prey is often larger than the snakes. The mouth is extremely flexible because of the arrangement of bones in the head and jaw. The lower jaw is loosely attached to the quadrate bone and even the bones of the palate are movable, all helping draw the prey into the gaping mouth. The oesophagus and stomach can stretch considerably as can the body wall. There is no sternum, so the ribs can move freely as the prey passes through the gut. This enables a snake to swallow animals larger than the diameter of its head.

(ii) Birds : With the advantage of flight, birds could hunt insects on the wing and carry their assault to insects refuges mostly inacessible to their earthbound tetrapod peers. Today there are birds to hunt nearly every insect. They probe the soil, search bark, scrutinize every leaf and twig, and drill into insect galleries hidden in tree trunks. Birds consume a variety of other animal foods such as worms, molluscs, crustaceans, fish, frogs, reptiles, mammals as well as other birds. A very large group of birds feed on nectar. Some birds are omnivorous which will eat whatever is seasonally abundant. However, omnivorous birds compete with numerous other omnivores for the same broad spectrum of food. Others are specialists called stenophagous, or "narrow-eating" species that have the pantry to themselves but at a price.

Beaks of birds are strongly adapted to specialized food habits from generalised types such as the strong, pointed beaks of crows, to grotesque, highly specialised ones in flamingoes, hornbills and toucans (Fig. 6.9). The beak of a wood pecker is a straight, hard, chisel like device. Anchored to a tree trunk with its tail serving as a brace, the woodpecker delivers powerful, rapid blows to build nests or expose the burrows of wood boring insects. It then uses its long, flexible, barbed tongue to seek out insects in their galleries (Fig. 6.10). Wood peckers skull is especially thick to absorb shock.

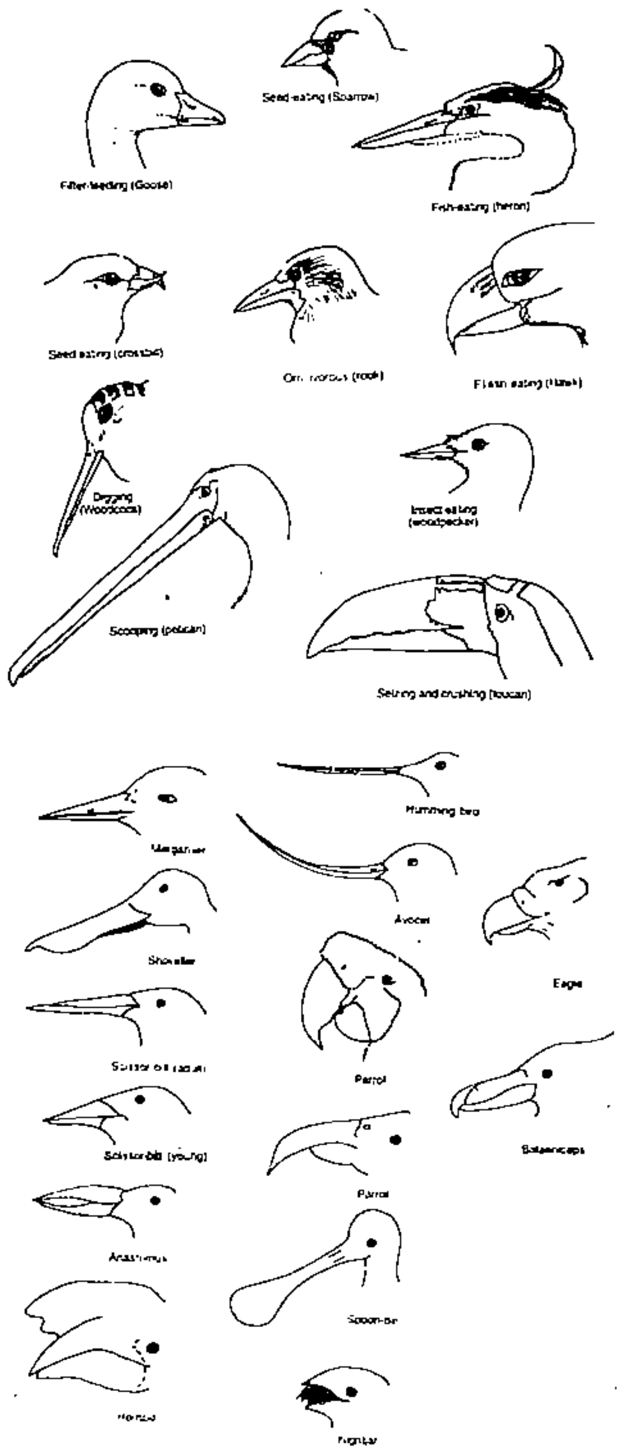


Fig. 6.9 : Bird beaks adapted to different modes of feeding.

Birds have no teeth, but instead have horny beaks which exemplify adaptive radiation suited to a **gastronomic** (art of choosing, preparing and eating good food) life style. For instance, beaks may have fine edges or sharp, hook like upper bill or sharp wood pecking points (Fig. 6.10). In some cases, the feeding habits are reflected in the feet as well. Typically raptorial birds or birds of prey, have long, curved talons for grasping prey. Ground foraging species such as grouse and pheasants have heavy, strong feet for scratching the soil, whereas the feet of the ostrich and emu can be deadly weapons. Seed eating birds eat their food as whole, but may subject it to grinding in a muscular gizzard containing pebbles which aid animals in the grinding process.

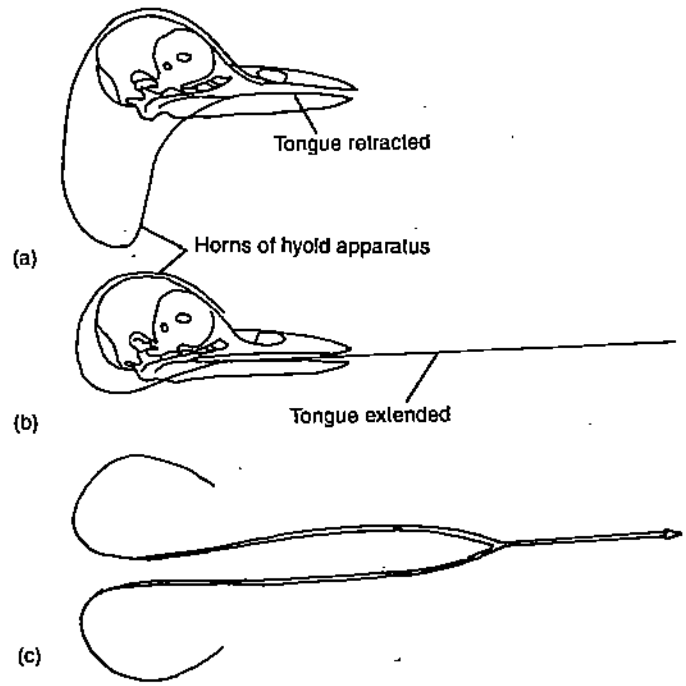


Fig. 6.10: Tongue protrusion in a woodpecker, (a) The flexible and thin hyoid apparatus supports the fleshy tongue. (b) When the woodpecker protrudes its tongue, the hyoid apparatus slips forward and the tongue extends from it. (c) Ventral view of the hyoid apparatus from the woodpecker *Picus*.

Fig 6.11 : Convergence in filter-feeding mechanisms in the flamingo. The fringe along the edge of the flamingo's bill acts as strainer.

Flamingo uses a filter feeding apparatus (Fig. 6.11) to filter small animals and other morsels it finds in the muddy bottoms of its fresh water habitat.

6.3.3 Mammals

Mammals have exploited a wide variety of food sources. Some mammals require highly specialised diets, while others are opportunistic feeders which live on diverse diet. In all mammals food habits and physical structure are intimately linked. Mammals are well adapted for attack and defense against enemies. Specializations for finding, capturing, reducing, swallowing, and digesting food determine the shape and habit of a mammal. Teeth, more than any other single physical characteristic, reveal the life habit of a mammal (Fig. 6.12). All mammals have teeth, except certain whales, monotremes, and anteaters and their modifications are correlated with what they eat.

As mammals evolved, major changes occurred in the teeth and jaws during the mesozoic era. Unlike the uniform homodont dentition of the reptiles, mammalian teeth became differentiated to perform specialiazed functions such as cutting, seizing, gnawing, tearing, grinding or chewing. Teeth differentiated in this way are called heterodont. Typically mammalian dentition is differentiated into four types: incisors, long conical crowns, specialized for piercing: **premolars and molars**, with large bodies and variable cusp arrangement, used for crushing and grinding. The primitive tooth formula, which represents the number of each tooth type in one half of the upper and lower jaw, was I, 3/3, C 1/1, Pm 4/4, M 3/3. Members of the order Insectivora e.g., shrews, some omnivores and carnivores come closest to this primitive pattern (Fig. 6.12). Unlike reptiles, mammals do not replace their teeth continuously throughout their lives. Most mammals grow just two sets of teeth, a temporary set called **deciduous** or **milk** teeth (set) which is replaced by a permanent set when skull has grown large enough to accommodate a full set. Only incisors, canines and premolars are deciduous; molars are never replaced and the single permanent set must last a life time.

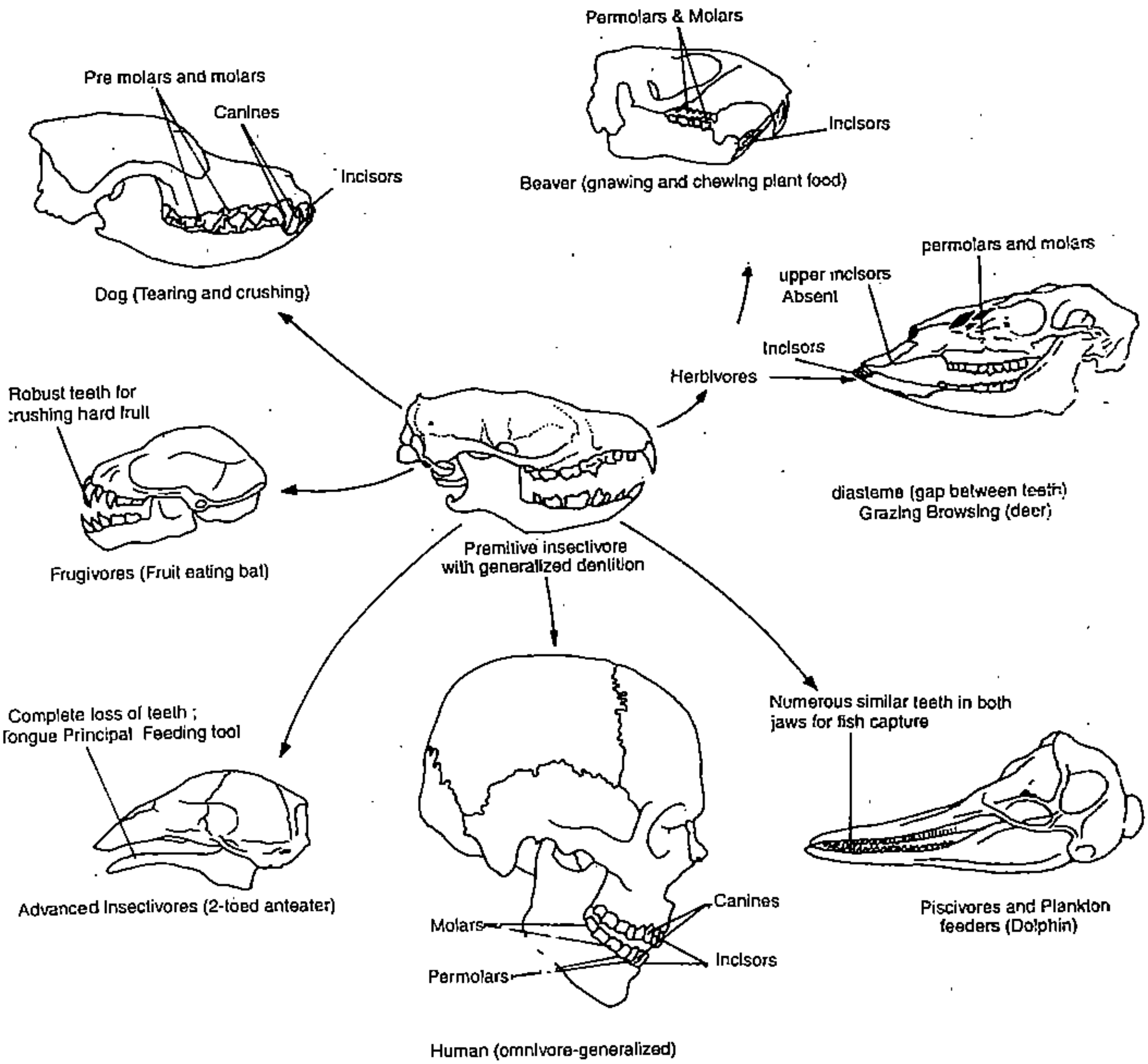


Fig. 6.12 : Feeding specializations of major trophic groups of eutherian mammals. The early eutherians were insectivores; all other types have evolved from them.

Mammals make extensive use of their teeth for killing, cutting and grinding, prey and so have evolved very different types of teeth for these purposes (Fig. 6.12). Chisel like incisors are used specially by *rodents* and lagomorphs (hares, rabbit) for gnawing. In the Proboscidea (elephants, mammoths), the incisors are modified as a pair of tusks. Pointed daggers like canines are used by carnivores. In some groups, like wild pigs and pinnipeds, canines are elongated as tusks, which are used for preying and as weapons.

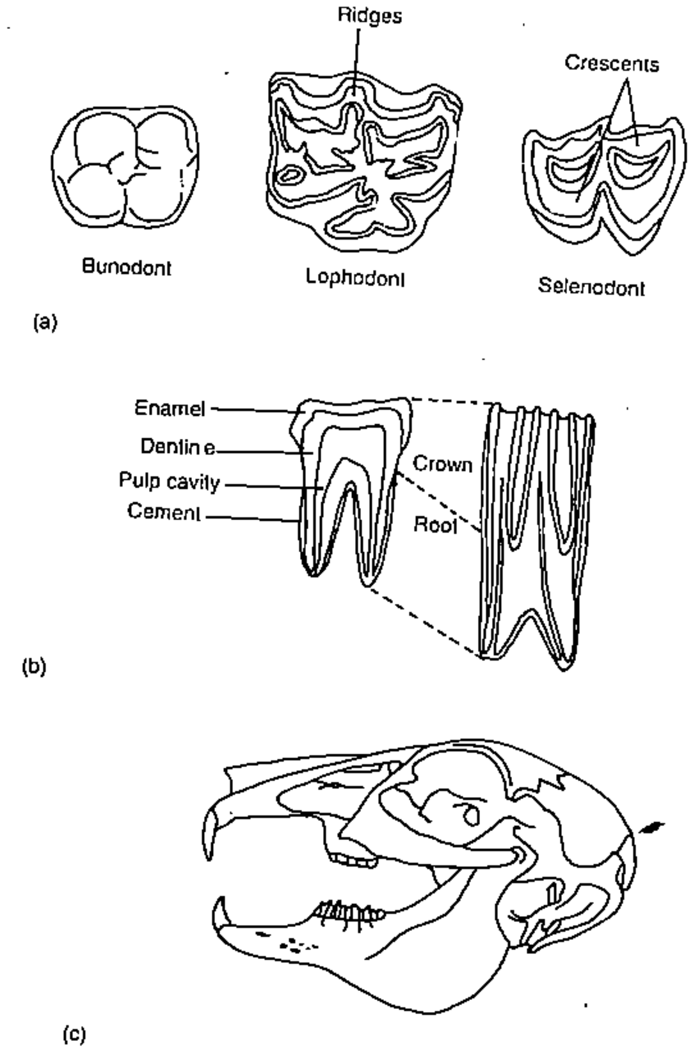
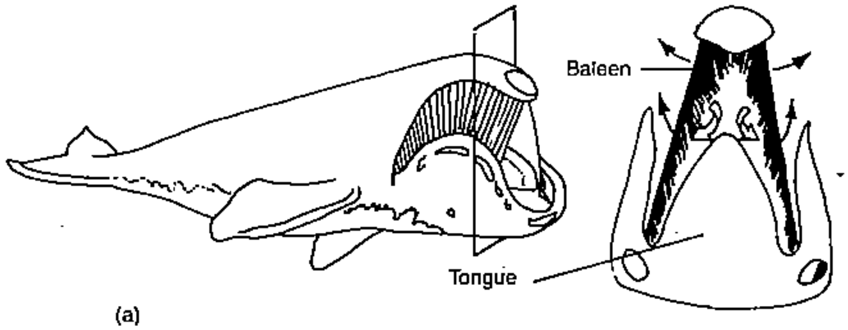


Fig. 6.13: Modifications of the molar teeth and jaws in herbivorous mammals. (a) Crownviews of common cusp patterns; (b) vertical sections of a low-crowned and a high-crowned tooth; (c) the jaws of a rabbit and other herbivores are hinged in such a way that the molar teeth come together simultaneously.

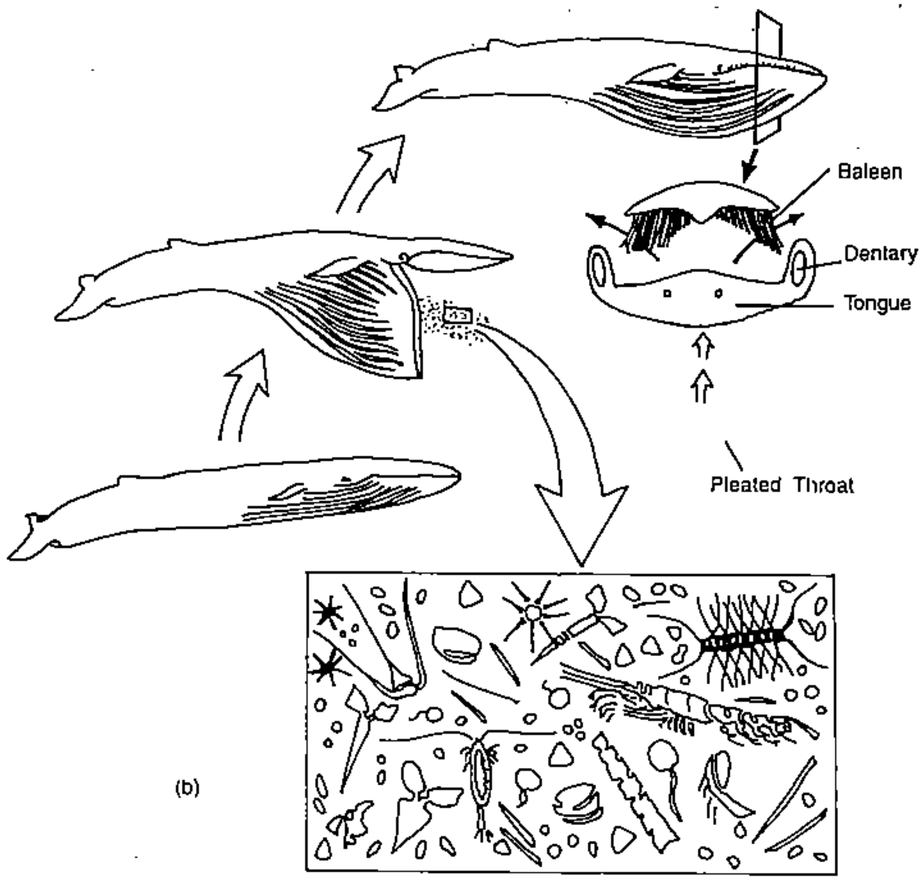
Rodents : any of various gnawing mammals, including rats, mice, beavers etc., that have constantly growing incisors, a rat or mouse.

Gnaw : to bite and wear away bit by bit.

Carnassials are knife like molars that, along with sharp incisors, are used by the carnivores to cut flesh into pieces small enough to swallow. Herbivores that feed upon leaves and other soft vegetation retain the primitive low crowned molar teeth. However, those herbivores which graze upon coarser grasses have evolved high-crowned molar teeth (Fig. 6.13). Most complex and interesting in their form are the molars of some herbivorous groups such as cattle, pigs, hippopotamus (Artiodactyla) and the horse, zebra (Perissodactyla) and elephants (Proboscidea). These teeth which are used in a side-to-side grinding motion, are composed of folded layers of enamel, cement and dentine which differ in hardness and in rate of wearing. Because softer dentine wears rather quickly, the harder enamel and cement layers form ridges that enhance the effectiveness of the molars in mastication of grass and other tough vegetation. Whalebone whales filter out plankton principally large crustaceans called "Krill", with whalebone or baleen. Water enters swimming whale's open mouth by force of the animal's forward motion and is strained out through more than 300 horny baleen plates which hang like a curtain from the roof of the mouth (Fig. 6.14). Krill and other planktons caught in the baleen are periodically wiped off with a huge tongue and swallowed.



(a)



(b)

Fig. 6.14: **Filter feeding mechanism. Whalebone whales (class Mammalia, phylum Chordata) filter out plankton, principally large crustaceans called "krill", with whalebone, or baleen. Water enters the swimming whale's open mouth by the force of the animal's forward motion and is strained out through the more than 300 horny baleen plates that hang like a curtain from the roof of the mouth. Krill and other planktons caught in the baleen are periodically wiped off with the huge tongue and swallowed.**

SAQ 2

Fill in the blank spaces with appropriate words from the text.

i) Majority of __________ use __________ to produce currents that can draw drifting food particles into their mouth.

ii) Fangs are either equipped with __________ which guides the __________ or are hollow, very much like a __________ needle.

iii) Raptorial birds capture prey with their __________ or __________.

iv) Flamingo uses a __________ apparatus to filter small __________ and other morsels in the muddy bottoms of its fresh water habitat.

v) In elephants __________ are modified as a pair of __________.

6.4 DIGESTIVE SYSTEM IN NON-MAMMALIAN VERTEBRATES

The development of extracellular digestion in an alimentary canal was an important evolutionary innovation. It freed many animals from feeding continuously, for they could not quickly ingest a few large chunks of food rather than slowly obtaining many particles small enough to enter cells and undergo intracellular digestion. The overall tubular organization of alimentary canal is efficient because it allows food to travel in one direction, passing through different regions of digestive specialization. Thus both acid and alkaline phases occur in the tract of Vertebrates, and both are active and at the same time provide different types of digestive action. In general, alimentary canals have four major divisions, the functions of which are (1) receiving, (2) conducting and storage, (3) digestive and absorbing nutrients and (4) absorbing water and defecating. Representative alimentary canal from different non-mammalian vertebrate classes are discussed in the following sections.

(1) Fishes

(a) Cartilaginous fishes

The digestive system of cartilaginous fishes comprises alimentary canal, glands of alimentary canal and physiology of digestion (Fig. 6.15).

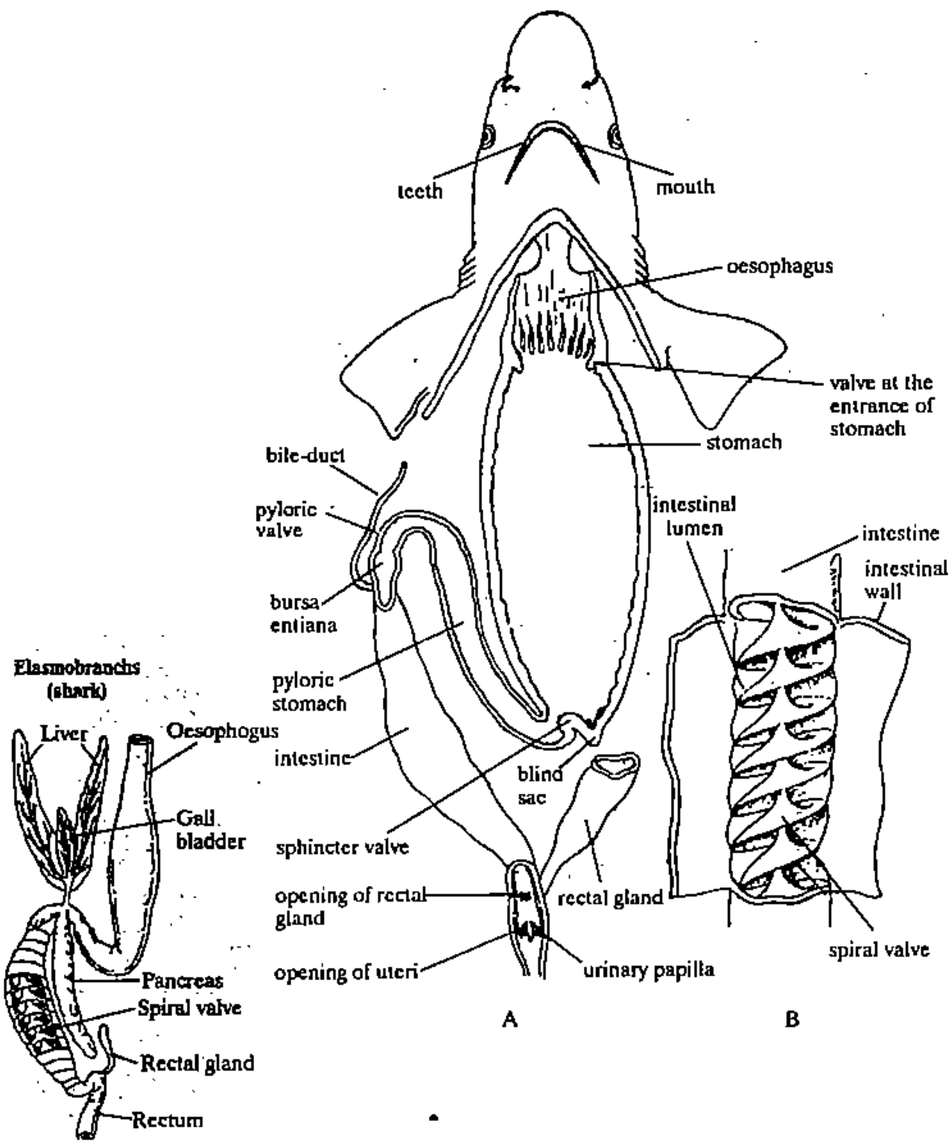


Fig. 6.15 : *Scoliodon*. Digestive tract.

The alimentary canal of Scoliodon consists of mouth, buccal cavity, pharynx, oesophagous, stomach, intestine and rectum. Mouth is a ventral crescentric opening which leads into a spacious dorso-ventrally compressed buccal cavity. The buccal cavity is lined with a thick mucous membrane raised ventrally into a thick fold to form the so called **tongue** which is non-muscular and non-glandular. The mucous membrane is rough due to the presence of dermal denticles. Teeth are oblique and have sharp more or less compressed cusps, the edges of which are smooth and non-serrated. Teeth are all alike in shape, **homodont**, and are borne in several parallel rows on the inner margin of the upper and lower jaws. Teeth are used to catch prey and prevent its escape but not to crush or masticate it. Though there are several rows of teeth (polyphyodont) yet only one row functions at a time and the old row is replaced by the new one. There are no glands in the buccal cavity comparable to the salivary glands of higher vertebrates.

The buccal cavity opens into pharynx on either side of which lie the internal openings of the spiracle and five gill-pouches. The spiracle is vestigial represented by an inconspicuous oval pit and the gill pouches are large. The cavity of pharynx is lined with mucous membrane containing numerous dermal denticles. The pharynx narrows posteriorly to form the short oesophagus. The oesophagus has thick muscular walls with an internal lining of mucous membrane raised into longitudinal folds.

The oesophagus widens posteriorily to form a large muscular stomach. The stomach is bent on itself and forms a J-shaped organ, the long proximal limb called the **cardiac stomach** while the short distal limb is called the pyloric stomach. At the junction of cardiac and pyloric limbs there is a blind outgrowth, the **blind sac**. The inner mucous lining of the **cardiac stomach** is also thrown into prominent longitudinal folds that end in the depression of the **blind sac**. At the end of **pyloric** stomach there is a muscular **bursa entiana**. The opening of pyloric stomach into the bursa entiana is guarded by a circular band of muscle fibres called the pyloric valve.

The bursa entiana contiues into the intestine. The intestine is a wide tube running straight backward into the abdominal cavity and opening posteriorily into the rectum. The internal surface of the intestine is increased by a characteristic fold of the mucous membrane, the **spiral valve**, having one edge attached to the inner wall of the intestine and the other rolled up longitudinally on itself into a spiral, making an anti-clock wise spiral of about two and a half turns. In a transverse section the spiral valve looks like a watch spring. The spiral valve serves not only to increase the extent of the absorptive surface of the intestine but also prevents rapid flow of food through the intestine.

The rectum is the last part of the alimentary canal. The tubular rectal (Caecal) gland opens dorsally into the rectum. The rectum leads into cloaca into which the alimentary canal as well as the urinogenital ducts open. The glands of alimentary canal comprise liver, pancreas and rectal glands.

Scoliodon is a carnivorous animal and feeds on other fishes, but diet also includes rock crabs, lobsters and spider crabs. The teeth of Scoliodon only prevent the escape of prey from the mouth and do not perform the function of mastication. Since there are no salivary glands in the mouth there is no digestion in the buccal cavity. The wall of the pharynx possesses numerous mucous glands. The secretion of these glands has no digestive function but simply helps in lubricating the passage of food. The oesophagus also has no digestive function. Digestion starts only in the cardiac stomach. The mucous membrane of cardiac stomach secretes gastric juice that contains pepsin and hydrochloric acid which convert proteins into proteoses and peptones. The gastric juice is not able to digest chitin. The pancreas secretes trypsin, amylopsin and lipases. Bile and pancreatic juices act upon semi-digested food as it enters intestine. Bile makes the food alkaline and helps the action of pancreatic juices. Trypsin acts on the remaining proteins, amylopsin converts starch into sugar and lipase turns fats into fatty acids. The digested food is absorbed in the intestine and spiral-valve.

(b) Bony fishes

The digestive organs vary much in structure. The mouth, which is placed at, or near, the anterior end of the head, usually has the form of a transverse slit, and can sometimes be extended forward by means of the movable supporting bones of the upper and lower jaws. Some fishes are toothless but in most instances teeth are present.

may be developed on the pre-maxilla, palatine, pterygoid, prevomer, parasphenoid, dentary, basihyal and bones of the branchial arches. It is characteristic of most **Teleostei** with the exception of **Isospondyli** that the maxilla is **edentulous** (toothless) and does not enter into the gape. The teeth may be either simply embedded in the mucous membrane and can be detatched when the bones are macerated or boiled or they may be implanted in sockets of the bone, or ankylosed to it. They are formed of some variety of dentine and are often capped with enamel. Their succession is perpetual, i.e., injured or worn out teeth are replaced at all ages.

In a very large majority of teleost species the teeth are small, conical, and recurved, suitable for preventing the struggling prey from slipping out of the mouth, but quite unfitted for either tearing or crushing. In some fishes such as the pike, the teeth are hinged backwards so as to offer no resistance to the passage of the prey towards the gullet, but effectually barring reverse movement. In many deep sea fishes the teeth are of immense size and constitute a very formidable armature of the jaws. A number of instances occur in which there is a marked differentiation of the teeth, those in front of the jaws being pointed or chisel-edged and adapted for seizing, while the back teeth have spherical surfaces adapted for crushing.

In some bony fishes alimentary canal shows little differentiation into regions, but as a rule, gullet, stomach, duodenum, ileum and rectum are more or less clearly distinguishable histologically. The stomach is V-shaped but its cardiac region may be prolonged into a blind pouch (Fig. 6.16). This is often very distensible, allowing some of the deep-sea Teleostei to swallow fishes as large as themselves. In many genera of several families stomach is entirely absent. This is also the case in the Holocephali and is no doubt a secondary and adaptive condition.

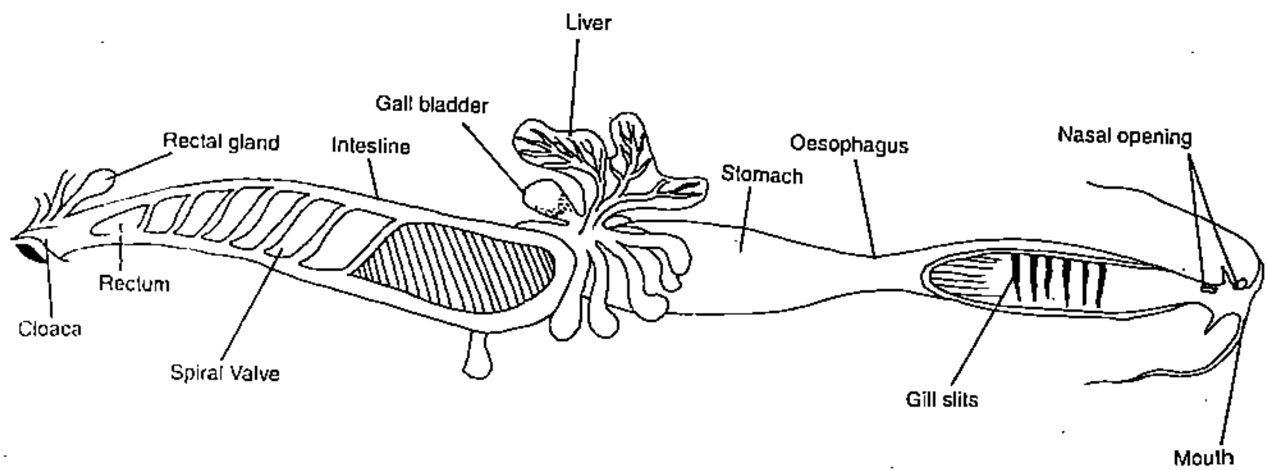


Fig. 6.16 : Digestive tract of a Teleost fish (bass).

Globe fishes can inflate the gullet with air or water, as a result of which they can float upside down. A spiral valve is very well developed in **Polypterus** and **Sturgeons**, vestigial in **Lepisosteus** and **Amia**, and absent or vestigial in all **Teleostei**, except possibly in **Chirocentrus** (Isospondyli). A trace occurs in the herring. Liver is usually large. A pancreas may be present as a compact gland, as in **Chondrichthyes** or may be widely diffused between layers of the mesentery, or in part surrounded by the liver. **Pyloric Caeca** are commonly present, and vary in number from a single one to two hundred. Anus is always distinct from, and in front of, the urinogenital aperture.

Amphibians

The mouth opening is a wide slit. Teeth, which are ankylosed to the bones, are present upon the premaxillae, maxillae and vomers, sometimes on dentaries, palatine and parasphenoid. They are absent in *Pipa* and some toads. Tongue is immovable in **Urodele**, absent in **Aglossa**, movable and free behind in other **Anura**, in which it is used as a prehensile organ. Salivary glands are not present. In many male **Anura** the lining of the buccal cavity is produced into sacs, the vocal sacs, which act as resonators. In *Rhinoderma* they are used as nurseries for the young. Oesophagus, stomach, small intestine and rectum are present.

Digestive system of frog mainly consists of food catching organs, the alimentary canal and the digestive glands. In the alimentary canal maceration, digestion and absorption occur while digestive glands secrete enzymes that help in digestion of the ingested food.

The alimentary canal of frog is a coiled tube extending from one end of the body to the other. It consists of buccal cavity, pharynx, oesophagus, stomach and intestine. Mouth leads into a wide and broad cavity called buccal cavity lying between the two jaws, the upper and the lower one. The buccal cavity in its roof near the vomerine teeth has two openings, the internal nares connecting with the nostrils through which respiratory gases pass to and from the buccal cavity during respiration.

The pharynx leads into a broad tubular part of the alimentary canal called oesophagus. This part of alimentary canal is very short due to the absence of neck. But the oesophagus is highly distensible as its inner lining is thrown into a large number of longitudinal folds that allow its expansion during the passage of the ingested food to the stomach. The stomach comprises two parts, the anterior expanded **cardiac part** and the posterier short narrow **pyloric part**. The stomach opens into a long tubular part the intestine consisting of two parts the **small** and **large** intestine. The small intestine leads to a short, broad colon or large intestine called **rectum**. The hind end of the rectum is called the **cloaca** (Fig. 6.17) and possesses a median ventral appendage, the urinary bladder. The urinary and generative ducts open into cloaca. The cloaca opens to the exterior by the anus. The digestive glands such as Liver and Pancreas are present and the liver has a gall bladder.

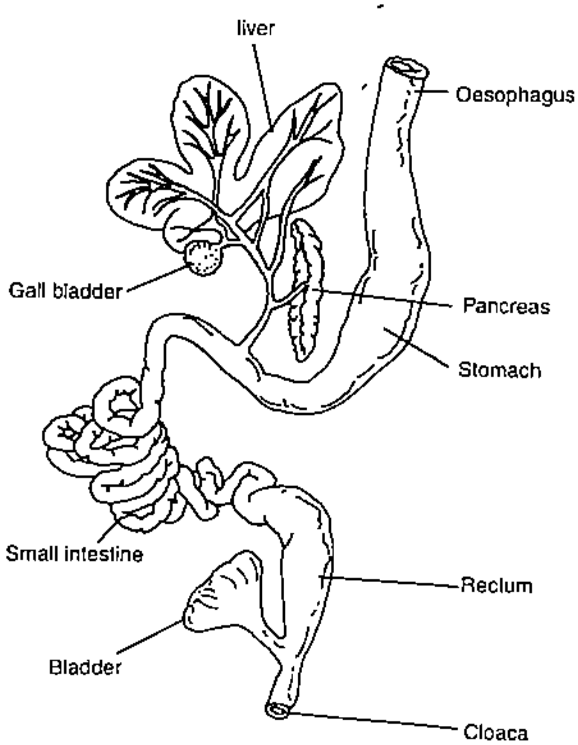


Fig. 6.17 : Digestive tract of an Amphibian (frog).

Reptiles

Teeth are usually present on the premaxillae, maxillae and dentary, and frequently on the palatine and pterygoid. They are continually replaced, and are pleurodont, acrodont, or thecodont. They are conical or hooked and are adapted for prehension not for mastication except in some extinct forms. In Chelonia teeth are absent, being replaced by the horny epidermal beak-like covering of jaws.

The alimentary canal of a lizard *Uromastix* is a long and convoluted tube. It can be divided into mouth, buccal cavity, pharynx, oesophagus, stomach, duodenum, ileum or small intestine, colon or large intestine, rectum and cloaca. The mouth opening is a wide gape bounded by the upper and lower immovable and muscular lips. The mouth opens into the buccal cavity which has a well developed muscular tongue on its floor. Tongue is attached to the floor of the buccal cavity along the median ventral line. The tongue is long, bifid and protrusible having voluntary muscles, taste buds and mucous glands. In the upper jaw teeth are present on premaxillae and maxillae. Whereas in the lower jaw the dentary bears teeth. The teeth of *Uromastix* are pleurodont which means teeth are attached to the outer border of the bones of jaw.

The pharynx lies posterier to the tongue. The lining of the pharynx is thrown into longitudinal folds. The pharynx leads posteriorly into the oesophagus. It is capable of great distension and it opens into long cylindrical sac like structure the stomach which is wider than the oesophagus. It has thick muscular walls and lies in the left half of the body and is curved having the appearance of U-shape. The stomach is differentiated into two parts; the anterior part is known as **Cardiac stomach** which lies dorsal to the left lobe of the liver, and the posterior part is known as **pyloric stomach** lying slightly to the right side. The wall of the stomach is much thicker than that of the oesophagus and of the intestine. Numerous well developed longitudinal folds of mucous membrane are seen in the lumen of both Cardiac and Pyloric stomach (Fig. 6.18). Stomach is the place where digestion occurs. The pyloric wall is in the form of a muscular ring lining of the inner wall of the posterier extremity of the pyloric stomach.

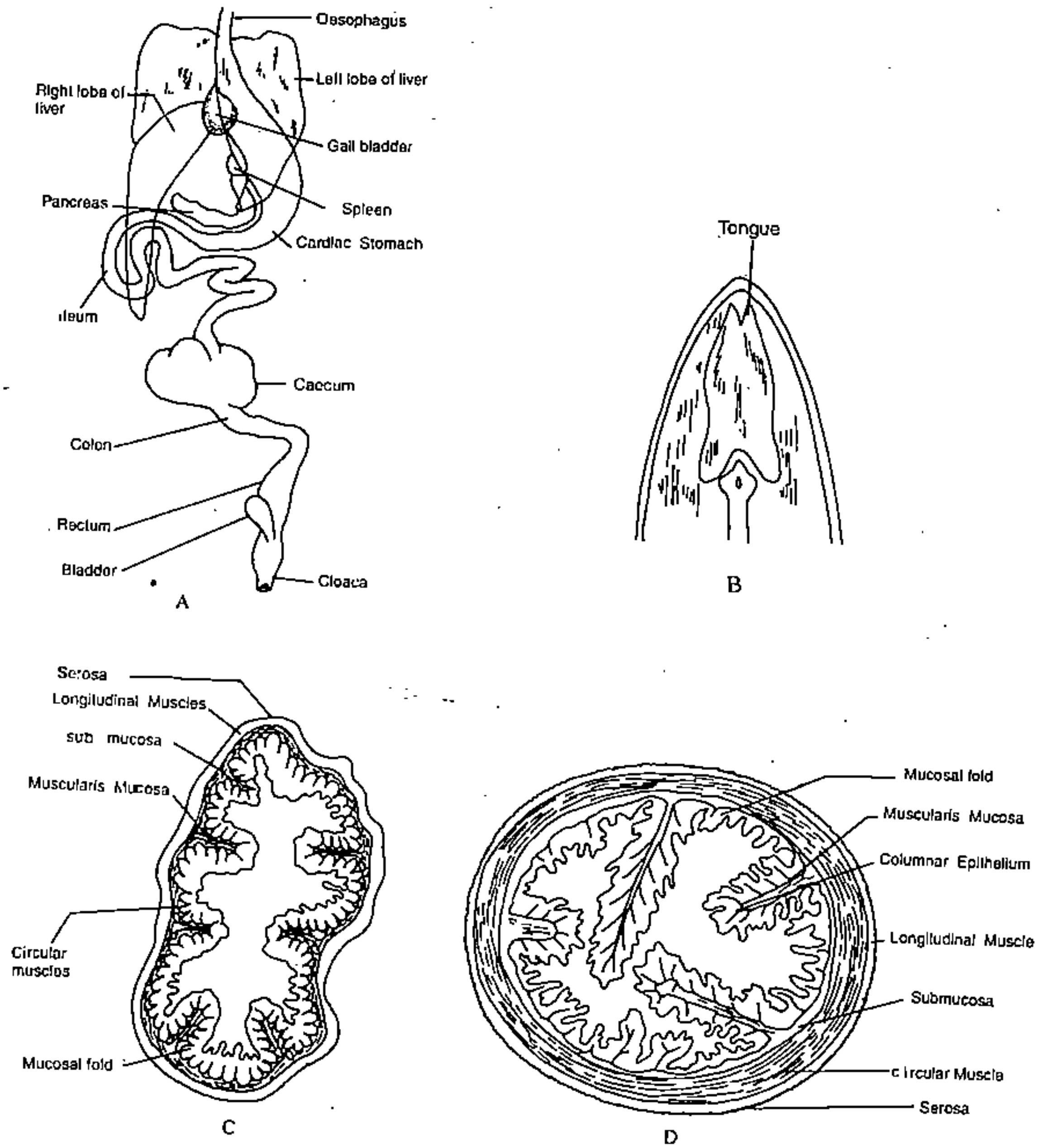


Fig. 6.18 : *Uromastix*, **A. Alimentary canal, B. Tongue, C. T.S. of pyloric stomach. D. T.S. of cardiac stomach.**

The small intestine consists of an anterior duodenum and a posterior ileum. The duodenum is U-shaped and receives bile and pancreatic ducts. Both duodenum and ileum show closely set wavy longitudinal folds of mucosa.

Ileum opens into a large intestine which comprises a proximal colon and distal rectum. The caecum a blind pouch arises from the junction of ileum and colon. Rectum opens into cloaca that in turn opens to exterior by the cloacal opening. The cloaca consists of three chambers, the coprodaeum, the urodaeum and the proctodaeum. Different chambers of cloaca serve for reabsorption of water both from faeces and urine. The digestive glands that are associated with the alimentary canal are gastric glands, liver, pancreas and intestinal glands.

The salivary glands are usually absent. There is a sub-lingual gland in *Chelonia*. Both upper and lower labial glands and palatal and lingual glands are always present. The poison glands of snakes are upper labial salivary glands. The alimentary canal presents no remarkable features. Large intestine is short and often has a small caecum (Fig. 6.18). It leads into the cloaca which receives the urinogenital ducts and in **Lacertilia** and *Chelonia* an allantoic bladder. Anus is a transverse slit in lizards and snakes, a longitudinal slit or a roundish opening in chelonians and crocodiles.

Birds

Inspite of great differences in the mode of nourishment the avian digestive organs present a fairly uniform structure; their peculiarities have relation to the power of flight. The jaws are covered by a hard horny sheath (rhamphotheca) and transformed into the beak. The rhamphotheca is often composed of several pieces (compound). True teeth are entirely absent, at least in living birds as opposed to some fossil forms such as *Ichthyornis, Hesperornis, Archaeopteryx*. While the upper beak is formed by the fused premaxillae, the maxillae and the nasal bones, the lower corresponds to the two rami of the lower jaw, the fused extremities of which are known as the **Myxa**. The lower edge reaching from the angle of the chin to the extremity is termed the **gonys**, the edge of the upper beak is the **culmen** (Fig. 6.19), the region between the eye and the base of the beak which is covered by cera (ceroma) is the lore. The form and development of the beak vary extremely according to the special mode of subsistence (Fig. 6.20).

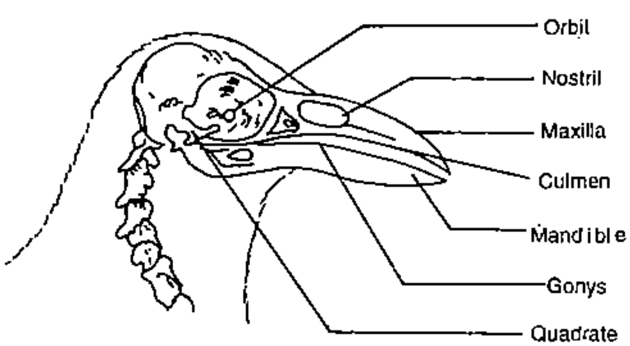


Fig. 6.19 : Type of Beak in birds.

Tongue which is always movable, lies on the floor of buccal cavity. It consists of horny or fleshy covering of two cartilages attached to the anterior end of the hyoid bone and serves for deglutition, and frequently for seizing food. The buccal cavity, which in pelicans is dilated into a large gular sac supported by the rami of the lower jaw, receives the secretion of a number of small salivary glands such as sublingual, sub-maxillary and parotid; in the woodpecker the sublingual glands are large and there is no velum palati. Oesophagus is muscular, longitudinally folded and the length of which in general depends on the size of the neck. It frequently possesses – especially in birds of prey, but also in granivorous birds – a crop like dilation, in which the food is softened (Fig. 6.19). In pigeons crop bears two small rounded accessory sacs.

The lower end of oesophagus is dilated into a glandular proventriculus, which is followed by wide muscular stomach called gizzard. While the proventriculus has, as a rule, an oval form and is smaller than the gizzard, the latter is provided with muscular walls, which are weaker (in birds of prey) or stronger (in granivorous birds) according to the kind of food eaten. In granivorous birds gizzard is well adapted for mechanical preparation of the softened food material by the possession of two solid plates, which form the horny internal wall and work against one another. It contains small stones which the bird swallows to aid in the grinding of the food. The first loop of small intestine which is corresponding to duodenum surrounds the elongated pancreas. The ducts of prancreas numbering 1 to 3 as well as the usually double bile ducts, open in this region. A gall bladder is usually present. The beginning of the short, large intestine is marked by the presence of a circular valve, and by the origin of two caeca; it presents no distinction between colon and rectum, and it passes into the cloaca, into which the urinogenital apparatus also opens. At its entrance into the cloaca it penetrates a sphincter-like circular fold. A peculiar glandular sac the bursa Fabricii-opens into the dorsal wall of the cloaca. There is no urinary bladder in adults.

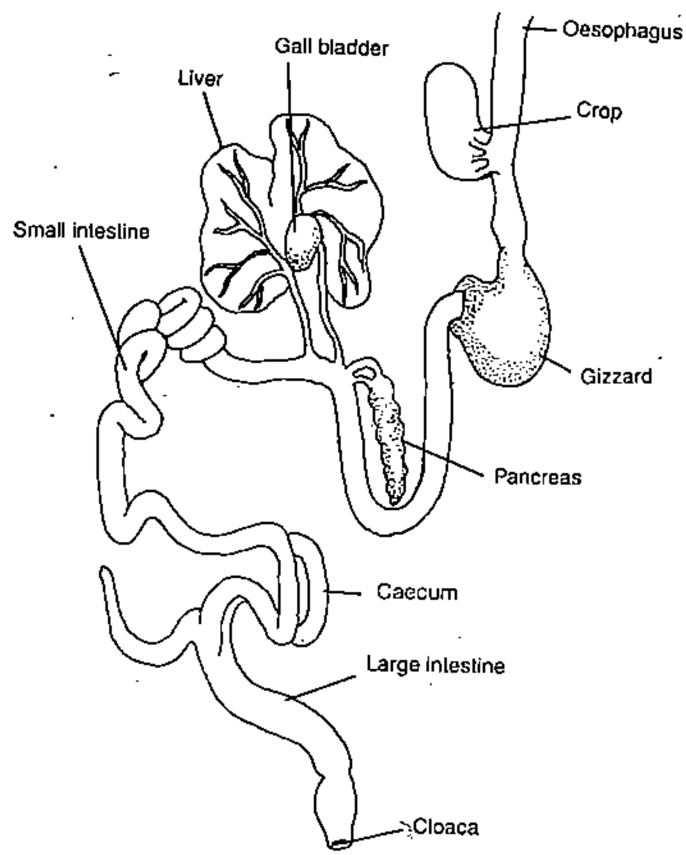


Fig. 6.20 : Digestive tract of pigeon.

Cloaca usually presents three fairly well-marked divisions separated by folds. The anterior of these, often called the **Coprodaeum** is the dilated hind end of the rectum.The lining of coprodaeum is, however, different from that of the rectum from which it is often separated by a fold. The middle chamber is called the **Urodaeum**: it is smaller than the other two chambers and receives the openings of the urinogenital duct. The posterior chamber which opens by the vent, may be termed the **Vestibule**; it receives the bursa Fabricii dorsally. Most birds are without an organ of copulation, sperm transfer being effected by a slight eversion of the cloaca. In Ratitae (except *Rhea*) there is solid grooved penis attached to the ventral wall of the vestibular division of the cloaca. It is very similar to the corresponding organ of chelonea, contains erectile tissue and can be extruded or retracted by special muscles. In birds like **Rhea** and **Anser** (duck) birds a very similar organ occurs, but its terminal portion is invaginated during rest and evaginated in erection like the finger of a glove.

SAQ 3

Match the statement given in column B with the chordate group given in column A.

Column A	Column B
Fish	(i) The lining of the buccal cavity is produced into sacs, the vocal sacs which act as resonators.
Amphibians	(ii) Salivary glands are absent.
Reptiles	(iii) In many genera of several families stomach is entirely absent.
Birds	(iv) True teeth are entirely absent.

6.5 DIGESTIVE SYSTEM IN MAMMALIAN VERTEBRATES

The feeding or trophic. apparatus of a mammal has teeth, jaws, tongue and digestive system, and is adapted to its particular feeding habits. On the basis of food habits, mammals are divided among several trophic or nutritional groups (Fig. 6.14). The three basic trophic groups are insectivores, carnivores and herbivores, but many other feeding specializations have evolved.

Insectivores are small mammals, usually opportunistic feeders, that feed on a variety of small invertebrates: such as worms, grubs and insects. Examples are shrews, moles, anteaters, and most bats. Since insectivores eat little fibrous vegetable matter which requires prolonged fermentation, their intestinal tract tends to be short (Fig. 6.21). The insectivorous is not a sharply distinguished category since **carnivores** and **omnivores** often include insects in their diet. Even many rodents which are considered herbivores, may have a mixed diet of insect larvae, seeds and fruits.

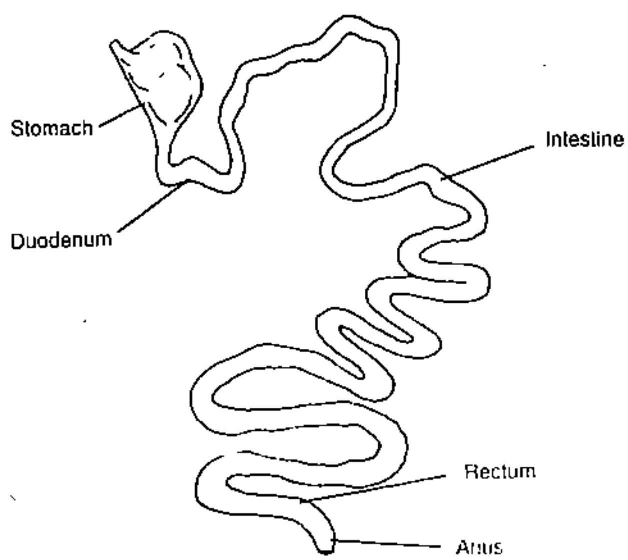


Fig. 6.21 : Digestive System of an insectivore showing short intestine no caecum

Herbivorous mammals which feed on grasses and other vegetation form two main groups; the browsers and grazers, such as the ungulates, hooved mammals including horses, deer, antelope, cattle, sheep and goats, and the gnawers such as the rodents which include rabbits and hares. In herbivores, the canines are either reduced in size or may be absent, while the molars that are adapted for grinding, are broad and usually high-crowned. Rodents have sharp chisel-shaped incisors which grow throughout life and must be worn away to keep pace with their continuous growth (Fig. 6.12). If the incisors do not grow continuously, the cutting surface of the teeth will get eroded soon by its excessive use due its continuous gnawing habit.

Herbivorous mammals have a number of interesting adaptations for dealing with their fibrous diet of plant food. **Cellulose**, the structural carbohydrate of plants, is potentially nutritious foodstuff, composed of long chains of glucose units. However, glucose molecules in cellulose are linked by a type of chemical bond that few enzymes can attack. No vertebrate synthesizes cellulose splitting enzymes. Instead, the herbivores harbour a microflora of anaerobic bacteria and protozoa in the gut. These bacteria and protozoa breakdown and metabolize cellulose, releasing a variety of fatty acids, sugars, and starches which the host can absorb and use.

In some of the herbivores like horses, zebras, rabbits, hares, elephants and many rodents, gut has a spacious side pocket or diverticulum, called a **caecum** that serves as a fermentation chamber and absorptive area (Fig. 6.22 & 6.23). Hares, rabbits and some rodents often eat their faecal pellets (**coprophagy**) giving the food a second pass through the fermentating action of the intestinal bacteria. The coprophagy also provides an opportunity for the animal to obtain vitamins produced by the bacteria lodged in the caecum.

Ruminants like cattle, bison, buffalo, goats, antelopes, sheep, deer, giraffes etc. have a huge four chambered stomach (Fig. 6.23). When a ruminant feeds, grass passes down the oesophagus to the rumen, where it is broken down by the rich microflora and then formed into small balls of cud. At its leisure the ruminant returns the cud to its mouth where the cud is deliberately chewed at length to crush the fiber. Swallowed again, food returns to the rumen where it is digested by the cellulolytic bacteria (Fig. 6.24). The pulp is then passed on to the **reticulum**, then to **omasum** and finally to the **abomasum** that is true acid stomach, where proteolytic enzymes are secreted and normal digestion takes place. In general herbivores having large, long digestive tracts must eat a considerable amount of plant food to survive. A large African elephant weighing 6 tons must consume 135 to 150 kg. of rough fodder each day to obtain sufficient nourishment to survive.

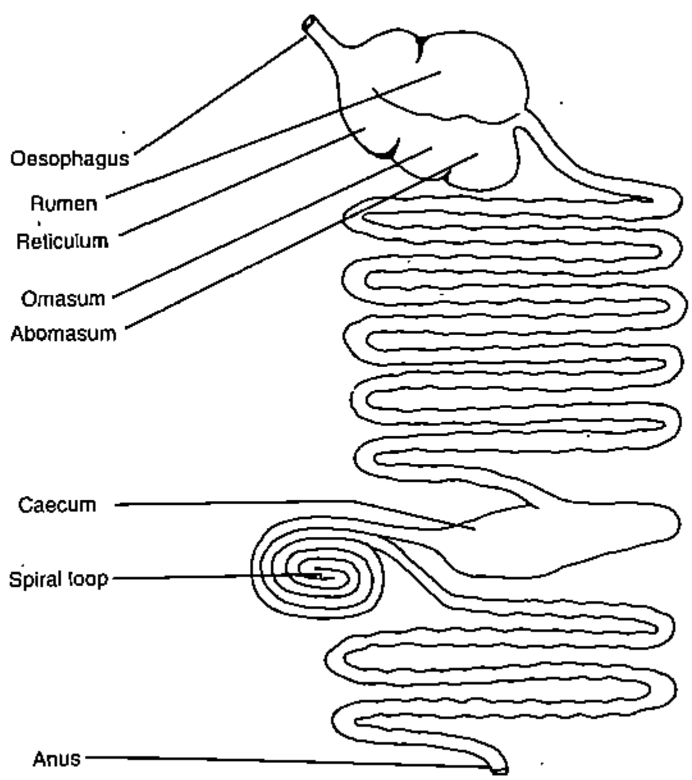


Fig. 6.22 : Digestive System of a ruminant herbivore (deer) showing four-chambered stomach with large rumen, and long sized small and large intestines.

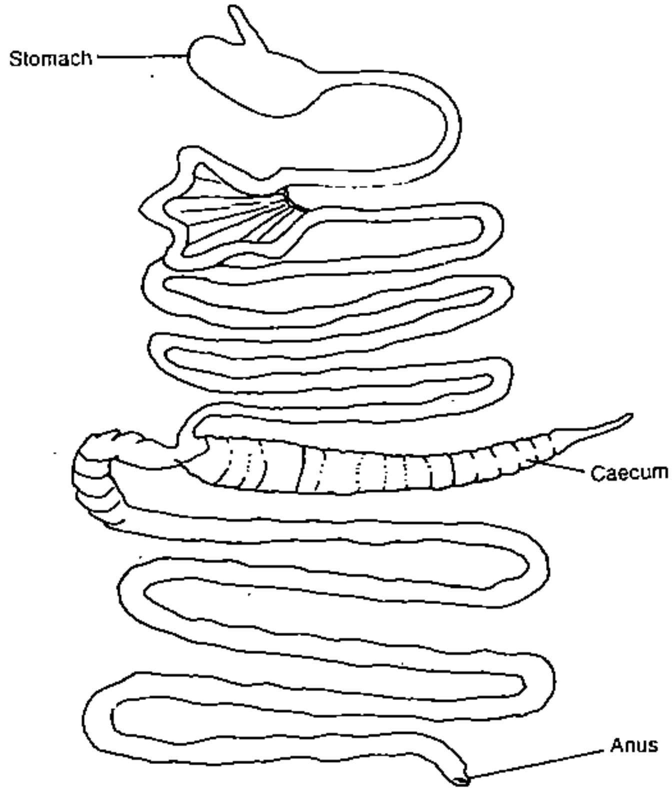


Fig. 6.23 : Digestive System of a non-ruminant herbivore (rabbit) showing simple stomach and a large caecum.

Carnivorous mammals feed mainly on herbivores. This group includes foxes, dogs, weasels, wolverines, cats, lions, tigers etc. Carnivores are well equipped with biting and piercing teeth and powerful clawed limbs for killing the prey. Since their protein diet is easily digested than is the woody food of herbivores, their digestive tract is shorter and the caecum is small or absent (Fig. 6.25). Carnivores eat separate meals and have much more leisure time for play and exploration.

Generally carnivores lead more active life than do the herbivores. Since a carnivore must find and catch its prey, there is a premium on speed and intelligence; many carnivores, such as cats are known for their stealth and cunningness in hunting prey. This has lead to a selection of herbivores capable either of defending themselves or of detecting and escaping carnivores. Thus for the herbivores, there has been a premium on keen senses and agility. Some herbivores, however, survive by virtue of their sheer size e.g. elephants or by defensive group behaviour for example North American musk oxen.

Omnivorous mammals live on both plants and animals for food. Examples are pigs., racoons, rats, bears and most primates including human beings. Many carnivore forms also eat fruits, berries and grasses when hard pressed. The fox which usually feeds on mice, small rodents and birds, eats frozen apples, beech nuts, and corn when its natural food is scarce. For most mammals, searching for food and eating occupy most of their active life. Some migrate to regions where food is in plenty, while others hibernate and sleep during the winter months. But there are many provident mammals which build up food stores during period of plenty. This habbit is most pronounced in rodents such as squirrels, chipmunks, gophers and certain mice.

The mouth in mammals is bounded by fleshy lips. On the floor of the mouth is situated a tongue which is usually well developed, but varies in size and shape in different orders. In some herbivorous animals it can be curled around grass and thus helps pull it into the mouth. Its surface is covered with papillae of different kinds. These are sometimes horny, serving either grinding of food, or for the dressing of the hairy coat. Thus the tongue and lip margins in many mammals are equipped with raised processes which can be moved up and down along the interspaces of the teeth (and on the surfaces of the teeth) in a cleansing action. In association with the papillae of the tongue there are special end organs of taste (taste buds) which are often arranged in zones. The sense of taste differs profoundly among various groups. The roof of the mouth is formed in front by the hard palate, consisting of the horizontal palatine plates of the maxillary and palatine bones covered with mucous membrane bearing palatal folds. Behind the hard palate there is a backward projection of the soft muscular fold of the soft palate which divides the cavity of the pharynx into two upper and lower chambers. In some forms the soft palate also bears taste buds. In **Primates** a free-hanging **uvula** and soft palate are raised to close off the nasopharynx and prevent the entrance of food thereto. In front of the opening, leading from the lower division of the pharynx into the larynx., is a cartilaginous plate called **epiglottis** a primitive form of which is found in certain lower vertebrates like frogs. The epiglottis, anatomically part of the larynx, assists the reflex swallowing mechanism by preventing food from entering trachea.

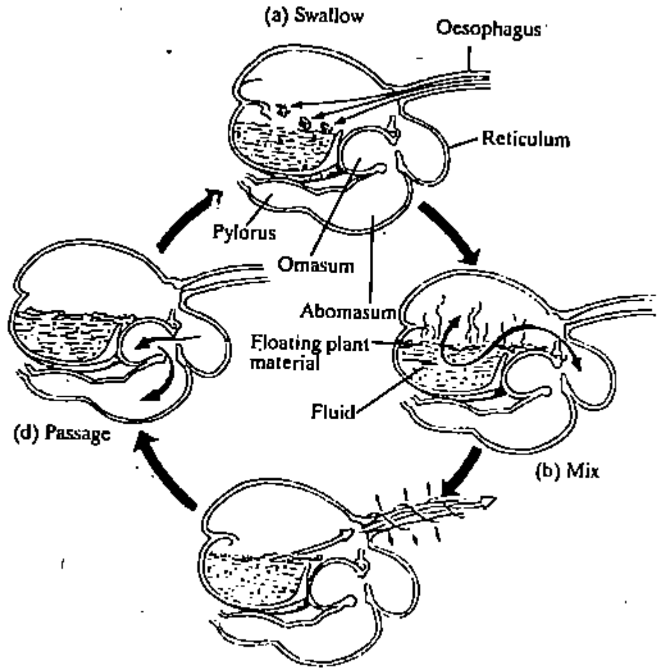


Fig. 6.24 : Foregut fermentation in the bovine stomach. (a) In ruminants, food is clipped, rolled into a bolus, mixed with saliva, and swallowed. (b) Contractions spread through rumen and reticulum in cycles that circulate and mix the bolus. Contents separate into fluid and particulate material. Floating, fibrous plant material and a pocket of gas forms during fermentation. (c) Poorly masticated boli of plant material are regurgitated and rechewed later to break down fibrous cell walls mechanically and expose further plant tissue to cellulases. Respiratory inhalation, without opening the trachea, produces negative pressure around the oesophagus to draw some of this poorly masticated material into the oesophagus through the gastroesophageal sphincter. Peristaltic waves moving forward in the wall of the oesophagus carry the bolus into the mouth for rechewing. (d) The omasum transports reduced bolus from the reticulum to the abomasum in two phases. First, relaxation of omasal walls produces negative pressure that draws fine particulate material from the reticulum into its own lumen. Next, contraction of the omasum forces these particulates into the abomasum, the stomach region rich in gastric glands. Thus, the abomasum is the first true part of the stomach.

The oesophagus is a simple, straight tube down which food is propelled by peristaltic contractions of the muscular walls, which like the act of swallowing or deglutition, are reflex and involuntary. The opposite action, **retroperistalsis** enables ruminants to regurgitate stomach content for more leisurely mastication, and many other animals to expel injurious substances accidentally swallowed. Retroperistalsis in man is sometimes used by spiritualist' fakers to regurgitate in dimly lit seances 'ectoplasm' i.e., previously swallowed filmy cloth or other material.

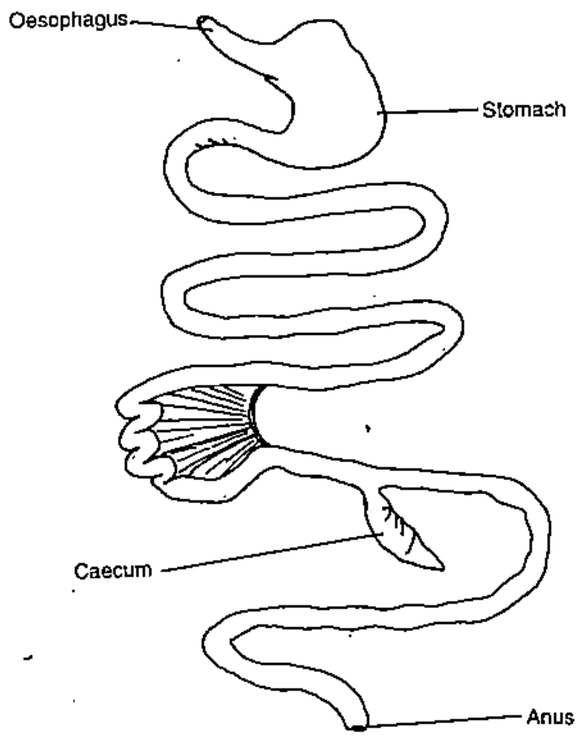


Fig. 6.25 : Digestive system of a carnivore showing short intestine and colon, small ceacum.

The stomach varies greatly in different mammalian orders. In majority of mammals it is relatively simple sac as in rabbit (Fig. 6.26). But in certain groups it is complicated by the development of internal folds, and may be divided by constrictions into several functionally different chambers. Such complication reaches its extreme in the **Ruminantia** especially in the **Tylopoda and cetacea.** In a typical ruminant (Fig.6.27) such as sheep or ox stomach is divided into 4 chambers – the rumen (or punch), the **reticulum, psalterium** and the **abomasum** (or rennet stomach). The epithelium of both rumen and reticulum is highly reminiscent of that of the oesophagus.

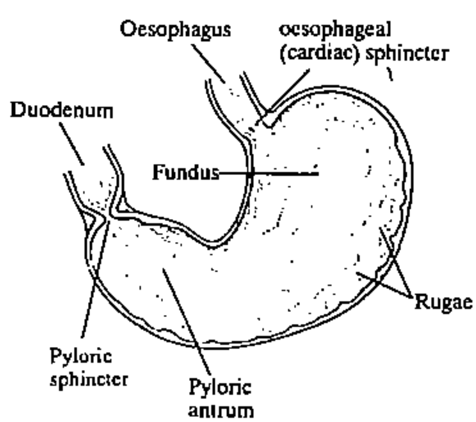
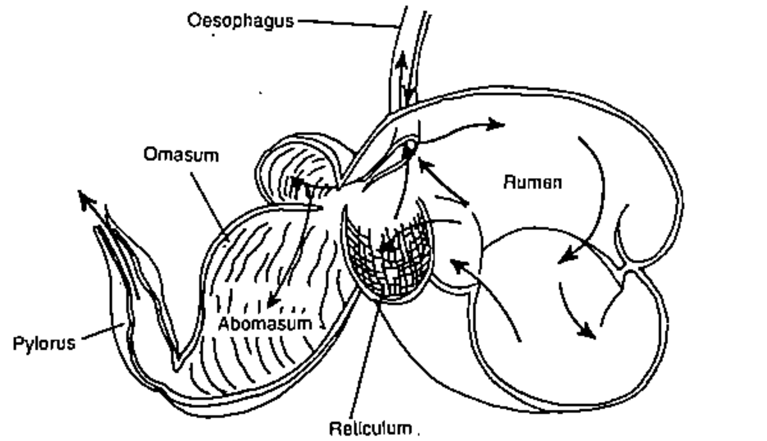
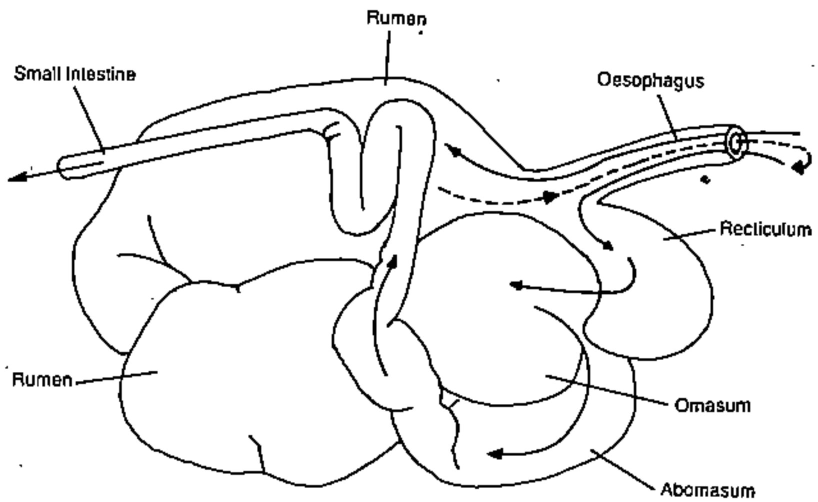


Fig. 6.26 : Monogastric stomach showing major parts of the mammalian stomach.

The oesophagus opens into the rumen close to its junction with the reticulum. The rumen is much larger than the rest. Its mucous membrane is beset with numerous short villi. The reticulum, which is much smaller than the rumen, has its mucous membrane raised up into a number of anastomosing ridges. These are capable of closing together in such a way as to convert the groove into a canal. The mucous membrane of psalterium is raised up into numerous longitudinal leaf-like folds. The abomasum, smaller than the rumen but larger than the reticulum, has a smooth vascular and glandular mucous membrane. Ruminants swallow herbage without mastication. The habit enables timid herbivores to snatch and swallow at intervals food that can be digested later in safer circumstances. It has arisen, with convergent specialisations in the grazing Quokka Wallaby (Fig. 6.28).



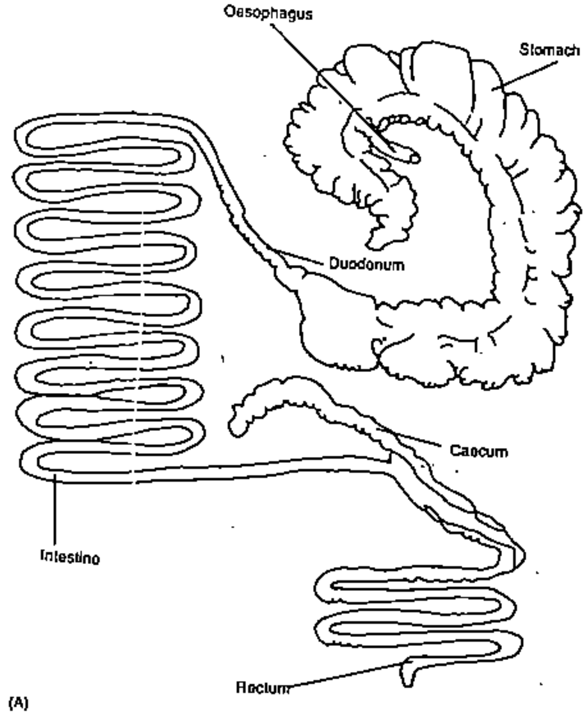
(A)



(B)

Fig. 6.27 : Digastric stomach, A. Sheep stomach characteristic of the Ruminidae, has two divisions made up of four chambers. The rumen and reticulum make up the fermentative division. The omasum and abomasum (true stomach) make up the digestive division. B. A four chambered stomach where cellulose is digested by symbiotic microorganism in the multichambered stomach of a cow. Food first enters the rumen and reticulum where digestion begins. Periodically food is regurgitated, chewed more and reswallowed. Many products of digestion are absorbed from the rumen, but rest of the food, together with some of bacteria which multiply in rumen and reticulum, pass through omasum to abomasum where protein digestion begins.

In ruminants food is swallowed, saturated by copious salivation and passes into rumen and reticulum; where it lies until, having finished feeding, the animal begins ruminating or chewing the cud. In this process, the sodden (soaked through) food is returned in rounded boluses from the rumen to the mouth. It now undergoes mastication. When fully masticated it is swallowed again in a semi-fluid condition,and, passes along the groove into the reticulum or over the unmasticated food contained in the latter chamber, to strain between the leaves of the psalterium **(Omasum)** and to enter the abomasum. In some ruminants psalterium is absent. In the rumen and reticulum of deer, cattle, sheep etc., there exists a dense population of protozoa and bacteria which attack and break down cellulose which forms the major part of the diet. Fermentation produces acetic, butyric and propionic acids which are neutralized by sodium bicarbonate secreted in the saliva. Absorption takes place in the rumen and liberated gases e.g., methane and CO_2 are regurgitated.



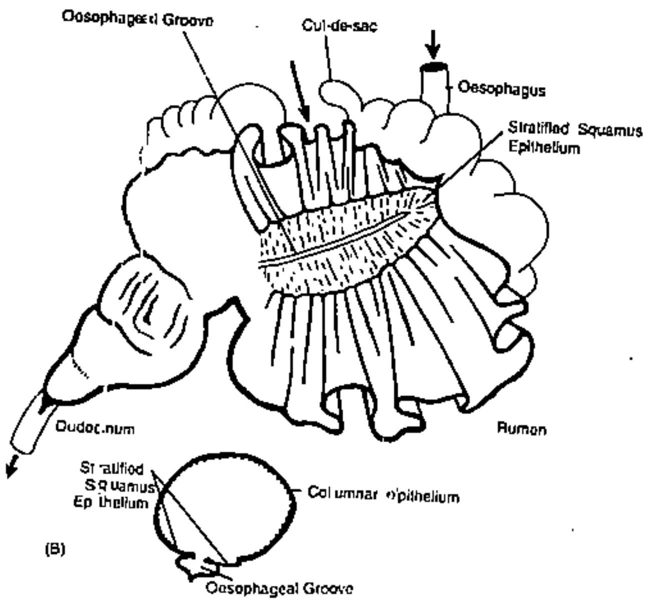


Fig. 6.28 : Marsupialis Digestion. A, Digestive system of Kangaroo; B, A ruminant like digestion has arisen by parallel evolution in the grazing marsupials (e.g. the Quokka, *Setonix brachyurus*) although stomach is not divided into four compartments like that of eutherian mammals. In *Setonix* oesophagus leads into a putative rumen (I). An oesophageal groove, by-passing the extensive sacculated main fermentative region (of tubular glands), passes through an area of stratified squamous epithelium like that of the rumen, reticulum and omasum of sheep. Region III may be analogous to the abomasum; the functions of II and IV are still unknown. These and other complexities are associated with the possession of a dense bacterial population (demonstrably concerned with fatty acid production) and a very small caecum.

Food residues fluid and micro-organisms move down the alimentary canal. In the Omasum fluid is absorbed. In the abomasum, the protozoa and probably the bacteria, are destroyed by secreted HCl. The abomasum also produces digestive enzymes and further absorption takes place in the small intestine. In ruminants caecum is relatively small; in Georgian times those of sheep were prepared for use as condoms. In ruminants the colon too, is comparatively unimportant; but in non-ruminant herbivores such as horses both caecum and colon are enormous. All material passing from ileum to colon enters caecum which in horses, may be some four feet long and hold as much as eight gallons. In horses caecum has fluid storing and digestive functions. The large colon in horses is principally absorptive in function although some bacterial but not enzymatic digestion occurs therein.

In camels stomach is not so complicated as in the more typical ruminants. There is no distinct psalterium, and the rumen is devoid of villi. Both rumen and reticulum have connected with them a number of pouch like diverticula, the openings of which are capable of being closed by sphincter muscles. In **cetacea** stomach is also divided into compartments. In porpoises (sea animals like a dolphin or a small whale) oesophagus opens into a spacious rumen, the cardiac compartment of the stomach, which has a smooth, thick, mucous membrane. This is followed by a second median chamber of considerably smaller dimensions. This has a glandular mucous membrane, which is thrown into a number of complex folds. A long and narrow third or pyloric compartment follows upon this, terminating in a constricted pyloric aperture. Beyond this beginning of the small intestine is dilated into a bulb.

A caecum, situated at the junction of large and small intestine is usually present, but varies greatly in extent in the different orders and families. In general, it is much larger in **vegetarian** than in **carnivorous** forms. Among herbivores it is those that have a simple stomach such as the rabbit, that have the largest caecum (Fig. 6.23). The hyraxes differ from the rest of the class in the possession of four definite caeca, of which there is a posterior pair, each carrying a vermiform appendix. The caecum is simple in **monotremes**, absent in sloths, some **cetaceans** and in a few **carnivorans**. It is relatively enormous (about 250 cm. long) in the marsupial Koala, *Phascolarctos* (which eats mostly eucalyptus leaves), next relatively largest in two other marsupials (*Trichosurus*, *Didelphys*) and big in all phalangers. In Man and a few other animals (civets, some rodents, monkeys) the distal end of the caecum has degenerated into an appendix vermiformis (Fig. 6.29). The proportion of vegetable material ingested is not, however, the only factor governing the size of the caecum.

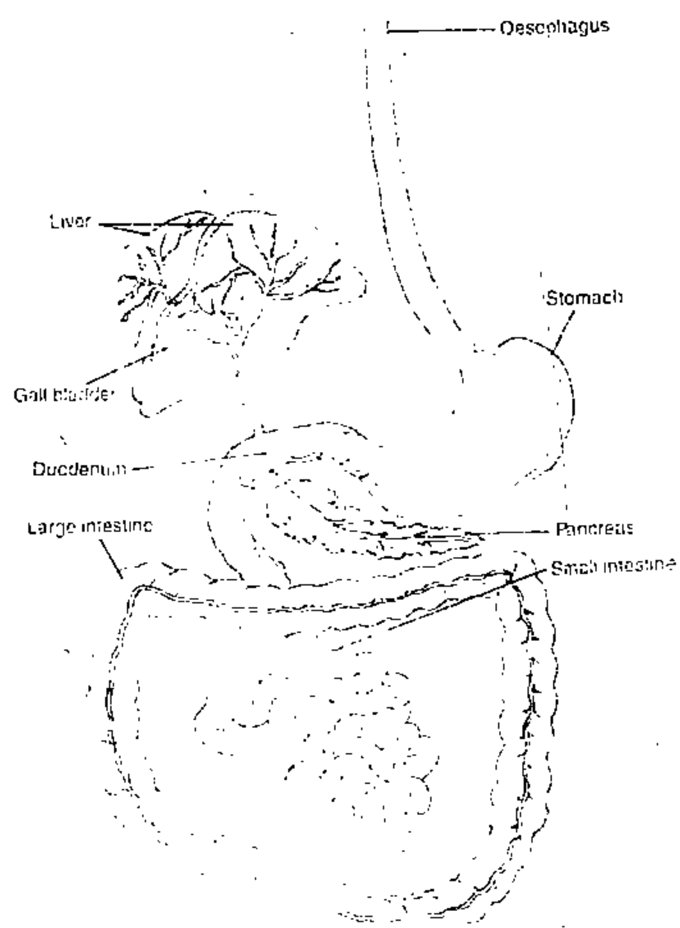


Fig. 6.29 Digestive tract of man

The Prototherians resemble, reptiles, birds and Amphibia and differ from most mammals in the retention of a cloaca. Into this not only rectum but the urinary and the genital ducts open. In marsupials a common sphincter muscle surrounds both anal and urinogenital apertures. In female there is a definite cloaca. In nearly all eutherians the apertures are distinct, and separated from one another by a considerable space the **perinaeum**.

Associated with the alimentary canal is the liver. It consists of two parts or main divisions (i.e. right and left) completely separted from one another by a fissure termed the **umbilical**, owing to its marking the position of the foetal **umbilical** vein. When a gall-bladder is present, as in the case of majority of mammals, it is attached to, or embedded in, the right central lobe. A gall bladder is absent in the perissodactyles, the hyracoids and some rodents. However, it is present in fruit-bats (Epomophorus).

SAQ 4

Tick out (✓) the correct answer in the box.

(i) Which organ in herbivores serves as a fermentation chamber and provides absorptive area ?

(a) Liver ☐

(b) Gall bladder ☐

(c) Pancreas ☐

(d) Caecum ☐

(ii) In which mammals stomach is divided into 4 chambers ?

(a) carnivores ☐

(b) ruminants ☐

(c) rodents ☐

(d) insectivores ☐

(iii) In which mammal caecum has fluid storing and digestive fucntions ?

(a) Kangaroo ☐

(b) Lion ☐

(c) Horse ☐

(d) Man ☐

(iv) In which mammals the distal end of the caecum has degenerated into an appendix vermiformis ?

(a) Horse ☐

(b) Man ☐

(c) Cow ☐

(d) Sheep ☐

6.6 SUMMARY

Let us sum up what we have learnt in this unit.

- Teeth are present in nearly all mammals, but in some such as whalebone whales they do not occur in adult condition. Teeth develop partly from the epidermis and partly from the underlying dermis. Mammals have two distinct sets of teeth, the deciduous (milk) and the permanent dentition. The milk teeth in mammals sometimes disappear at an early stage e.g. seal and sometimes persist and do not get replaced by the permanent teeth till long after birth. Some mammals have teeth indefinite in number e.g. dolphins and porpoises. The number of various categories of teeth in the jaws is conveniently expressed by a dental formula in which the kind of tooth is such as incisor, canine, premolar and molar is indicated by the initial letters as i, c, pm, m.
- Animals use various strategies to feed. Some species search, stalk, pounce, capture, and kill. In lower vertebrates such as cyclostomes, elasmobranchs, teleosts, amphibians the most successful and widely used method for feeding is filter feeding. These filter feeders use ciliated surfaces to produce currents which draw drifting food particles into their mouths. In reptiles jaws or palate are provided with pointed teeth which help these animals in holding, tearing or swallowing their prey. Whereas birds have no teeth, but instead of that they have horny beaks which exemplify adaptive radiation suited to a gastronomic life style. Mammals make extensive use of their teeth for killing, cutting and grinding it up and accordingly teeth have evolved very different shapes for those purposes.
- The digestive organs vary much in structure in different vertebrate groups. Overall this is a tubular organization of alimentary canals because it allows food to travel in one direction, passing through different regions of digestive specialization. In general alimentary canals have four major divisions, the functions of which are (1) receiving (2) conducting and storage, (3) digestive and absorbing nutrients and (4) absorbing water and defecating.
- In majority of mammals the stomach is relatively simple sac like structure but in ruminants such as cattle, buffalo, goats, sheep, deer etc. it has four chambers. In ruminants food is swallowed, saturated by copious salivations and passes into the rumen and reticulum where it lies until, having finished feeding, the animal begins ruminating or chewing the cud. The caecum is simple in monotremes, absent in sloths, some cetaceans and in a few carnivores. In man and a few other animals like civets, some rodents, monkeys the distal end of caecum has degenerated into an appendix vermiformis.

6.9 TERMINAL QUESTIONS

1) What is the difference between dentition of herbivore and carnivore ? Illustrate your answer with suitable examples.

....

....

....

....

2) Describe the various strategies used by fishes and amphibian to feed.

....

....

....

....

3) Explain the major differences between reptilian and avian digestive systems.

....

....

....

....

4) State the differences between digestive system of herbivores and carnivores.

....

....

....

....

6.8 ANSWERS

Self Assessment Questions

1. i) correct (ii) incorrect
   (iii) correct (iv) incorrect
   (v) correct (vi) incorrect

2. (i) filter feeders, ciliated surfaces
   (ii) groove, venom, syringe
   (iii) talons, beak
   (iv) filter feeding, animals
   (v) incisors, tusks.

3. (i) Amphibian (ii) Reptiles
   (iii) Fish (iv) Birds

4. (i) d, (ii) b, (iii) c, (iv) b

Terminal Questions

(i) Refer to Section 6.2 of the unit.
(ii) Refer to Section 6.3 of the unit.
(iii) Refer to Section 6.4 of the unit.
(iv) Refer to Section 6.5 of the unit.

UNIT 7 RESPIRATORY SYSTEM

Structure

7.1 INTRODUCTION

Every living cell in a living organism consumes oxygen. Oxidation of substances within the cells results in the liberation of heat and energy and in the production of carbon dioxide. Carbon dioxide, the end product of respiratory metabolism is continuously removed from the body. The exchange of oxygen and carbon dioxide between an organism and its environment is known as respiration.

In vertebrates blood serves to transport oxygen and carbon dioxide. Haemoglobin, the respiratory pigment present in the blood of all vertebrates binds to oxygen and transports it from the respiratory structures to the cells and tissues. In vertebrates, haemoglobin is confined to the red blood corpuscles (RBC) or erythrocytes. RBCs and blood plasma play important role in the transport of the carbon dioxide. The process by which oxygen is obtained from the environment by the respiratory structures and its subsequent transport to the cells and tissues can be referred to as **external respiration**. The utilization of oxygen for oxidation of nutrients in cells and tissues may be termed as **internal respiration**. Internal respiration has been treated extensively in LSE-01 (Cell Biology) and LSE-05 (Physiology) courses. In this unit you will study respiratory structures that facilitate external respiration.

Objectives

After reading this unit you should be able to :

- describe the various water and air breathing respiratory structures of vertebrates,
- explain the mechanisms involved in the exchange of gases.
- describe accessory respiratory organs for air breathing in fishes and buccal respiration in frog.
- describe the functions of pharynx, trachea, bronchi and alveoli.

7.2 RESPIRATORY SYSTEM OF AQUATIC VERTEBRATES

External respiration is facilitated by the respiratory organs, the gills or lungs and in some cases the skin. For the respiratory organs to function efficiently they must have

1. a large surface area provided with ample capillary network that has an access to the environment.

2. a thin and moist membrance surface that facilitates passage of gases.

3. a provision for renewing the supply of oxygen-containing medium, namely, air or water that comes in contact with respiratory surface and for removing carbon dioxide that is released from the surface.

With a few exceptions organs of respiration in vertebrates are formed in association with pharynx. However, a certain fish, the loach has developed a peculiar habit of swallowing air, passing the air bubble through the intestine, voiding it at the anus. Oxygen is absorbed en route by blood vessels in the richly vascular intestine.

In water breathing animals gills are the main respiratory organs. Gills are composed of numerous gill filaments or gill lamellae, which are thin walled extensions of epithelial surface. Each gill contains a vascular network. Blood is brought extremely close to the surface, thus facilitating ready exchange of gases.

Gills are of two types : (i) external gills and (ii) internal gills.

External gills (Fig.7.1) develop from the integument covering the outer surfaces of visceral arches. They are usually branched; filamentous structures derived from ecotoderm. Internal gills (Fig.7.2) are composed of a series of parallel gill lamellae although in some forms they may be filamentous. They may be borne on both sides of the interbranchial septa but in some cases are present on one side alone. A series of lamellae on one side of an interbranchial septum is termed a half-gill or **hemibranch.** Two hemibranchs are jointed with interbranchial septum to form a complete gill or **holobranch.** It is generally assumed that internal gills are derived from endoderm, although the exact origin is not clear. In some animals both external and internal gills are present.

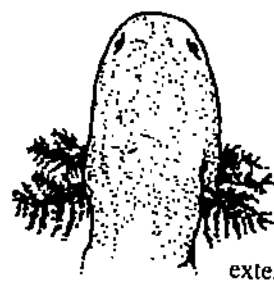


Fig.7.1: External gills of a salamander larva.

The functioning of external gills poses no problem since the filaments are in direct contact with water containing dissolved oxygen. When internal gills are used in respiration, water containing dissolved oxygen enters through the mouth and passes through the internal gill slits into the gill clefts. As the water passes over the gill lamellae, oxygen is taken from the water and carbon dioxide is released. The water then passes through the external gills slits to the outside.

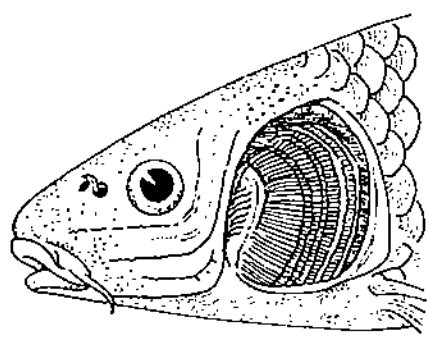


Fig. 7.2 : Operculum of a bony fish removed to show internal gills.

SAQ 1

Indicate whether the following statements are true or false :

1. External respiration would mean utilisation of oxygen for oxidation of nutrients in cells and tissues. T/F

2. One of the criteria for efficient functioning of the respiratory organs is that the respiratory surface should be thin and moist to facilitate exchange of gases. T/F

3. Internal gills develop from the integument covering the outer surface of visceral arches. T/F

4. Holobranch refers to a series of lamellae on one side of an interbranchial septum. T/F

7.2.1 Respiration in *Amphioxus*

In *Amphioxus* the walls of pharynx are provided with nearly 200 (the number may increase as the animals gets older) vertically elongated gill clefts (Fig. 7.3). Gill bars formed of a stiff, gelatinous chitin-like material separate gill clefts. Gill bars are of two kinds : (i) the primary gill bars and (ii) the secondary gill bars or tongue bars. The primary gill bars bifurcate at their ventral ends. A secondary bar, or tongue bar, grows down from dorsal to ventral side between two primary gill bars and thus divides each primary gill cleft into two. There are no gill filaments or lamellae. Blood vessels pass through the pharyngeal bars. Gill clefts open into a chamber around the pharynx, the peripharyngeal chamber or the atrial cavity.

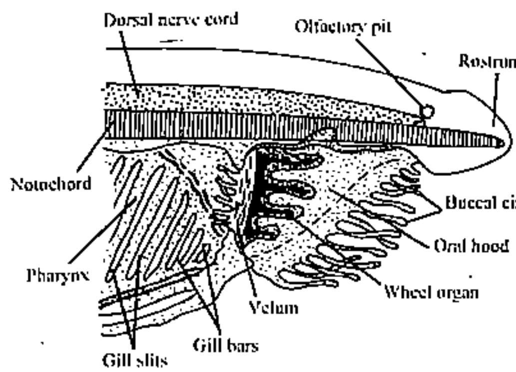


Fig. 7.3 : Anterior region of the body of *Amphioxus* showing pharynx and gill slits.

Although much of the respiration of *Amphioxus* takes place through the skin, a constantly renewed stream of water passes from the mouth to pharynx, through the gill clefts. By the action of cilia in the gill bars, water from the pharynx is drawn in to the atrium or pharyngeal chamber. When water passes over the gills bars, exchange of gases takes place and the blood is oxygenated. Water leaves the atrial cavity through an atriopore.

7.2.2 Respiration in Cyclostomes

Among cyclostomes, lampreys and hagfishes show small differences in their respiratory system. In lampreys, seven pairs of internal gill slits open from the pharynx into seven pairs of gill clefts, which are rather large and spherical in shape. The gill lamellae are arranged in a more or less circular fashion except the ones located in proximity to the anterior and posterior walls. Thus, there are 14 hemibranchs on each side, but only 6 holobranchs. The seven pairs of gills in lampreys are separated by interbranchial septum. The pouches do not open into pharynx in adults though they do so in larva. They open separately to the exterior. The inner walls of gill pouches contain folded respiratory epithelium and are vascular. Thus the respiratory tube is really the pharynx (Fig.7.4). Gullet in adults is a later development as an anterior extension of the intestine. Muscles surround gill pouches, and these together with elastic cartilages and appropriate valves pump the water tidally in and out of the external openings. In fact exhalation is the active movement and passive elastic recoiling of the branchial basket results in inhalation.

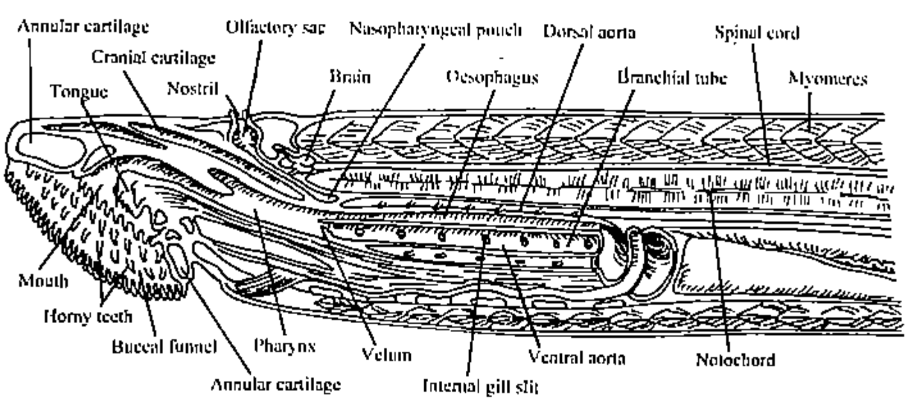


Fig. 7.4 : Organisation of the anterior region of a *Petromyzon* showing the respiratory tube

Among hagfishes in *Myxine* six pairs of internal gills slits and gill pouches are present. However, only a single pair of external openings exists. A series of long tubes coming from the gill pouches unite to form a common duct on each side that opens to the exterior (Fig.7.5).

The external aperture is located near the midventral line at some distance from the anterior end. This may be of advantage to the animal when it is feeding, or boring its way into the body of a fish in order to devour the soft internal organs. In myxines, an oesophageo-cutaneous duct connects the oesophagus with the common duct on the left side. It lies posterior to the last gill pouch on that side and is similar to a gill cleft but lacks gills. In hagfish of the genus *Bdellostoma* the number of gill clefts varies from 6-7 upto 13-14 pairs. The gills clefts connect internally with pharynx and not with a blind pouch of the type found in the lamprey; and externally they open separately.

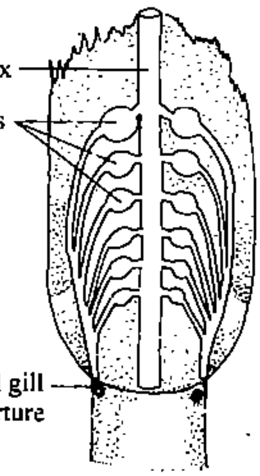


Fig. 7.5 : Diagram showing the relation of gill pouches of the hagfish to the pharynx and to the single pair of gill apertures.

7.2.3 Respiration in Fishes

A series of skeletogenous visceral arches encircles the pharynx of fishes and of tetrapods. In fishes these arches primarily support the gills. They are located between the gill clefts, one behind the other at the bases of the interbranchial septa. The first arch is called mandibular arch; and the second, hyoid arch. The remaining visceral arches are referred to by numbers (3,4,5,6, etc.). The first gill pouch or cleft lies between mandibular and hyoid arches and is often referred to as the hyomandibular cleft. In fishes it is either modified to form a spiracle or is closed altogether. The arrangement of gill arches and gills in elasmobranchs and bony fishes is shown in Fig. 7.6.

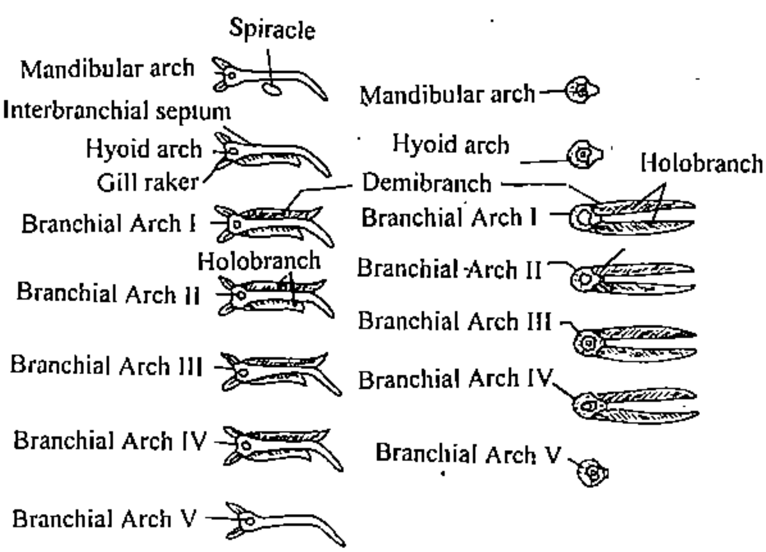


Fig. 7.6 : Arrangement of gill arches and gills in (a) an elasmobranch and (b) a teleost.

Gills develop in close association with paired lateral pouches of pharynx, extend towards the surface of the body and open to the exterior. Each gill pouch thus has an internal branchial aperture that opens into pharynx and an external branchial aperture that opens to the outside. The relationship between the pharynx and branchial chamber is shown in Fig.7.7. The successive gill pouches are separated by interbranchial septa. Branchial filaments containing blood vessels line gill pouches. The water passing through the gill chamber bathes the vascularised filaments facilitating respiratory exchange of gases.

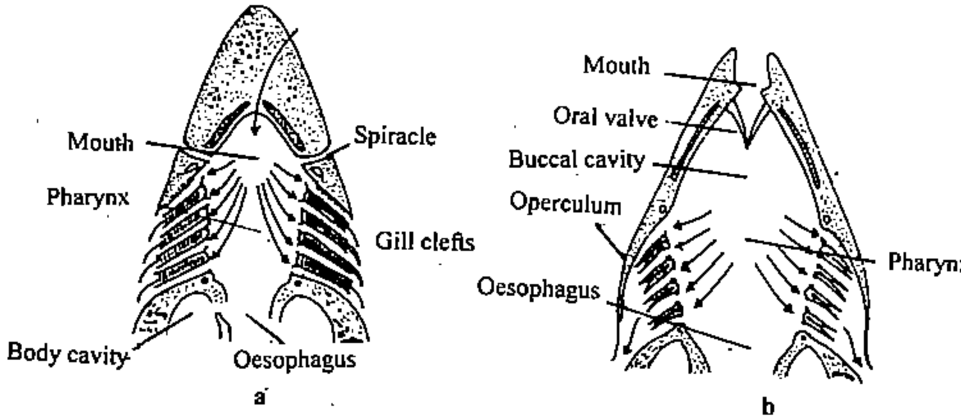


Fig. 7.7 : Relationship between the gills and branchial chamber in (a) an elasmobranch and (b) a teleost.

As stated earlier, the visceral arches which support the wall of the pharynx are located on the inner edge of the interbranchial septa. There are two sets of branchial or gill filaments. One attached to the anterior end and the other to the posterior end of the interbranchial septum. Each set is known as a hemibranch or demibranch. The two hemibranchs are attached to a gill arch, constituting a holobranch. In other words, each gill pouch has an anterior demibranch of one holobranch and the posterior demibranch of the other. Each branchial arch has a set of aortic arch vessels that brings blood to gills and taking it away after oxygenation. The gill filaments and their lamellae are arranged in the form of a system of pores and the water flows through the pores (Fig.7.8). The counter current flow of water across the gills ensures that water leaving the gills has only 20% of the orginal oxygen content. (Refer to Unit 2 of LSE-05 for details of counter current flow of blood and water).

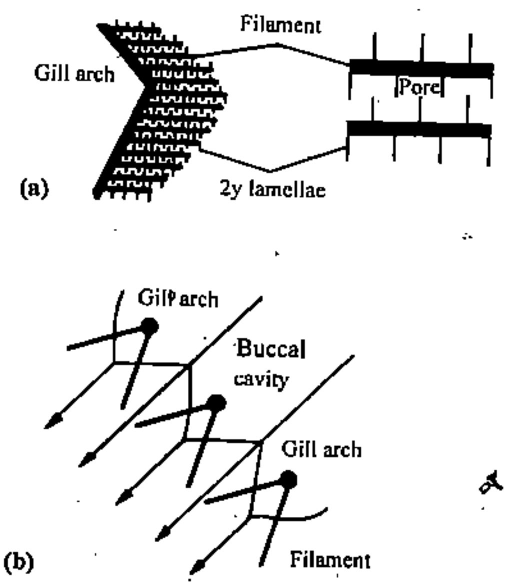


Fig. 7.8 : Transverse section of the gill of a teleost, showing the secondary lamellae forming pores that allow the water flow.

There are two main types of internal gills in fishes. The first and more primitive type is characteristic of elasmobranchs. In this group the interbranchial septa are exceptionally well developed and extend beyond the hemibranchs (Fig. 7.9a). The interbranchial septa, in addition to separating the gill clefts, serve to protect the gills themselves. The second type of gills is found in bony fishes. In these forms, the interbranchial septa are reduced to varying degress (Fig.7.9b) from which hemibranchs protrude into a single branchial or extrabranchial chamber located on each side between the operculum and gills. The gill cover or operculum, a fold formed by the backward elongation of the hyoid arch, protects the gills in the branchial chamber which thus opens to the outside through a single gill aperture. In fishes having an operculum, a branchiostegal membrane supported by bony branchiostegal rays usually extends for the inner surface of the operculum to the body wall. Raising the opercula and closing the branchiostegal folds bring about gill respiration in these fishes. As the water passes over the gills emerging through the opercular slit oxygen is taken up and carbon dioxide is liberated. Respiration in fishes thus involves a series of muscular contractions in the wall of pharynx and mouth, bringing about a flow of water. The act of inspiration causes water to enter the mouth and pharynx, and expiration results in its expulsion.

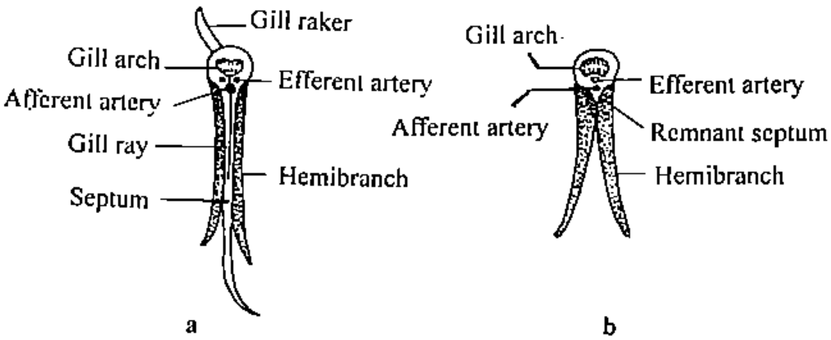


Fig. 7.9 : Types of gill in fishes (a) elasmobranch (b) teleost

In most elasmobranchs and in a few other fishes (*Acipenser*, *Polydon*, *Polypterus*), the first gill pouch has become modified and opens to the outside by means of a spiracle. Rudimentary gill lamellae may be located on the anterior wall of the spiracle. Since blood supply to these lamellae consists of oxygenated blood, they do not perform a respiratory function and the term false gill or **pseudobranch** is applied to them. The spiracles generally open on the top of the head and in some species they are provided with valves.

In most bony fishes, a true hemibranch, receiving non-oxygenated blood is lacking on the posterior side of the hyoid arch. Instead a modified opercular gill or a pseudobranch, receiving oxygenated blood may be present. Opercular gills of this type are found in *Amia*, the Dipnoi and many teleosts. The lamellae of pseudobranch are shown to contain many receptors and ionocytes (chloride secreting cells). The receptors respond to changes in blood including partial pressures of oxygen and carbon dioxide, pH and osmotic pressure. The organ, thus, is comparable to the carotid body of mammals. Most elasmobranchs have five pairs of clefts in addition to the spiracles. One form, *Hexanchus*, has six and another *Heptanchus* has seven clefts. *Heptanchus* also has the largest number of gill clefts of any gnathostome, Chimaeras have four pairs of clefts but the spiracle is absent and the last cleft is closed. *Polypterus*, *Acipenser* and *Polydon* like most elasmobranchs have five pairs of clefts. Dipnoi which lack spiracles, also show variation in the number of clefts. *Neoceratodus* and *Protopterus* have five pairs of clefts, but *Lepidosiren* have only four.

The presence of external gills is rare among fishes. In *Polypterus* a single pair of external integumentary gills is present in the region of the hyoid arch. Larval Dipnoi possess four pairs of external cutaneous gills located on the visceral arches. Most fishes die soon after being exposed to air, even though their gills are kept moist. Lack of water in the branchial chambers as well as the accumulation of mucus causes the gills to stick to each other. With the result the exposed respiratory surface is decreased and the exchange of gases is no longer adequate. Fresh-water fishes face the problem of their environment getting dried up and to overcome this problem, in addition to gills, they have evolved accessory organs for breathing air. In the following subsection you will briefly learn about the accessory respiratory structures of certain fresh water fishes.

SAQ 2

Fill in the blanks with suitable words.

1. ________ is the major respiratory organ of *Amphioxus*.
2. The number of pairs of gill pouches present in lampreys is ________ and in myxines is ________

3. In lampreys inhalation is a ________ process and exhalation is an ________ process.
4. The number of gill openings in lampreys is ________ and in myxines is________.
5. The first visceral arch of vertebrates is ________ arch and the second is________.
6. The system of water flow across the gills in fishes that ensures an 80% oxygen uptake is known as ________ ________ flow.
7. In elasmobranchs ________ ________ are well developed and extend beyond hemibranchs.
8. Opercular gills that are not true hemibranchs but which contain receptors and ionocytes are known as ________.
9. Among gnathostomes the largest number of gills is present in ________
10. Presence of a single pair of external integumentary gills is characteristic of _____

7.2.4 Accessory Respiratory Organs in Fishes

The accessory respiratory organs of fishes are the outgrowths either of the pharnyx or the branchial chamber that are richly supplied with blood vessels. Air from outside is drawn into these chambers by mouth and retained there for aeration of the blood. Actinopterygians *Anabas*, *Ophiocephalus*, *Amphipnous*, *Clarias*, and *Saccobranchus* are some of the fishes provided with accessory respiratory organs.

Anabas, the climbing perch, migrates from pond to pond and during such times while it progresses on land breaths air from the atmosphere. The two air chambers are the extensions of the branchial cavities and lie one on each side of the head. The accessory organs, also known as labyrinthine organs (Fig.7.10) are outgrowths of the upper part of the first branchial arch. Each organ consists of concentrically arranged wavy plates. covered by a vascular membrane. The air chamber communicates with pharynx by an opening situated between hyoid and the first branchial arch. Essentially air that is drawn by the mouth passes into the branchial chamber and exits through the branchial apeture. *Anabas* can remain outside water for nearly six to seven hours.

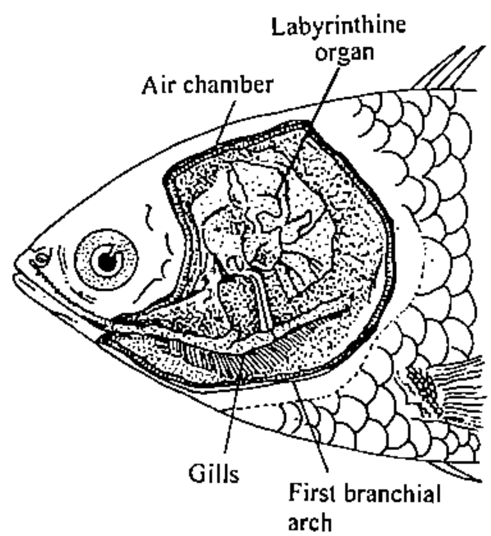


Fig. 7.10 : The labyrinthine organ of *Anabas*.

Ophiocephalus, the murrel, also has a pair of air chambers one on each side of the head (7.11). Each air chamber arises as an outgrowth of pharynx above the first gill arch and extends as far as the last gill cleft. The vascularised surfaces are derived from hyomandibular arch and the epibranchials of the first two branchial arches. Air enters into the chamber by the mouth and leaves through the opercular arch.

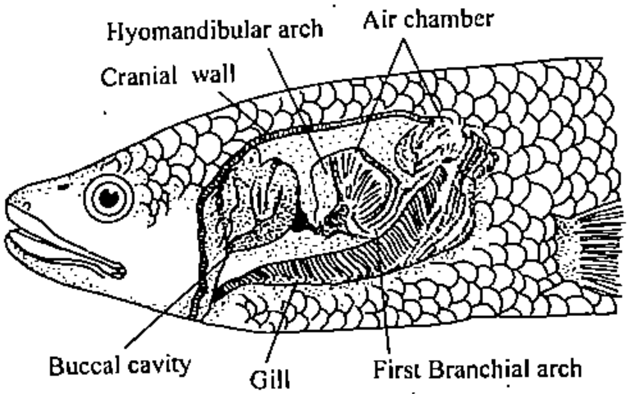


Fig. 7.11 : The accessory respiratory organ of *Ophiocephalus*.

In *Clarias*, the catfish, the highly branched and vascularised paired accessory respiratory organs are the outgrowths of the gill cavity. The arboriform or dendriform organs (Fig.7.12) as they are called, are more specifically derived from the upper parts of the second and fourth branchial arches.

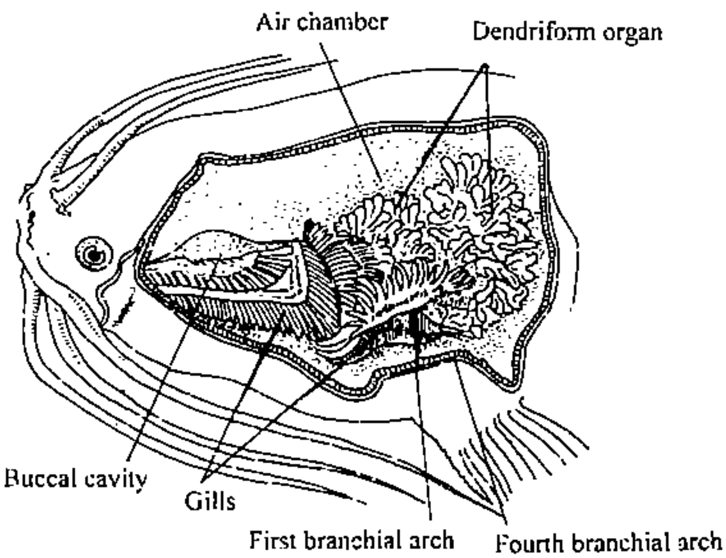


Fig. 7.12 : The arboriform accessory respiratory organ of *Clarias*.

In *Amphinous* the air chambers (Fig.7.13) arise as saccular outgrowths of dorsal wall of the pharynx extending as far as the third branchial arch. The walls of the sacs are folded and vascular. The sacs communicate with pharynx by an opening through which air is drawn in. The air exits through the gill slits and opercular opening. The gill filaments of the first gill arches are highly reduced.

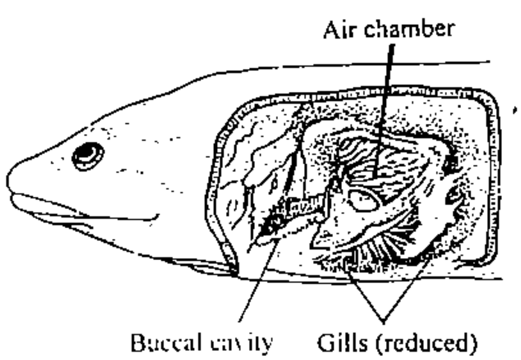


Fig. 7.13 : The air chamber in *Amphipnous*.

In *Saccobranchus* there is a pair of tubular sacs that arise as outgrowths of gill chambers extending upto the middle of the tail region (Fig.7.14). The folds in these tubes form a sort of air chamber that communicates with the buccal cavity by a slit.

The air passes in and out of the chamber through the slit. The mudskipper *Periophthalmus* that lives in brackish waters has large opercular cavities that are filled with air drawn through the mouth. Mudskipper is so accustomed to life out of water; it dies of suffocation if prevented from living on land for a long period. A similar arrangement in which the opercular cavity functions as an aerial respiratory organ is noticed in the tropical rock skipper *Andamia*.

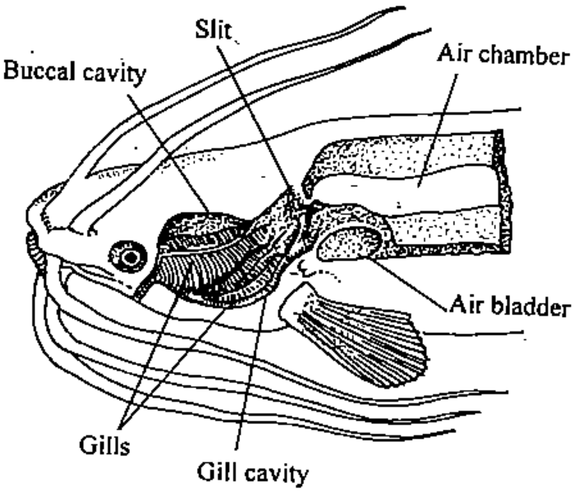


Fig. 7.14 : The accessory respiratory organ of *Saccobranchus*

SAQ 3

Match the type of accessory respiratory organ with the fish that possesses it.

a.	Air Chamber	1.	*Amphipnous*
b.	Tubular Chamber	2.	*Anabas*
c.	Arborescent organ	3.	*Ophiocephalus*
d.	Saccular Chamber	4.	*Saccobranchus*
e.	Labyrinthine organ	5.	*Clarias*

7.2.5 Respiration in Aquatic Amphibians

Most amphibians spend their larval life in water and, after metamorphosis into adults move to the land. During larval life, external gills of integumentary type are used as organs of gas exchange. In addition the moist and highly vascularised skin also serves as the respiratory organ.

The three pairs of external gills that appear at the time of hatching are branched processes arising from the upper external edges of the third, fourth and fifth branchial arches. The last pair is smaller than the first two pairs. Each gill has an ectodermal lining with a mesodermal core and is connected with the blood vessel from aortic arches. Subsequently folds from the posterior edges of the hyoid arches cover the gills as operculum. At a later stage the gills are resorbed.

The internal gills are formed with the establishment of mouth opening. The internal gills consisting of branchial filaments are formed ventral to the external gills on the branchial arches and project into the opercular cavity. The third, fourth and the fifth visceral arches possess two rows of filaments and the sixth arch has only one row on its anterior side. Blood vessels from aortic arches provide vascular connections. Water passes from mouth to pharynx and then through the gill slits into the opercular chamber. It finally leaves through the opercular aperture. The internal gills disappear at the time of metamorphosis.

In a few urodeles, gills are retained throughout life, but in most urodeles and all the tailless amphibians, they disappear at the time of metamorphosis. Newly developed lungs then take over the function of respiration. During embryonic development, with few exceptions, five pairs of pharyngeal pouhces form in the characteristic manner.

The first and the last are not perforated and only 2, 3, 4 actually connect to the outside. In certain urodeles all the gill slits persist throughout adult life. In *Siren* (7.15a) all the three clefts remain functional. *Necturus* (7.15b), *Typhlomolge* and *Proteus* possess only two pairs of clefts. In *Amphiuma* only one pair persists. In hellbender, *Cryptobranchus alleganiensis*, when the external gills disappear, the edges of the operculum fuse to the throat except on the dorsal side, leaving an opening on either side.

Structures analogous to gills may develop in reptiles, birds and mammals. In reptiles five pairs of pharyngeal pouches are formed during embryonic life and in birds and mammals only four develop. In the latter groups a fifth one may also develop, but it remains rudimentary and attached to the fourth pair. The pouches do not break through to the outside, but very occasionally, they may do so. If the pharyngeal pouches fail to become obliterated in the normal manner, they may lead to the formation of branchial cysts and fistulae.

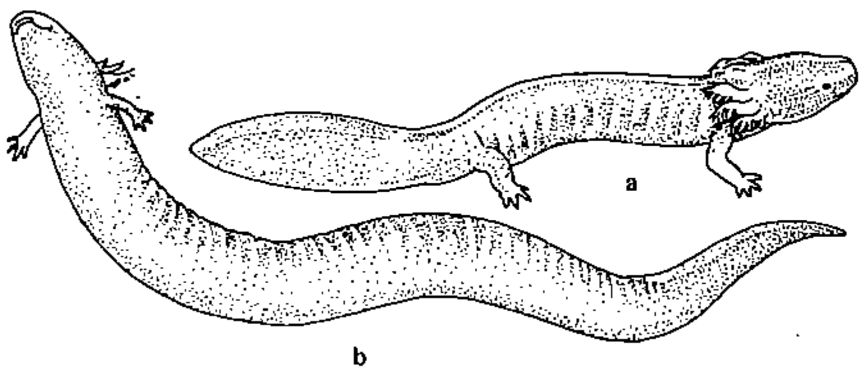


Fig. 7.15 : a. *Siren* and b. *Necturus* with external gills.

In the latter condition, there is an opening in the neck region, which communicates with pharynx. In such cases perforated gill clefts have failed to disappear. In fact, gills do not develop in association with the pharyngeal pouches of reptiles, birds and mammals. Some transitory structures that appear for a short time during development as outgrowths of gill pouches in chick embryos and the embryos of certain turtles may possibly be homologous gills. It is certain that they have no respiratory function.

SAQ 4

Choose the correct answer from the alternatives provided.

1. Most larval amphibians have external gills/internal gills of integumentary type.
2. The internal gills appear appear/disappear at the time of metamorphosis.
3. In a few taillesss amphibians/urodeles, gills persist throughout adult life.
4. In *Proteus* only two/three gills clefts remain functional.
5. Gills develop/do not develop in association with the pharyngeal pouches of reptiles, birds and mammals.

7.3 RESPIRATORY SYSTEM IN TERRESTRIAL VERTEBRATES

In air breathing animals the main respiratory organ is lung. Embryologically, the diverticulum that grows out ventrally from the floor of the pharynx posterior to the last gill pouch develops into lungs. The diverticulum divides into two halves, the lung buds, which are destined to give rise to the bronchi, and the lungs proper. The lung buds grow posteriorly, invested by an envelope of mesoderm, until they reach their final destination in the body. They may branch to varying degrees, depending upon the species. The original unpaired duct, which connects the lungs to the pharynx, serves to carry air back and forth and is known, in most cases, as windpipe or trachea. In most salientian amphibians the duct is so short as to be practically nonexistent. The trachea at its lower end divides into two bronchi which lead directly to the lungs.

7.3.1 Fishes with Lungs

Most actinopterygian fishes have structures called swim bladder or air bladder between alimentary canal and vertebral column. The distended sac like air bladder varies in length and form in different fishes. It is essentially hydrostatic in function. But in crossopterygian fishes as well as in the certain chondrostean fishes, the lungs derived in a similar way as air bladder have a respiratory function. In the chondrostean *Polypterus*, there is a bilobed lung developed symmetrically and the duct opens ventrally into pharynx (Fig.7.16). The epithelial lining of the lung is not smooth and there are a few furrows that increase the surface in contact with air. In *Polypterus*, lungs are supplied by pulmonary arteries off the sixth embryonic aortic arch, but the venous return is through the hepatic veins. Dipnoans, the lungs fishes are characterised by either a bilobed lung as in most cases or just one lobe as in *Neoceratodus*. The ducts in dipnoans open into oesophagus slightly to the left of the midventral line, but the sacs grow into the dorsal mesentery of the gut, where they lie in the adult. The lungs in dipnoans are divided into many chambers. *Neoceratodus* comes to the surface to breathe air but only when oxygen tension falls below 83 mm Hg and is known to survive foul waters that kills other fishes. At the same time, the fish can not live out of water. The other lungs fishes, *Protopterus* and *Lepidosiren*, have been shown to obtain nearly 98% of their oxygen requirements from air. The floor of the mouth is lowered and air drawn in through the mouth is forced back by a buccal pump, with the mouth being closed and the tongue pressed against the roof as a seal. The hyoid apparatus and the pectroal girdle help in the process of inspiration. Expiration is exclusively by the elasticity of the lungs, with ribs playing no role in the process.

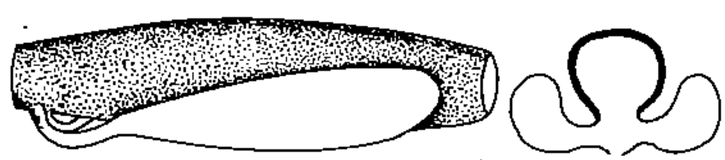


Fig. 7.16 : The bilobed lung of *Polypterus*.

7.3.1 Respiration in Amphibians

Generally amphibians respire by lungs as well as by skin. Respiration by skin is known as the cutaneous respiration and by lungs, the pulmonary respiration.

- **Cutaneous respiration**

The skin of the amphibians is kept moist by the cutaneous glands present in it. Further the skin is supplied with the capillaries of the cutaneous artery that carries the deoxygenated blood. Respiratory exchange of gases takes place between the atmospheric oxygen and the carbon dioxide carried in the blood. The oxygenated blood is returned to the heart by the cutaneous vein and thence to the general circulation.

- **Pulmonary respiration**

Lungs of amphibians appear as two simple sacs, elongated in urodeles and bulbous in anurans. They occupy the pleuriperitoneal cavity along with other viscera. The left lung is usually longer except in caecilians, in which it is rudimentary. The internal lining of the amphibian lung may be entirely smooth or there may be simple sacculations in the proximal region or the entire lining may be pocketed.

The lungs of the perennibranchiate urodeles apparently function primarily as hydrostatic organs except when the dissolved oxygen in water is insufficient to permit branchial respiration. A few urodeles develop no lung bud and lack both gills and lungs throughout life. A specially vascularised region of the pharyngeal and oesophageal lining is used as a respiratory membrane along with the skin. Salamanders inhabiting swift mountain streams may have only vestigial lungs a few millimeters in length. since buoyancy would be a disadvantage in swiftly flowing currents.

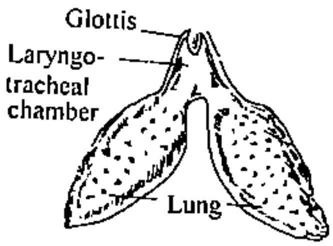


Fig. 7.17 : The lungs and the laryngo-tracheal chamber of frog.

In frogs, the external nostrils, internal nostrills, buccal cavity, laryngo-tracheal chamber and lungs constitute the respiratory system (Fig.7.17). The lungs open anteriorly into a laryngo-tracheal chamber whose wall is supported by five cartilagenous plates–a ring-like cricoid, a pair of small arytenoids and a pair of small prearytenoids. This chamber corresponds to the larynx and the trachea of the human body; but the two regions are short and are not differentiated in frog. The laryngo-tracheal chamber opens in front into the buccal cavity through glottis. The buccal cavity itself communicates to the exterior by the mouth as well as the external nostrils. The air passes in and out of the buccal cavity via the external nostrils.

There are two processes involved in pulmonary respiration. One, the drawing in of the air into lungs – the inspiration and two, the forcing out of air from lungs – the expiration. Inspiration occurs in two stages (Fig.7.18). In the first stage, the external nostrils are kept open and the mouth is tightly kept closed. The lowering of the floor of the buccal cavity causes an increase in buccal space. This in turn leads to the rushing of air from outside into buccal space through external nostrils. The buccal cavity thus functions as a suction pump. Essentially in the first stage the air is drawn into the buccal cavity from outside. In the second stage, the valvular external nostrils as well as the mouth are kept closed. The floor of the buccal cavity is raised. The air in the buccal cavity is under pressure; but the pressure is insufficient to open the mouth or the pharynx. The air enters the laryngo-tracheal chamber through the glottis. The elastic wall of the lungs causes the dilation of lungs allowing the entry of air. Exchange of gases takes place in the alveoli of the lungs. During expiration, the elastic wall of the lungs recoil expelling the air contained in them. The air arrives at the buccal cavity and from there moves outside through the external nostrils.

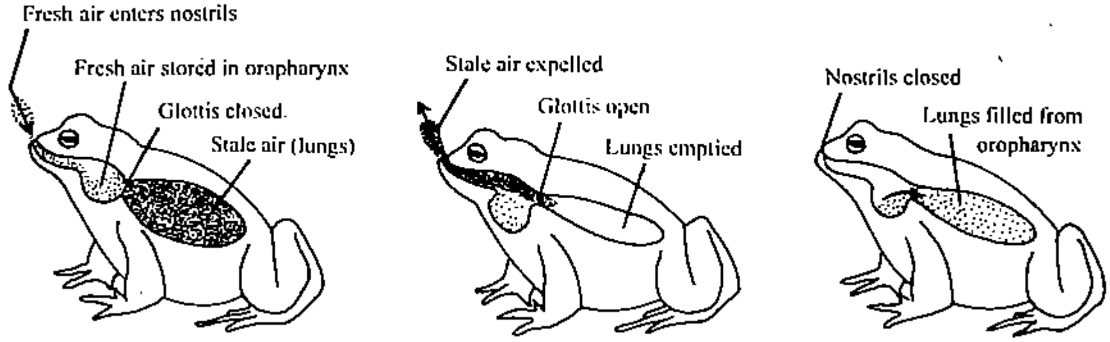


Fig. 7.18 : Stages in inspiration of frog (a) first stage (c) second stage (b) expiration.

7.3.2 Respiration in Reptiles

In *Sphenodon* and snakes lungs remain as simple sacs. The posterior third of the lining of the snake lung is septate and is filled with stored air. In higher lizards, crocodilians and turtles, the septa are so constructed that there are numerous large chambers, each with a multitude of individual subchambers (Fig.7.19). The trachea bifurcates to form two bronchi, and from each bronchus arise numerous bronchioles, which lead to the air chambers. Lungs are spongy because of the numerous pockets of the trapped air. Volume of lungs is relatively larger than in mammals but the surface area is sometimes 100 times smaller in proportion to body weight. The purpose of the large volume is to provide a reservoir of air, useful in diving species for holding breath when startled and so remaining still. In aquatic forms lungs are often provided with smooth avascularised air sacs. They are useful for maintaining buoyancy.

The left lung in limbless lizards and in snakes is rudimentary or absent altogether except in occasional forms such as black snakes. In puffing adder an enormous diverticulum of the left lung extends into the neck region. Inflation of the diverticulum causes the neck to spread characteristically, and inflation of the lungs causes the body to swell. In the spotted king snake, the lung and its bronchus extend fully two-thirds the length of the body.

The oxygen requirement of reptiles is relatively low. Their standard metabolic rate is only 10 to 20 percent of that in homeotherms. Most reptiles are therefore incapable of sustained activity. Their movements are in short bursts during which their muscles contract anaerobically. However reptiles can tolerate much greater changes in the circulatory components of the blood than in mammals. Such a property enables them exist for long period in low oxygen conditions. Lizards, snakes and crocodiles can survive for 30 minutes in pure nitrogen and turtles for several hours.

Fig. 7.19 : The lungs of chameleon.

Generally the respiratory system of lizards has the following features. The glottis leads into larynx, which is supported by cricoid and arytenoid cartilages. From the larynx the trachea passes backwards on the ventral side of the neck. Rings of cartilage support the long trachea. It bifurcates behind into two bronchi and each bronchus enters into a lung. The inner lining of the lung is raised into a network of delicate ridges so as to produce a spongy or honeycomb-like appearance. The ribs are pulled backwards and forwards by the muscles, which extend between them, thereby altering the size of the body cavity. When the body cavity is increased in size, air from outside passes through the nostrils into the lungs and dilates them, resulting in inspiration. The expiration is a passive act. The skin of reptiles does not participate in respiration.

Although many reptiles use the floor of the oral cavity as an air pump, others take advantage of atmosphereic pressure to help fill lungs. The long body ribs are elevated and this action enlarges the body cavity. The pressure in the coelom around the lungs falls and just as quickly atmospheric pressure inflates the lungs until they occupy the additional available space. By this method the lungs are passively rather than forcibly inflated. Turtles can not use the ribs for respiration since they are fused with the shell, but muscular peritoneal membranes increase the cavity (for inhalation) and others compress the lungs (for exhalation).

7.3.3 Respiration in Birds

In birds, as in reptiles, respiration is pulmonary. The respiratory system occupies as much as 20% of the volume of the body, as against only 5% in man. In birds the lungs and the respiratory passages are highly modified. The highlights of such modification are : (i) the formation of extensive diverticula or air sacs in lungs that invade most parts of the body; (ii) the anastomosing of the air ducts within the lungs so that no passage terminates blindly within the lungs and (iii) the isolation of lungs in pleural cavities. The air sacs are blind thin walled, distensible diverticula of the lungs that invade most parts of the body (Fig.7.20).

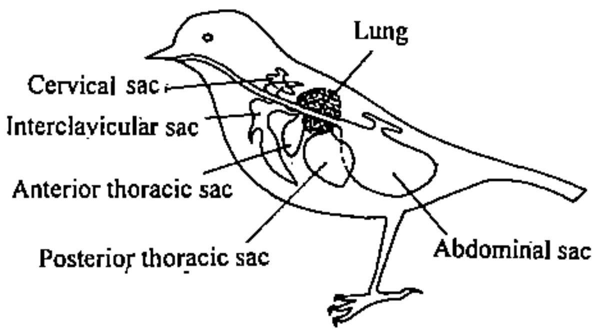


Fig. 7.20 : The lungs and air sacs of a bird. The main bronchus runs through the lung and has connections to air sacs and lung.

The glottis leads into the larynx, the walls of which are supported by paired arytenoid and cricoid cartilage. The larynx is followed by a long trachea, which is supported by complete rings formed of ossified cartilage. The trachea divides into two bronchi, which by a peculiar system of branching gives rise to lungs and air sacs. The primary bronchus of each side enters the medioventral side of the lung and is dilated into a vesicle. From there it continues as mesobronchus into the distal end of the lung (Fig. 7.21). The mesobronchus gives rise to secondary bronchi that are variously termed as ectobronchus, endobronchus, laterobronchus and dorsibronchus depending on their position. The secondary bronchi further branch and give rise to tertiary bronchi or parabronchi which divide and subdivide into a system of bronchioles. The bronchioles form a system of air capillaries that are surrounded by blood capilaries. These are the sites at which the exchange of gases takes place. The tertiary bronchi are connected with one another and are responsible for the circulation of pure air in the lungs. Structures known as 'recurrent bronchi', which arise as outgrowths of air sacs, connect the lungs with the air sacs.

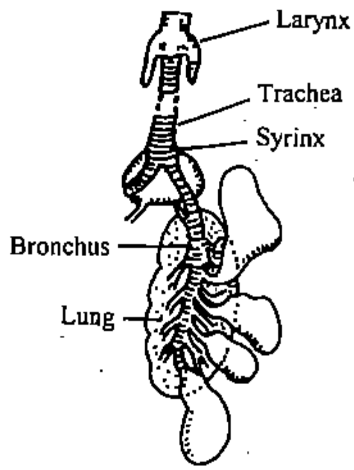


Fig. 7.21 : The respiratory system of a bird.

Lungs are small spongy inelastic organs. The thin walled air sacs are divided into two sets of chambers, the posterior inspiratory chambers and the anterior expiratory chambers. The abdominal and posterior thoracic air sacs constitute the posterior chambers and they are filled with air rushing into them through primary bronchus. The anterior thoracic, median interclavicular and cervical air sacs constitute the anterior set of air sacs. These air sacs continue as spaces in the bones. During inspiration some of the air passes directly to the posterior sacs. Another part passes into secondary and tertiary bronchi and into the air sacs indirectly. During expiration the air again passes through the tertiaries and secondaries and then into anterior sacs and trachea (Fig. 7.22). The posterior sacs contain 4% CO_2 and 17% O_2 and in the anterior sacs it is 7 and 14% respectively. The blood vessels are so arranged that the air richest in oxygen meets the blood just before it leaves the lungs. Thus a system of cross currents allows the blood to become fully oxygenated (Fig.7.23).

The lungs of birds are capable of little expansion, as they are attached to the ribs and thoracic vertebrae. The raising of the sternum when the animal is at rest, and lowering of the backbone when the animal is in flight diminishes the size of the body cavity, leading to the forcing of the air outside (expiration). Thus expiration is an active process in birds. Inspiration is a process, brought about by the rebounding of the muscles to their original size, causing an increase in the size of the body cavity.

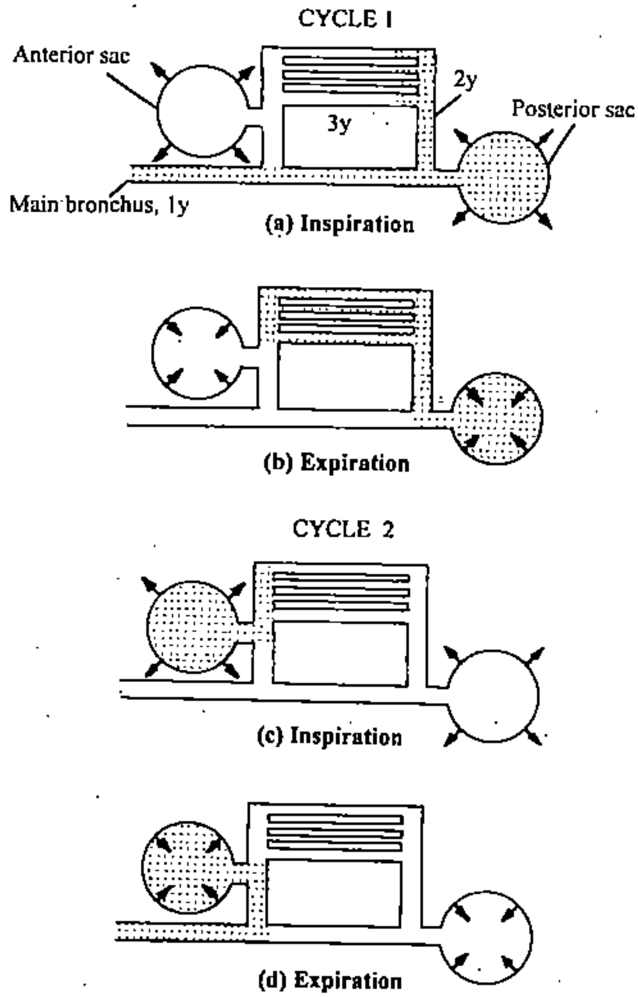


Fig. 7.22 : Passage of air through avian respiratory system. In order to complete its path the air moves through two full cycles.

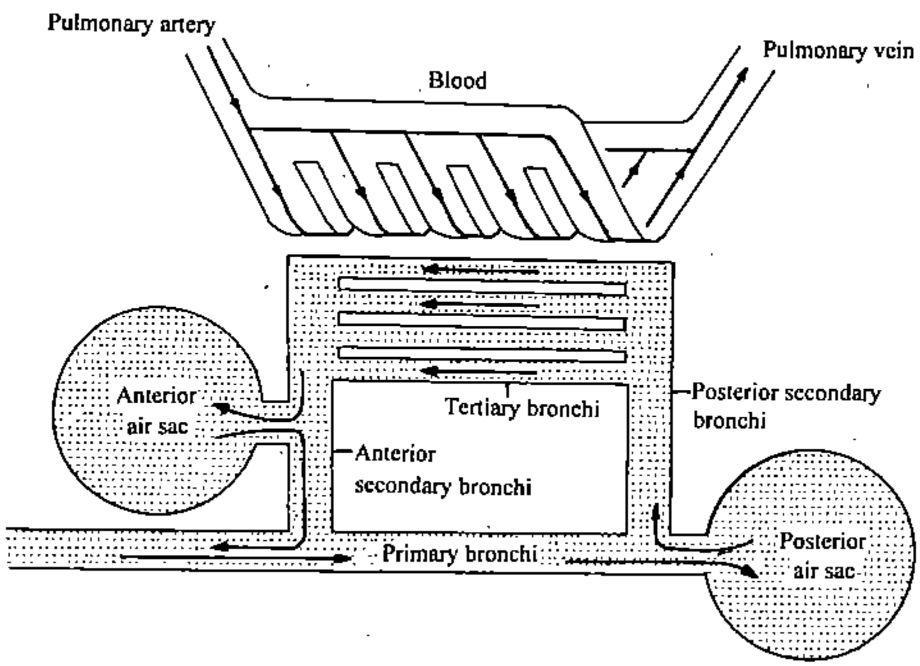


Fig. 7.23 : Diagram showing the pathway of airflow in the lung of a bird and the counter current flow of blood.

Mammals have a pair of lungs enclosed in a thoracic cavity. The bony framework of the thoracic cavity is formed of thoracic vertebrae, ribs and sternum. The lungs of the mammals are multichambered and usually divided into lobes. Usually the right side has more lobes than the left side. Man has three right and two left lobes (Fig.7.24). Rabbits have three lobes on each side, but the right posterior lobe is subdivided. Cats have three left lobes and four right ones, and several are subdivided. The lungs of whales, sea cows, elephants, and perissodactyls lack lobes. In monotremes and rats only the right lung is lobed.

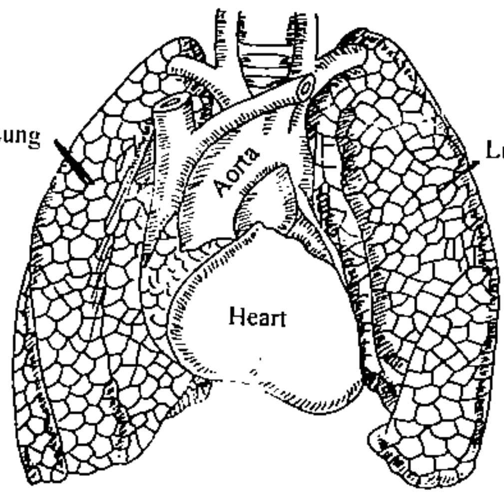


Fig.7.24 : The human lungs.

The air from outside passes through the external nostrils and nasal passages into pharynx. From the pharynx it passes through the glottis into trachea. The trachea is a long tube that traverses the neck and lies ventral to gullet. The anterior part of the terachea is enlarged to from the voice box or larynx. The larynx has its walls supported by four cartilagenous plates. The thyroid cartilage supports the ventral and lateral walls of cartilage; the lower part of the trachea is supported by the ring-like cricoid; and a pair of arytenoids supports the dorsal part. The vocal cords are located inside the larynx and the vibrations of the vocal cords results in the production of the sound. The trachea bifurcates into two primary bronchi. Each primary bronchus enters into lungs and branches into secondary and tertiary bronchi, and finally into bronchioles. Terminal bronchioles lead into thin walled delicate alveolar ducts, the walls of which are evaginated to form clusters of alveoli.

Each lung is enclosed in pleural cavity formed by two thin layers of walls. There is an outer parietal layer lining the cavity of the thorax and an inner visceral layer forming an investment to the lung. The parietal layer is reflected ventrally and is continuous with the visceral layer. The reflected layer of the parietal layer is continuous with pericardium (Fig. 7.25a and b). The cavity of thorax is thus divided into pleural cavities that enclose lungs and the pericardial cavity that contains heart. The space between the two lungs is the mediastinum.

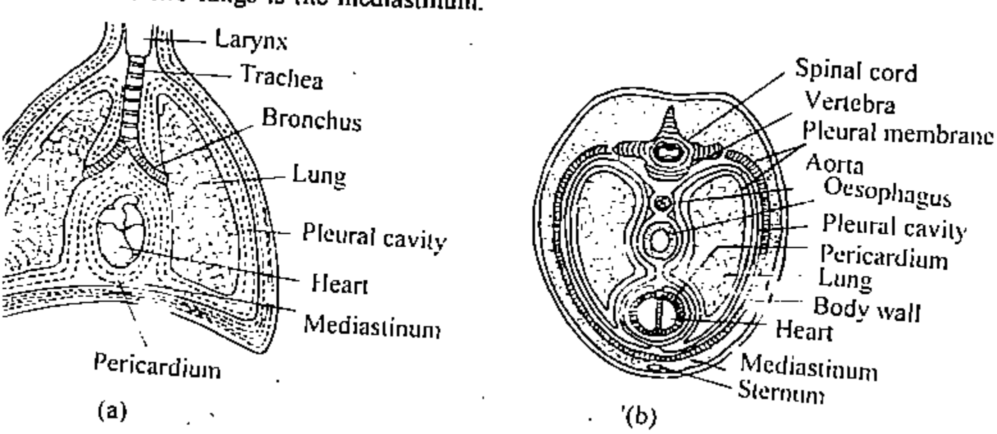


Fig. 7.25 : (a) The respiratory organs of a rabbit. (b) Transverse section through thorax.

In mammals buccal cavity plays no role in respiration, and the diaphragm and ribs play an important part. In respiration, the raising of the ribs and flattening of the diaphragm increases the size of the thoracic cavity. The contraction of the external intercostal muscles, which extend between the ribs, causes it to rise, and with the increase in the size of the thoracic cavity, the plural cavities, which enclose the lungs, are also enlarged. The pressure in the pleural cavity decreases and the air enters into lungs. The entire process constitutes inspiration. Expiration is a passive process, brought about by the relaxation of the intercostal muscles and the diaphragm. The thoracic cavity is brought to its normal size and as a result the air is forced out.

SAQ 5

Indicate weather of the following statements are true or false.

1. In terrestrial vertebrates, a diverticulum that grows out ventrally from the floor of the pharynx posteriorly to the last gill pouch develops into lungs. T/F
2. Salientian amphibians have a long and well developed tracheal tube. T/F
3. In dipnoans lungs have only an hydrostatic function. T/F
4. *Protopterus* and *Lepidosiren*, the lung fishes can obtain nearly 98% of their oxygen from the air. T/F
5. In amphibians cutaneous artery carries deoxygenated blood and the cutaneous vein the oxygenated blood. T/F
6. In frogs the laryngo-tracheal chamber is supported by cartilages. T/F
7. During pulmornary respiration, the buccal cavity of frogs functions as suction pump. T/F
8. In crocodilians and turtles lungs appear as a simple large chamber with no subdivisions in them. T/F
9. Higher reptiles have voluminous lung but with a surface area that is 100 times smaller in proportion to body weight. T/F
10. In aquatic reptiles, lungs are provided with vascularised sacs that have hydrostatic function. T/F
11. Lizards, snakes and crocodiles have a higher standard metabolic rate and hence their oxygen requirements are quite high. T/F
12. In turtles as in other reptiles, the bony ribs are elevated and this action enlarges the body cavity leading to inhalation. T/F
13. In birds respiratory system occupies 5% of the volume of the body as against 20% in man. T/F
14. The special feature of avian respiratory system is the presence of blind, thin walled distensible diverticula of lungs that invade most parts of the body. T/F
15. In man right lungs have two lobes and the left lung has three lobes. T/F
16. In mammals inspiration is an active process and expiration is a passive process, but in birds reverse is true. T/F

7.4 VOICE APPARATUS

In vertebrates the main voice producing structures are larynx and syrinx.

7.4.1 Larynx

With increased importance of lungs in land life, the entrance section of the lung passage of tetrapods undergoes differentiation to form larynx. Larynx is an enlarged vestibule in the upper part of the trachea. The laryngeal cavity is surrounded by a complex of cartilages or bones. Associated muscles adjust the larynrgeal cartilages and open and close the glottis. This slit like opening from the pharynx is protected in many forms by a flap of skin folding over it from the front, and in mammals develops as the epiglottis, containing a special cartilage (Fig.7.26).

Many tetrapods are voiceless in a true sense. This is particularly true of salamanders and apodans among the amphibians and of the great majority of reptiles, although certain of these forms can make hissing or roaring noises by a violent expulsion of air through the glottis. In frogs, toads, a few lizards and notably mammals larynx is a vocal organ. Voice production is accomplished through the presence of a pair of vocal cords, ridges containing an elastic tissue, which are stretched across the larynx. The two cords can be set in vibration by the passage of a current of expired air between them.

In birds larynx is present, but lacks vocal cords, and voice production takes place in a special organ called the syrinx. This is strucutre somewhat comparable to the larynx, but situated farther down the air passage typically at the point on which the trachea divides into the two major bronchi.

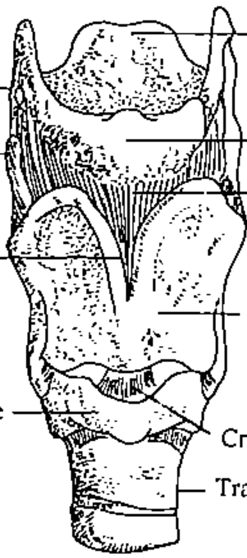


Fig. 7.26 : Human larynx-frontal view.

7.4.2 Syrinx

At the bronchial bifurcation is a small or large syrinx, a special voice box found only in birds (Fig. 7.27). There are three types of syrinx : bronchotracheal, tracheal, and broncheal. In the bronchotracheal type of syrinx the last several tracheal rings support the walls of an expanded resonating chamber (tympanus), into which project membranous folds of the lining of the syrinx. A bony structure bearing a semilunar membrane may be present within the chamber. When air is expelled from the lungs and the striated syringeal muscles are contracted, the membranes become taut and bird calls and songs are produced. The bronchotracheal syrinx may be median or asymmetrical.

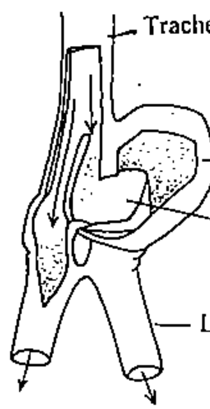


Fig. 7.27 : The voice box of a bird.

The other two types of syringes are simpler. In the tracheal syrinx the lateral portions of the last several tracheal rings are absent and the resulting membranous wall vibrates and thereby produces the sound. In the broncheal syrinx, the membrane between two broncheal cartilages becomes folded into the lumen of the bronchus. When the cartilages are drawn together vibrations of the simple vocal cord produces sound.

SAQ 6

Fill in the blanks with suitable words.

i) Larynx is an enlarged ________ at the beginning of trachea and it was is supported by ________.

ii) Among amphibians ________ and are ________voiceless.

iii) In birds larynx is present but lacks________.

iv) Syrinx is situated at the ________ ________ and is found only in ________.

v) Vibration of ________ ________ produces sound.

7.5 SUMMARY

- The respiratory system is designed for exchange of oxygen and carbon dioxide between the organism and the environment.
- In all chordate embryos a series of visceral pouches develops on either side of the pharynx. In fishes and larval amphibians perforations occur, forming gill slits which connect the pharynx to the outside. The pouches are then called gill clefts.
- External gills, generally covered with ectoderm, may project form the outer surfaces of the visceral arches as filamentous outgrowths.
- Internal gills, supported by viscreal arches, are vascular, lameller or even filamentous extensions of the epithelial surface of the gill pouches. In elasmobranchs the interbranchial septa are exceptionally well developed and extend well beyond hemibranchs.

  In other fishes, the interbranchial septa are reduced to varying degrees from which hemibranchs protrude into a single branchial or extrabranchial chamber located on each side between the operculum and gills. The gills are thus protected by the operculum.
- In amphibians the gills are usully confined to larval life and disappear at the time of metamorphosis. In a few urodeles, however gills occur throughout the adult life. Of the five pairs of pharyngeal pouches that develop during the embryonic life of amphibians, only the 2^{nd},3^{rd} and 4^{th} pairs are perforated and are connected to the outside. Also during metamorphosis, intially external gills appear which degenerate and a new set of internal gills develop from the tissue covering the same visceral arches.
- A few fresh water fishes have evolved accessory respiratory structures that are useful at times when there is an oxygen deficiency in the medium in which they live. The highly vascularised structures are essentially outgrowths of pharynx of the branchial chamber. *Anabas, Amphipnous, Clarias, Saccorbranchus* and *Ophiocephalus* are some of the actinopterygians, which posses, such organs.
- Lungs develop as a bilobed diverticulum from the floor of the pharynx posterior to the last gill pouch. In higher forms the connection between lungs and pharynx lengthens and is called the trachea. The upper part of the trachea becomes modified as a larynx or voice box, the walls of which are supported by skeletal elements derived from the visceral arches. In birds a syrinx which develops at the lower end of the trachea is the organ of sound production.
- Lungs of lower vertebrates are rather simple, vascular sacs but in higher vertebrates the walls become subdivided into numerous pocket-like air spaces. The divisions become more and more complex in the higher classes of vertebrates and reach the highest degree of branching in mammals. The lungs of birds are complicated in that they give rise to air sacs, which penetrate among the viscera and even enter the hollow bones. Similar structures in certain lizards foreshadow their appearance in birds. The thin walled, moist and highly vascular lining of the lungs forms an ideal respiratory surface.
- The mechanism employed for inflating and deflating lungs differ in different vertebrates. The most complex condition is encountered in mammals, in which the lungs lie in separate pleural cavities partitioned from the abdominal cavity by a muscular diaphragm.
- Nasal passages develop in connection with the olfactory apparatus. Blind nasal pits are found in most fishes, but in choanichtyes they form connections between the oral cavity and the outside. This condition is retained in amphibians, which for the first time employ the nasal passage for inhaling and exhaling of air. In reptiles a secondary palate begins to form, partially separating the nasal and mouth cavities. In crocodiles and mammals the secondary palate becomes completed so that the two passageways are in communication only in the region of the pharynx. In these forms the internal nasal opening are located relatively far back and are situated near the opening of the trachea.

In vertebrates the main voice producing apparatus are the larynx and syrinx. Larynx is present in most amphibians, reptiles and mammals but the syrinx is present only in birds.

7.5 TERMINAL QUESTIONS

1) Define external and internal respiration.

....

....

....

....

....

....

2) Describe the structure of the respiratory system of cartilagenous fishes and state how does it differ from that of bony fishes.

....

....

....

....

....

....

3) Briefly discuss the mechanism of pulmonary respiration in frog.

....

....

....

....

....

....

....

4) How is the respiratory system of birds modified to meet their high oxygen requirement ?

....

....

....

....

....

....

7.6 ANSWERS

Self Assessment Questions

1. 1. F; 2. T; 3. F; 4. F.

2. 1. skin; 2. Seven, six; 3. passive, active 4. Seven, one; 5. mandibular, hyoid, 6. Counter current;

3. a–3, b–4; c–5; d–1; e–2;
4. external gills; 2. disappear; 3. urodeles; 4. two; 5. do not.
5. 1. T; 2. F; 3. F; 4. T; 5.T; 6.T; 7.T; 8.F; 9.T; 10. T; 11.F; 12. F; 13. F; 14. T; 15. F; 16. F.
6. 1. Vestibule, cartelages
   2. Salamanders, apowon
   3. Vocal cords
   4. bornchial bifurcation
   5. Vocal cords

Terminal Questions

1. Refer to Introduction
2. Refer to section 7.2.3
3. Refer to section 7.3.1
4. Refer to section 7.3.3

UNIT 8 CIRCULATORY SYSTEM

Structure

8.1 INTRODUCTION

Circulatory system of vertebrates consists of a heart, arteries, veins, capillaries and blood (the blood vascular system) and of lymph channels and lymph (lymphatic system). Blood carries oxygen collected in respiratory organs, nutrients from extraembryonic membranes of embryos and from the adult digestive tract. It also carries hormones from endocrine tissues, substances associated with maintaining homeostasis, immunity and disease. While flowing, it removes waste products of metabolism from the excretory organs. Lymph channels collect interstitial tissue fluids not taken up by the blood stream and emulsified fats absorbed in the small intestine. These lymph channels terminate in one or more of the large venous channels of the blood vascular system.

Arteries carry blood away from heart. They have muscular elastic and fibrous wall capable of swelling with each intrusion of blood and of active constriction and dilatation in response to nerve impulses. Arteries, thereby assist in regulating blood pressure. They terminate in capillary beds. Veins have proportionately less muscle and elastic tissue and more fibrous tissue and are therefore, capable of less dilatation or constriction. They carry blood towards heart from capillary beds. Capillaries consist of endothelium only, with a lumen just large enough to accommodate red blood cells. In fact, the red cells must "squeeze through" and, in so doing, become deformed. In vertebrates respiring by gills, blood is pumped from the heart to the gills, where external respiration takes place. From the gills it typically flows via arteries to capillaries throughout the body.

A portal system is a system of veins commencing in the capillaries of one or more organs and terminating in the capillaries of another organ.

Objectives

After studying this unit you should be able to:

- trace origin and evolution of heart of vertebrates,
- describe arterial and venous systems of vertebrates,
- trace origin and evolution of aortic arches,
- describe composition of blood,
- describe lymphatic system and
- explain the phenomenon of double circulation.

8.2 HEART

Heart is a modified blood vessel with highly muscular walls. Valves preventing backflow of blood occur in veins and heart. Heart consist of three layers:

1) Endocardium	-	inner lining (Endothelium and elastic tissue)
2) Myocardium	-	between endocardium and epicardium (Muscular layer)
3) Epicardium	-	outer fibrous tunica, covered by visceral pericardium (Subdivision of coelom).

Heart pulsates as a result of response of the muscle cells to electrolytes that infuse it. Evolutionary changes of the heart lead from a primitive, simple, straight tube in the protochordates through the sinuous multichambered organ seen in fishes and the partially subdivided, but otherwise simple structure of early tetrapods, to the compact, highly efficient structure of mammals and birds. The evolution is summarized as follows:

i) the protochordate stage with alimentary pharynx.
ii) the piscine stage with branchial pharynx.
iii) the early tetrapod stage with primitive lungs.
iv) the late tetrapod stage of higher ectotherms,
v) the stage of endothermic tetrapods.

As implied by the names designating these stages, evolution of heart reflects changes in other structures, particularly respiratory organs.

8.2.1 Protochordate Heart

Protochordates possess a simple, tubular heart, beating simply by peristaltic waves. Arteries, because of being more muscularized than veins, may be taken as primitive heart. The extensive muscularization of arteries has its functional significance in forcing blood into the smaller vessels (capillaries) from which blood may return back without special means of propulsion since it is passing from smaller into larger vessels.

Lack of need in the protochordate stage for a more specialized heart can be explained on the basis of lack of proper respiratory function of the pharyngeal clefts. The pharyengeal clefts in protochordates primarily serve as a sieve to aid in capturing the food.

8.2.2 Piscine Heart

When pharynx is provided with capillary network, then in order to facilitate the gaseous exchange, a more efficient and specialized pump is required to force blood through to the dorsal aorta. Thus a true heart is seen for the first time in fishes; a heart consisting of a series of specialized chambers to which the function of forcible propulsion of blood in arterial channels is restricted.

Actually two operations must be performed to carry out the cardiac function efficiently in a gill-respiring vertebrate. The blood must be first collected and then pushed along. Collecting chambers thus appear at the rear and propulsive chambers at the front. Fishes are provided with a posterior sinus venosus, followed by an atrium, then a ventricle, and finally a conus arteriosus in the anterior (Fig. 8.1). There is a flap-like enlargement, the auricle, on each side of the atrium in many if not in all fishes. The sequence of beat is the peristaltic sequence; from the rear towards the front so the blood flows from posterior chambers to anterior chambers.

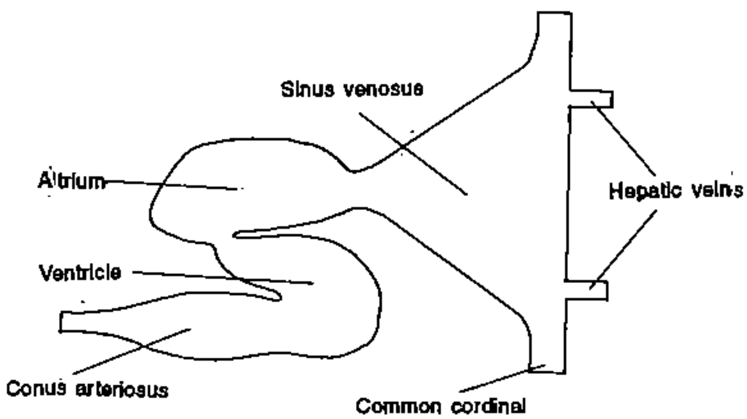


Fig. 8.1 :Piscine heart, ventral view with parts drawn to side instead of superimposed as in life.

The sinus venosus is little more than an expansion of the junction of the primary somatic (common cardinal) and visceral (hepatic) veins. The walls are very thin and apparently incapable of contraction. A slight negative pressure actually exists in this chamber, resulting from the integration of atrial contraction and action of the sinoatrial valve. The venous blood fills the sinus venosus and through the sinoatrial valve blood passes with minimum cardiac assistance into the atrium. Because the S-shaped arrangement of the chambers (Fig. 8.1) in the fish heart places the thin-walled sinus venosus and atrium dorsal to the ventricle, the blood is forced by gravity and atrial contraction through the atrioventricular valve into the ventricle. The sinoatrial and atrioventricular valves prevent the back flow of the blood. The thickened walls of ventricle provide certain resistance to the incoming blood, and so the atrium must be more active in pumping the blood than the sinus venosus. The relatively powerful ventricular walls then provide energy to move blood into the gills.

Once received in the ventricle, blood passes through one or more series of semilunar valves (conal valves) in reaching conus arteriosus, which adds still further push to the blood and smooths its flow on its way to the ventral aorta. The entrance into the latter is guarded by several rows of other semilunar valves. The semilunar valves are the wall foldings which prevent the back flow of blood and possibly help in distributing blood to the aortic arches (Fig. 8.2 & 8.3).

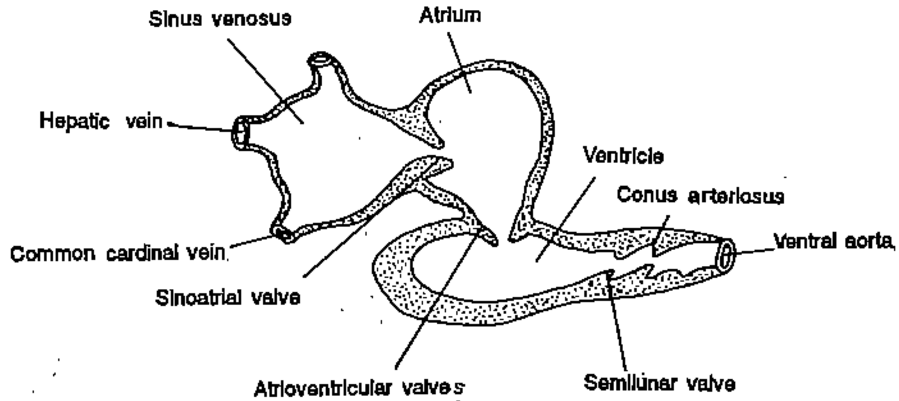


Fig. 8.2 : Lamprey heart showing the chambers characteristic of most fishes.

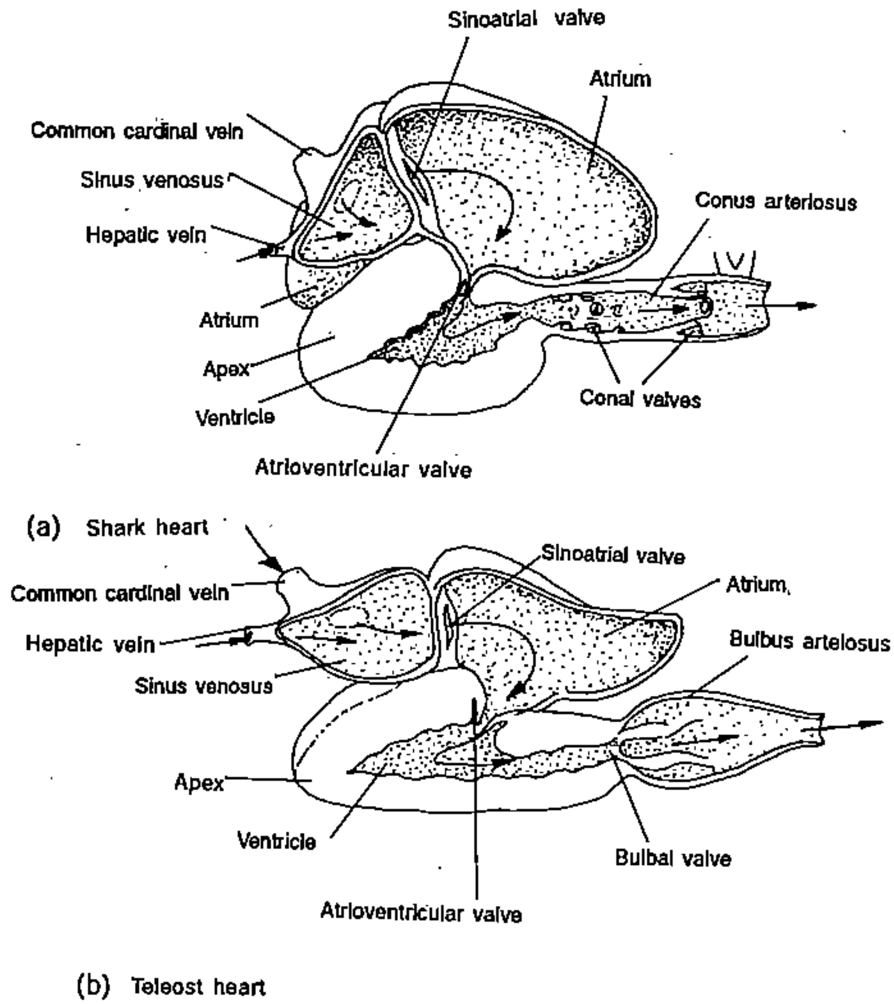


Fig. 8.3: Fish hearts, (a) Shark (b) Teleost. Blood leaves the shark heart through the muscular conus arteriosus, a chamber that is absent in teleost fishes. In the teleost heart, the base of the ventral aorta is swollen, creating the elastic, non contractile bulbus arteriosus. A single pair of bulbal valves prevent the back flow of blood into the ventricle.

8.2.3 The Early Tetrapod Heart

The stage was initiated by the development of air bladder in pretetrapod ancestors for the perfection of aerial respiratory function in tetrapods. Gradually, the air bladder became perfected to serve the role in external respiration. This modification of the lungs led to improvement on the mechanism(s) responsible for supplying aerated blood o the body. This chiefly involved changes in the heart. First the atrium was subdivided nto two chambers; a systemic chamber (right), receiving non-aerated blood from the sinus venosus, and a pulmonary chamber (left), receiving aerated blood from the pulmonary veins (Fig. 8.4).

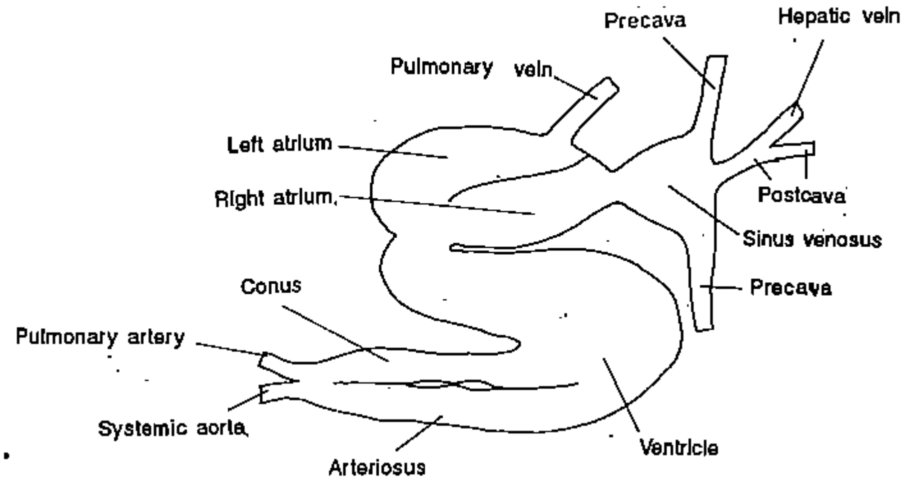


Fig. 8.4 : **The early tetrapod heart, ventral view with parts drawn to side instead of superimposed as in life.**

This alteration was specifically associated with the development of an air breathing mechanism (lungs) instead of an aquatic device for exchange of gases. At least the initial phase of establishment of a double circulatory cycle in the heart was thus accomplished.

It would seem that all efforts to separate pulmonary and systemic chambers in atrium were not successful because of the absence of a mechanism to keep separation in the next chamber (ventricle) into which blood entered. However, this appears not to be wholly true. A second related alteration involved a partial separation of two chambers in the conus arteriosus, serving apparently to direct the aerated blood (from the left side) chiefly into the anterior vessels of the ventral aorta, whereas the non-aerated blood (from the right side) was directed chiefly into the posterior pair of vessels bearing the pulmonary arteries. Thus we can recognize a pulmonary and a systemic chamber in the conus arteriosus. So in amphibians that have functional lungs the heart consists of a sinus venosus, atrium completely divided into right and left atria, a ventricle and a conus arteriosus which is partially divided with the help of a spiral valve. In frogs, whose cardiovascular system is best studied, the conus arteriosus arises from the single trabeculate ventricle. Trabeculae are the projecting cones of the muscles that arise from the inner wall of myocardium of the ventricle creating deep recesses or compartments in the wall. As shown in Fig.8.5, semilunar valves lie at the base of conus arteriosus and prevent the backflow of the blood into the ventricle.A spiral valve twisting almost through a complete rotation establishes chambers within the conus arteriosus that target blood to the systemic and pulmocutaneous arches, both of which arise from truncus arteriosus, a remnant of ventral aorta. The sources of oxygenated blood vary in amphibians; as for respiration they depend on the skin, on gills, on lungs or on all the three modes . It is for this reason the heart structure varies in different amphibians.

In lungless salamanders or the ones with reduced lung function the septum dividing the atrium as well as the spiral valve may be much reduced or entirely absent. For example in lungless plethodontids in which 90 per cent of the respiratory needs are fulfilled through skin and 10 per cent through buccal cavity, the heart lacks left atrium, the compartment that would receive blood returning from the lungs. In amphibians such as *Necturus* where gills dominate lungs as respiratory organs, the interatrial septum is reduced or perforated. The atrium is completely divided in modern anurans and in all living reptiles, birds and mammals. Actually heart of most living fishes, lacking a pulmonary vein or a homologous structure thereof, is an evolutionary side-line not involved at all with the tetrapod line in which, in all stages a pulmonary vein was present.

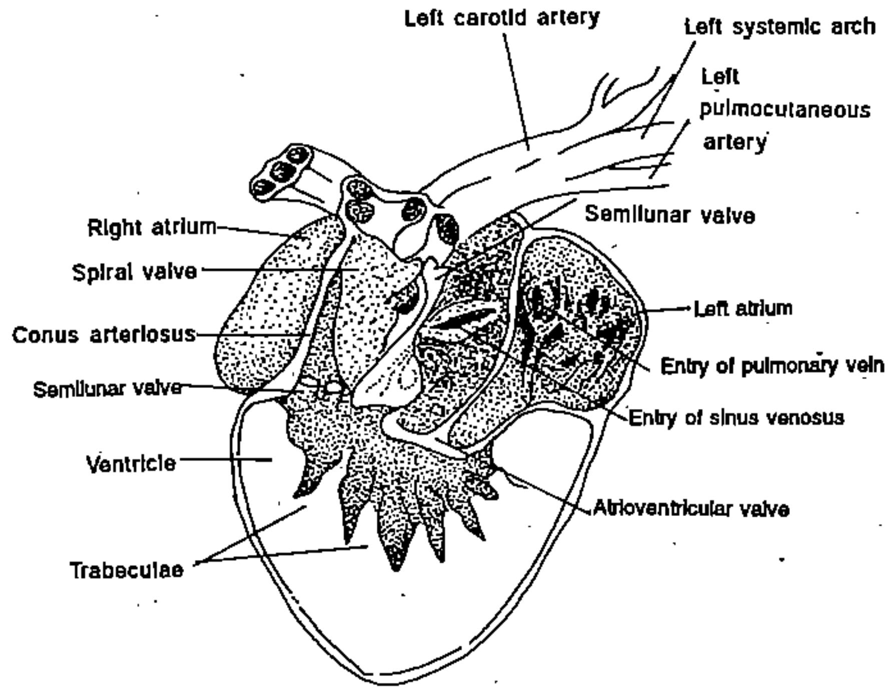


Fig. 8.5 : Structure of the heart of a bull frog.

Another alteration in amphibian heart is the reduction of sinus venosus both in size and importance as a blood-gatheri· chamber. A large thin-walled heart chamber (sinus venosus), into which the blood can flow against an absolute minimum of resistance is essential for fishes. In land-dwelling vertebrates, subjected to the markedly lesser atmospheric pressure, such an elaborate collecting device is not essential; in later stages it is discarded completel. The early tetrapods are thus, advanced to a stage in which the heart has six completely or partially separated chambers, and two main entrances and two main exits.

In amphibians the deoxygenated and oxygenated blood streams returning from systemic and pulmonary circuits are kept separate as they pass through the heart. The deoxygenated blood is selectively directed to the lung via pulmonary artery and the oxygenated blood is directed to the systemic tissue via aortic arches. In frogs during the time of air breathing, the trabeculae in the ventricle separate the two different streams of blood in the heart. It is thought that as one stream enters the ventricle, it fills the compartments between the trabeculae, and then the second stream occupies the centre of the ventricle. Because of their different positions, the oxygenated and deoxygenated streams depart by different exits to reach appropriate set of arteries. Whenever a frog dives in the water, the lung collapses from the water pressure on the body wall. The blood flow is reduced in the lungs and increased in the skin. Thus, the loss of pulmonary respiration is somewhat compensated by increased cutaneous respiration in submerged frogs. Before we proceed further try the following SAQ.

SAQ 1

Fill in the blanks with appropriate words.

i) The tubular heart of protochordates beat by ________.

ii) In the early tetrapod heart the ________ is divided into two chambers.

iii) Ventricle is ________ in frogs.

iv) In *Necturus* the ________ ________ is reduced or perforated.

v) In amphibians during diving the ________ respiration is increased.

8.2.4 The Late Ectotherm Heart

Living reptiles varied in cardiac structure though they exhibit uniformly a number of improvements over the early tetrapod heart (Fig.8.6). Since reptiles are adapted to more fully terrestrial environment and have more active lifestyle, their cardiovascular system supports the accompanying higher metabolic rates and elevated levels of oxygen and carbon-dioxide transport. It is also capable of generating higher cardiac out-put, elevated blood pressures and more efficient separation of oxygenated and deoxygenated blood streams as compared to that in amphibians. Basically two types of reptilian heart (one in chelonians and squamates and other in crocodiles) have been recognised.

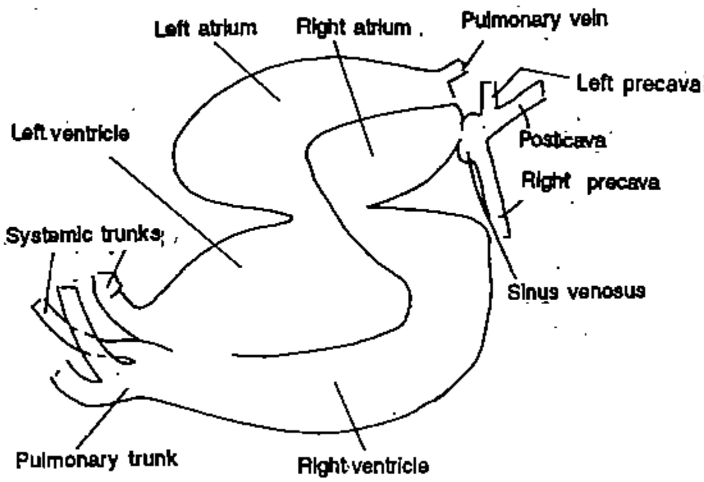


Fig. 8.6 : Late ectothermic heart, ventral view with parts drawn to side instead of superimposed as in actual structure.

In chelonian/squamate heart, the sinus venosus is reduced in size as compared to that in amphibians and in advanced types ancestral to mammals, it has disappeared completely as a chamber, although it is present in all living reptiles. From the very first vertebrates, however, the sinus venosus served a function not only as a collecting chamber but also as a site of origin of heartbeat. Although its identity as a chamber may have been lost in at least some reptiles and certainly in birds and mammals, the function it formerly performed for initiation of heart beat could not be discarded. The excitatory tissue remained embedded in the wall of the right atrium near the point of the entry of veins, that now with the loss of the sinus as a chamber, empty directly into the atrium. This myogenic center is the sinoatrial node, which serves in all amniotes lacking sinus venosus as the originator of each heartbeat. The conus arteriosus also disappeared, but not simply by reduction in size. Though it appears during early embryonic development, in adults it was subdivided to form the bases (trunks) of the three large arteries leaving the ventricle: the pulmonary trunk and the right and left aortic trunks (systemic trunks). This pairing of systemic trunk is seen in many reptiles, the right trunk connected with the left side of the heart, the left with the right side. The conus is not essential to the air breathing vertebrates and is eventually lost by subdivision into the late ectothermic stage. Despite the loss of the role of the conus arteriosus as a cardiac chamber in reptiles, the semilunar valves that conus formerly possessed remained intact and unchanged. These persist at the bases of the pulmonary and systemic trunks in all amniotes, but are reduced into three valves in each vessel. Atrium is divided into right and left atria. Entry to the ventricle is guarded by the atrioventricular valves. Ventricle is partially divided internally resulting in a rather effective separation of venous and arterial blood. As you can see in Fig. 8.7, it has three interconnected compartments: cavum venosum, cavum pulmonale, cavum arteriosum. Cavum venosum and cavum pulmonale are seperated from each other by a muscular ridge and cavum arteriosum is connected to the cavum venosum through an interventricular canal.

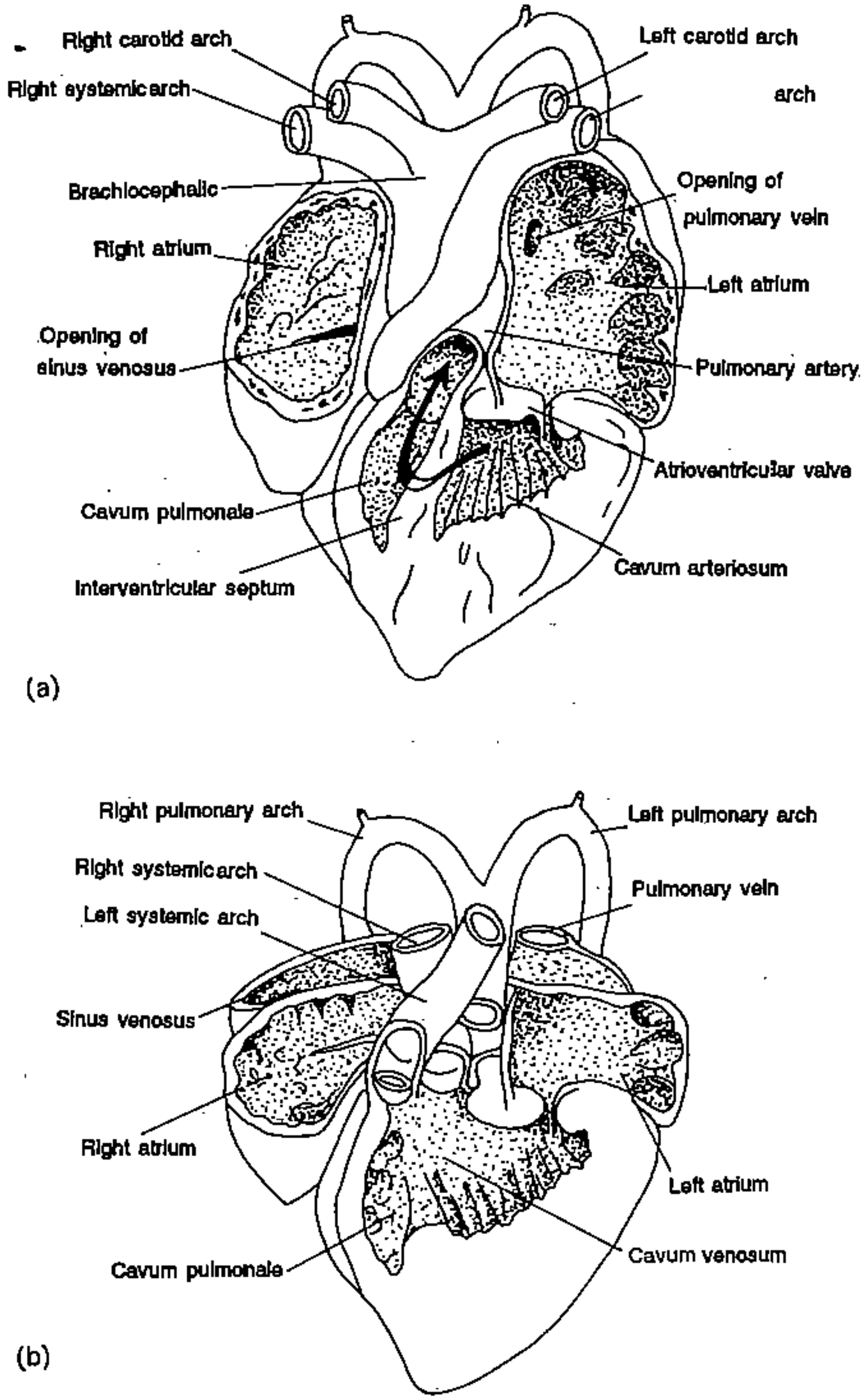


Fig. 8.7 : Ventral view of the lizard heart. (a) Small part of the ventral wall has been removed. The arrow shows the direction of blood flow from cavum arteriosum to cavum venosum through interventricular canal. The blood goes to systemic arches from cavum venosum. (b) Structure of the heart after some more part of the ventral wall has been removed.

Apnea, a condition of holding breathe occurs not only during diving. Most reptiles, while resting on land go for long intervals without taking a breath. As apnea continues, oxygen from the lungs becomes depleted and pulmonary perfusion declines until just before another breath.

As you can see in Fig. 8.8, the pattern of blood flow through the hearts of chelonia and squamates vary depending on whether they breathe air or hold their breath (a condition called apnea). For example, when turtle is air breething on the land most of the deoxygenated blood returning from systemic tissues is directed to the lungs and most of the oxygenated blood from the lungs is directed to the systemic tissues via the aortic trunk. When the turtle dives in the water, the heart responds with a right to left cardiac shunt. Blood flowing in the cavum venosum is directed to the aortae rather than the pulmonary circuit. This shunting is controlled by the differences in the resistances of systemic and pulmonary circuits.

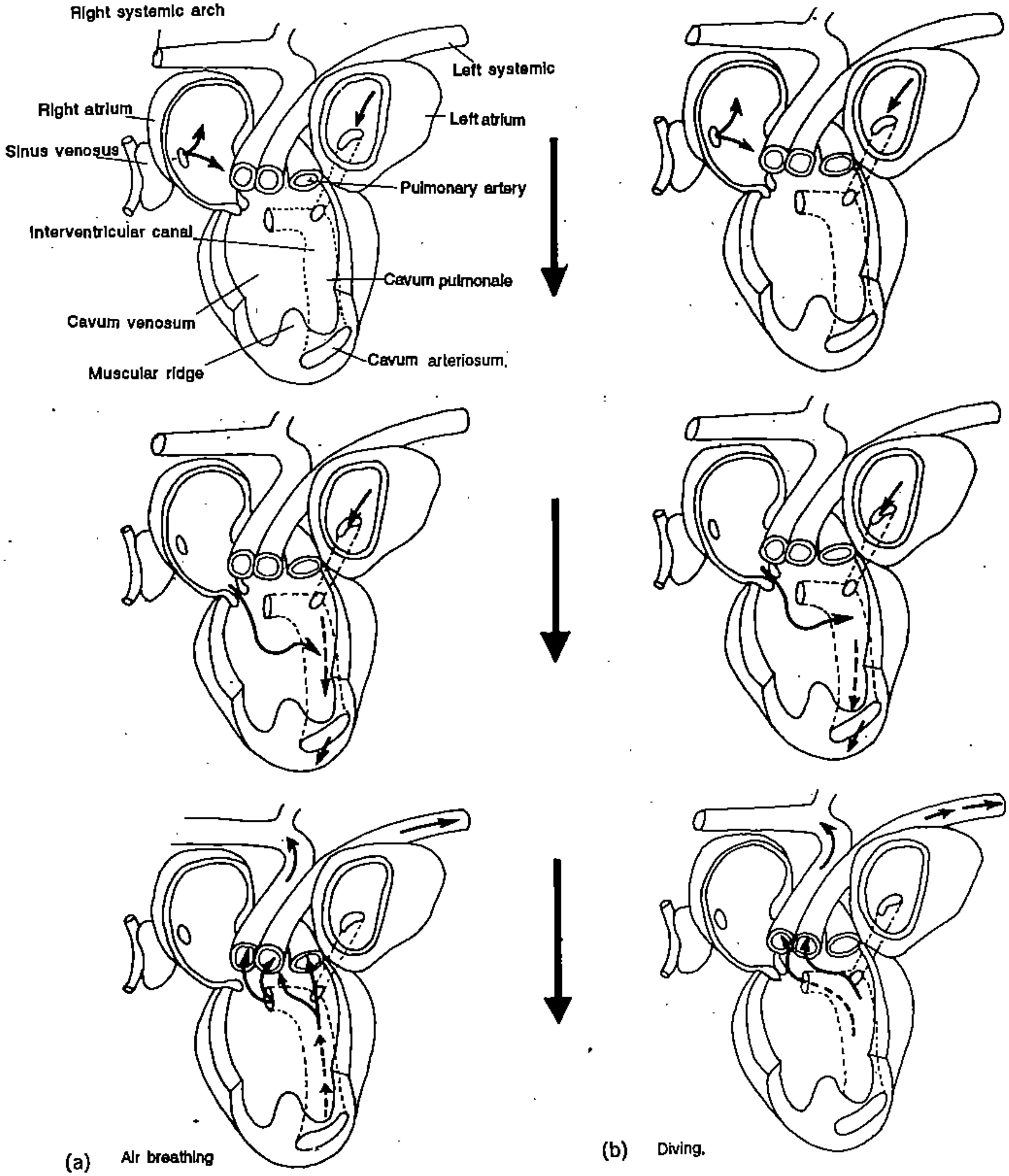


Fig. 8.8 : The path of blood flow in the squamate heart. (a) In the squamates breathing air, venous blood from the right atrium enters the cavum venosum, crosses the muscular ridge and fills the cavum pulmonale. When ventricle contracts, most of this blood flows in the pulmonary artery. Simultaneously, blood from the left atrium enters the deep cavum arteriosum. Upon contraction of the ventricle this blood passes through the interventricular canal to the left and right aortic arches. (b) On diving, due to the resistance to the pulmonary blood flow, the blood moves across the muscular ridge and departs mainly through the left aortic arch.

The heart of crocodiles is similar to that of other reptiles in many respects. However, it shows structural variations in certain aspects. The ventricle is completely divided into right and left chambers by a complete interventricular septum. The pulmonary trunk and the left aortic arch opens off the right ventricle and the right aortic arch opens off the left ventricle.

Curiously, the left arch does not receive blood directly from its own (right) ventricle, since the semilunar valves actually prevent flow from ventricle to aorta except under unusual stress situation. The left arch receives blood, through the foramen of Panizza that connects the right and left arches where they cross a short distance from the heart (Fig. 8.9). You can see in Fig. 8.10 the comparison of the path of blood flow in the hearts of chelonia/squamates and crocodiles.

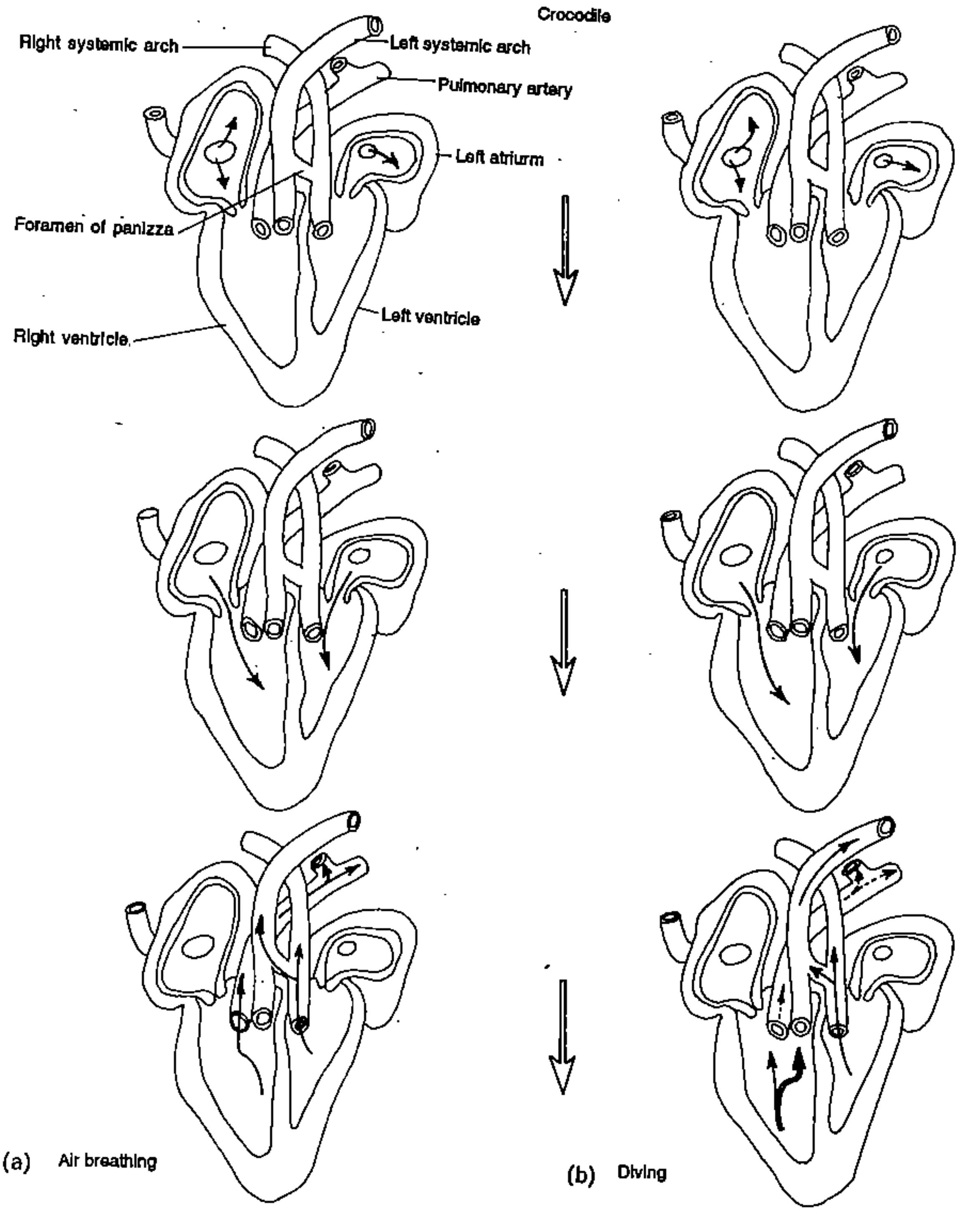
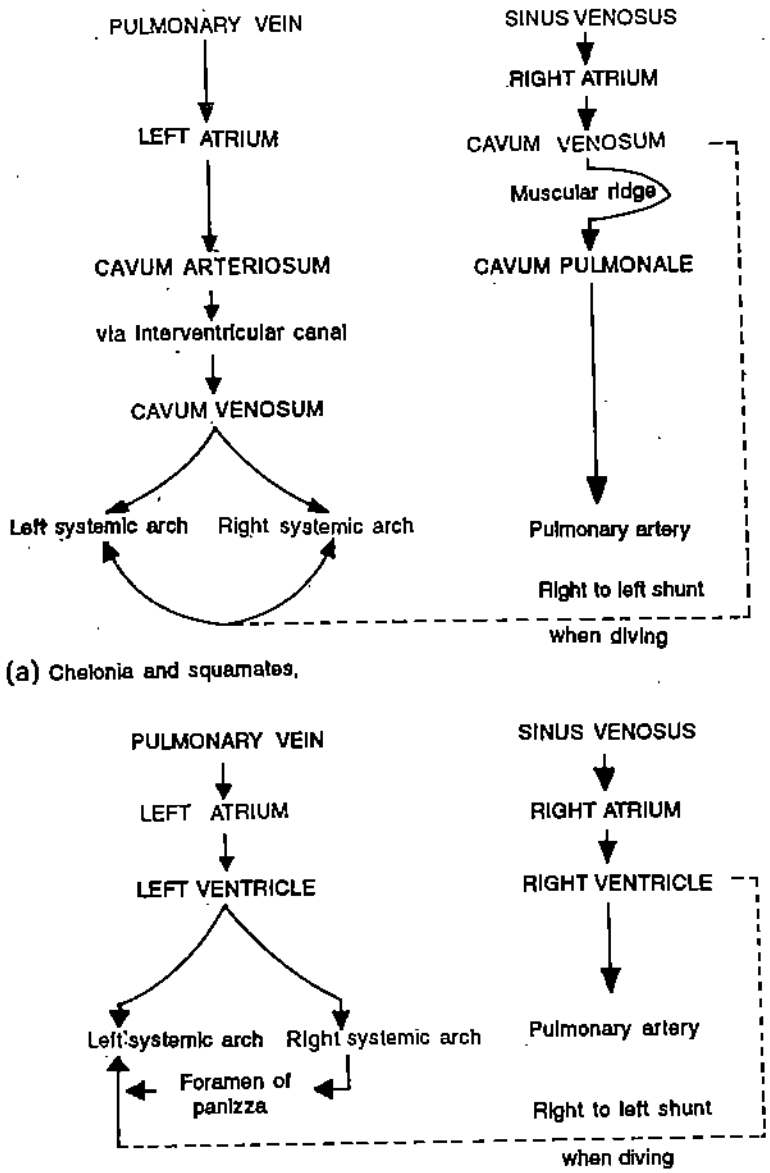


Fig. 8.9 : Blood flow through the crocodile heart. (a) Systemic and pulmonary blood flow during air breathing period. (b) Internal changes that result in decreased pulmonary flow when the crocodile dives.



(b) Crocodilians

Fig. 8.10 : The flowchart comparing the blood flow patterns in the hearts of (a) chelonia and squamate, and (b) crocodiles. Dashed lines indicate the cardiac shunts that divert blood flow from pulmonary circuit to systemic circuit while diving. During this cardiac shunt resistance to pulmonary flow increases due to contraction of the sphincter at the base of pulmonary artery. In crocodiles the vasoconstriction of the vascular supply to the lungs also aids in this resistance.

So we can summarise that in the later ectothermic stage, out of the six occurring in the preceeding stage, only three cardiac chambers remain. One of these three (the ventricle) is further subdivided so that in this stage there are four cardiac chambers at least partly separated from each other.

8.2.5 Endotherm Heart

Only a few, relatively slight alterations have occurred in endotherms to effect the maximum efficiency of the heart (Fig. 8.11).

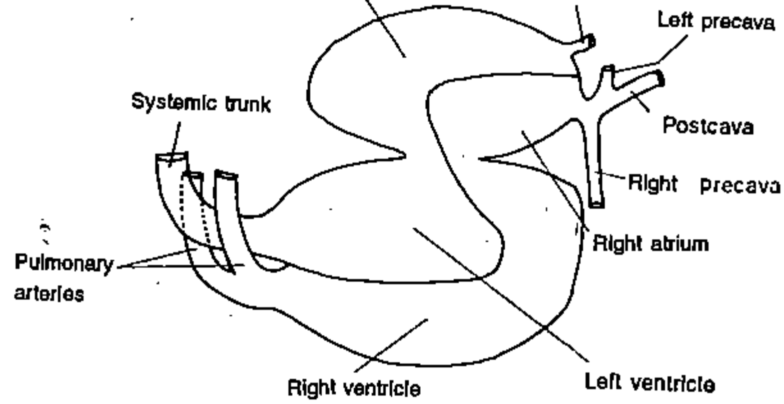
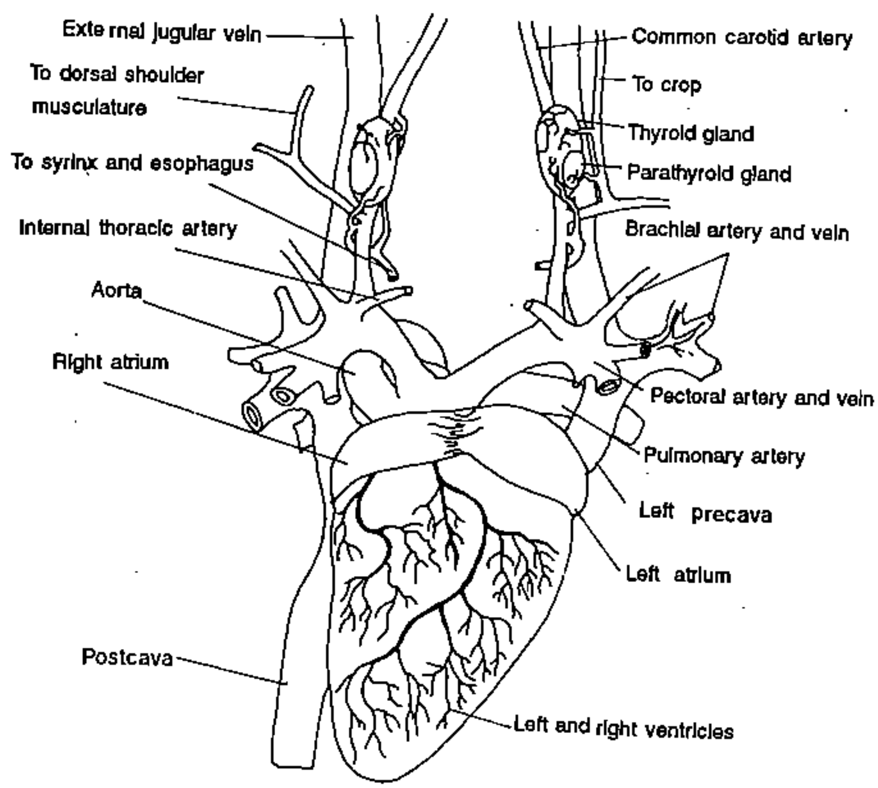


Fig. 8.11 : Endothermic heart, ventral view with parts drawn to side.

Choanichthyes or sarcopterygians are a subclass of bony fishes. In this group of fishes, external nostrils open internally to the mouth through holes named *choane*, hence the name, choanichthyes.

Most important is the complete closure of the ventricular wall, rendering absolutely impossible any mixture of aerated and non-aerated blood. The trend towards double circulation in the heart was initiated certainly in choanichthyes. It attained final perfection in endotherms. Closure of the ventricles along with simplification of the systemic aorta is the last step in reaching the greatest possible perfection in the cardiac link of the "forced draft" respiratory mechanism unique to birds and mammals and chiefly responsible for their endothermic condition.

In birds, though the sinus venosus is reduced, it still remains a small discreat area. The conus arteriosus is only transiently present in embryonic stage, that gives rise to the pulmonary trunk and a single aortic trunk in the adult (Fig. 8.12).



Avian heart (ventral view)

Fig. 8.12 : The heart of a bird (ventral view).

In mammals the sinus venosus is reduced to a patch of Purkinje fibres (also called sinoatrial node) in the wall of right atrium. This node acts as a pacemaker, initiating the wave of contraction i.e. rythmic heart beat that spreads across the heart like in all other vertebrates. Another mass of typical muscle fibres called as the atrioventricular node in the wall of right atrium in the four chambered heart, also acts as pacemaker under experimental conditions when the sinoatrial node is destroyed or prevented from functioning. Similar to that in birds the conus arteriosus during embryonic development splits to produce the pulmonary trunk and single aortic trunk of the adult (Fig. 8.13). The mammalian heart possesses only two of the three sets of valves present in piscine ancestors; the semilunar valves and the atrioventricular valves. The latter set is now divided into two, to which the names tricuspid valve and bicuspid or mitral valve are applied in mammals.

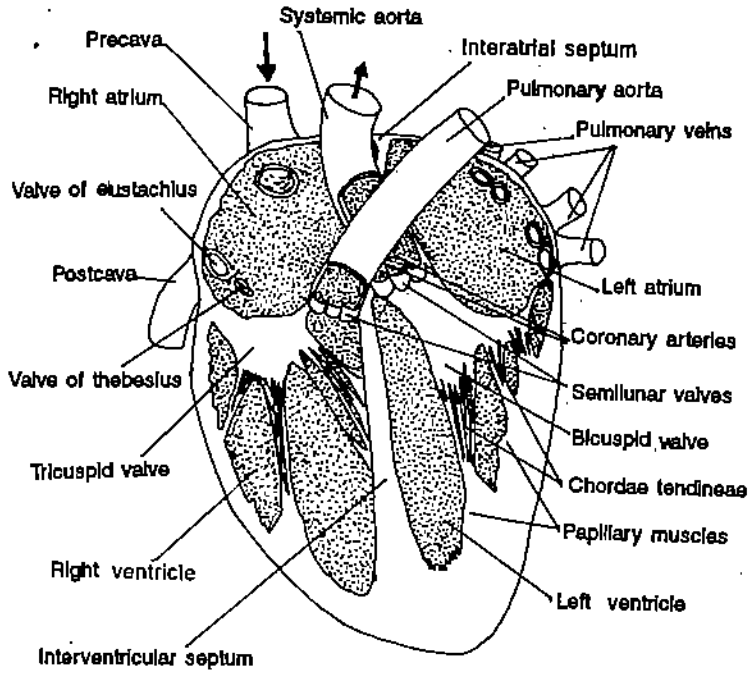


Fig. 8.13 : Ventral view of the mamlian heart.

Although the structure of avian and mammalian heart is similar they both have evolved from different reptilian groups. This difference is reflected in their embryonic development. Both these hearts also function similarly as both consist of parallel pumps with double circulation circuits. The right side of the heart gathers deoxygenated blood from the systemic tissues and pumps it in pulmonary circuit. The left side of the heart pumps oxygenated blood from the lungs through the systemic circuit. There is no cardiac shunting as hearts of birds and mammals are divided into right and left chambers.

In single circulation pattern the blood passes only once through the heart during each complete circle as seen in most of the fishes (Fig. 8.14a). Amniotes have double circulation pattern in which blood passes twice through the heart in every circuit (Fig. 8.14b). From the heart the blood goes to the lungs, back to heart out to systemic tissues and again back to the heart. The major evolutionary event was addition of pulmonary circuit in the circulatory pattern. The intermediates that have characteristics of both the conditions include lung fishes, amphibians and reptiles. The evolution of this type of circulatory system design is the adaptive advantage of the transitional forms that came onto land.

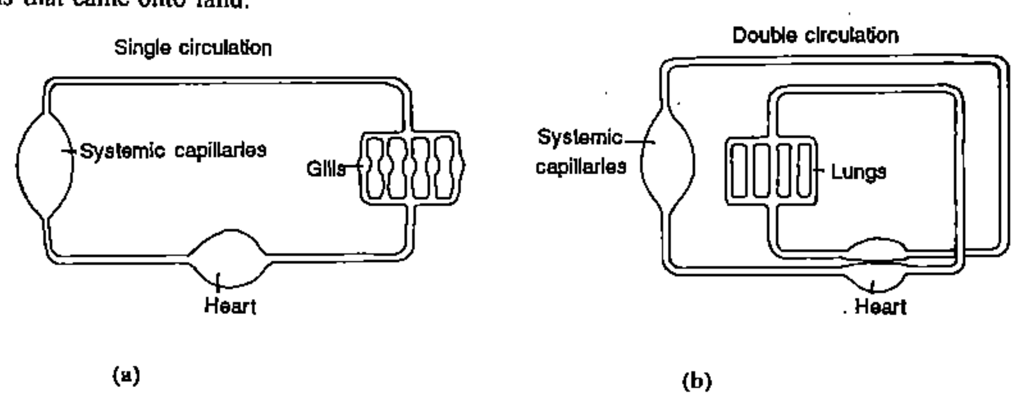


Fig. 8.14 : Diagrammatical representation of single circulation (a) and double circulation (b).

You have finished studying about the evolution and structure of heart. In order to judge your progress attempt the following SAQ.

SAQ 2

i) Fill in the blanks with appropriate words.

a) Sinus venosus is ________ in size in chelonian heart.

b) Pacemaker or sinoatrial node ________ the heart beat.

c) The ventricle is ________ divided in squamates and is ________ divided in crocodiles.

d) The systemic trunk is paired in ________ and ________ .

e) Double circulation in heart was initiated in ________.

f) Tricuspid and bicuspid valves are present in the ________ heart.

ii) What do you understand by the rhythmicity of heart beat in mammals?

....

....

....

....

8.3 ARTERIAL SYSTEM

Although arterial system in different vertebrates appears to be different in arrangement, a study of development reveals that all are built upon the same fundamental plan. The increasing complexity of the heart from the simple two chambered structure of the lower forms to the four-chambered organ of crocodilians, birds and mammals is associated with certain variations to be found in the blood vascular system. Modifications of the embryonic pattern, which occur during later ontogeny are of such a nature that they adapt the aortic arches for respiration either by gills or by lungs.

8.3.1 Aortic Arches

During embryonic development the anterior end of the ventral aorta divides into two arches called as aortic arches, which course dorsally into the mandibular region. Dorsal to the pharynx these are continued posteriorly where they are known as paired dorsal aortae. Additional pairs of aortic arches then appear in an anterio-posterior sequence. forming connections between ventral and dorsal aortae on each side and are called as aortic arches. Each courses through the tissue between the adjacent pharyngeal pouches. The typical number of aortic arches that are taken as basic embryonic pattern in vertebrates is six pairs, although there are certain discrepancies among lower forms, such as eight in lampreys. fifteen in hagfishes and ten or twelve in some species of shark. The first is known as mandibular aortic arch and the second is hyoid aortic arch. The remainder are referred to as the third, fourth, fifth and sixth aortic arches, respectively and all are designated by roman numerals (Fig. 8.15). Each aortic arch lies anterior to the visceral cleft bearing the corresponding number. The two dorsal aortae soon fuse posterior to the pharyngeal region, so that ultimately only a single dorsal aorta is present. It is continued in the tail region as a caudal artery. Blood which is pumped anteriorly by the heart, passes through the ventral aorta to the aortic arches. These vessels carry blood to the paired dorsal aortae, from which it goes anteriorly to the head and posteriorly to the single dorsal aorta which distributes it to the remainder of the body. Veins return blood to the sinus venosus, atleast during early stages of development. The changes in the aortic arches in different groups of animals are described below.

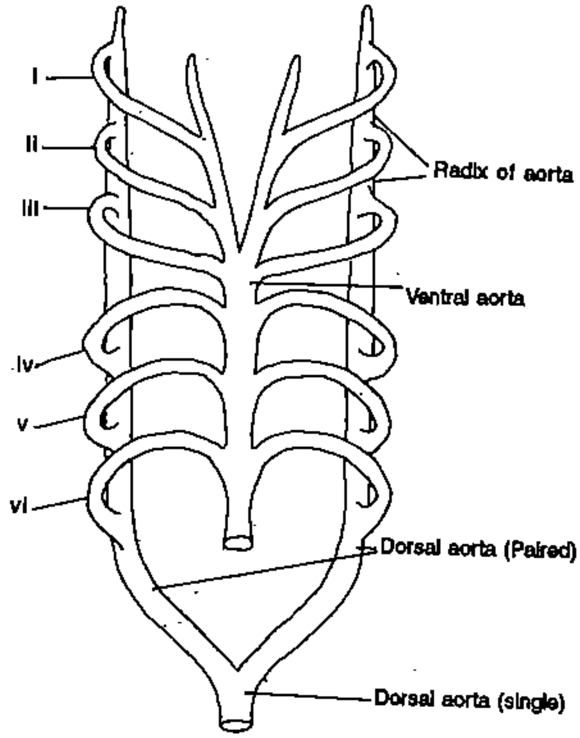


Fig. 8.15 : Diagram illustrating the basic pattern of aortic arches in vertebrate embryos. Ventral view. Six pairs of arches connect ventral and dorsal aortae.

8.3.2 Amphioxus

The paired dorsal aortae connect the ventral aorta (heart) with the afferent and efferent branchial arteries, present around the gill bars. In *Amphioxus* the aortic arches are much more numerous than in higher chordates (Fig. 8.16). The section of aortic arch delivering blood to the gills is afferent artery and the dorsal section of the aortic arch carrying it away from the gills is called efferent artery.

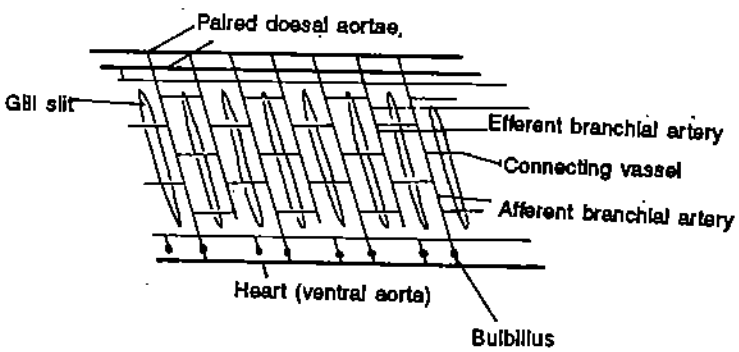


Fig. 8.16 : Diagram of portion of pharyngeal region of Amphioxus, showing arrangements of aortic arches.

8.3.3 Fishes

In fishes there is a reduction in the number of aortic arches within the superclass. The greatest number occurs in certain primitive sharks, where it is directly related to the number of gill pouches. But all pass through a stage in embryonic development in which six pairs of aortic arches connect dorsal and ventral aortae. The anterior continuation of the paired dorsal aortae gives rise to the internal carotid arteries supplying to the brain; those arising from the ventral aorta form the external carotid arteries which supply blood to jaws and face. In most fishes, each aortic arch except the first, or mandibular, consists of afferent and efferent branchial portions with an interarterial capillary network interposed in between. The capillary network partially or completely encircles the gills and empties first into the collecting loop that delivers to efferent artery. It is in the capillary network of the gill lamellae that aeration of blood occurs.

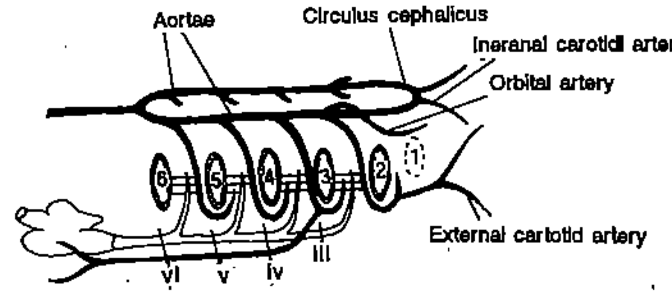


Fig. 8.17 : Diagram of aortic arch region as found in most teleost fishes : ventral view. Arches I and II have degenerated. Each remaining arch is divided into afferent and efferent branchial arteries that are connected by gill capillaries.

In teleosts and most other fishes only the last four pairs of aortic arches remain, numbers I and II having been modified or reduced to small branches of the third (Fig. 8.17). In *Protopterus*, the third and fourth gills are absent entirely but the third and fourth aortic arches exist and pass directly to the dorsal aorta without interruption (Fig. 8.18). In most sharks, only five aortic arches persist, the first having been modified. Five afferent and four efferent branchial arteries are present. In both cladistians and dipnoans a pulmonary artery, arising from sixth arch (or from the dorsal aorta) carries blood to the swim bladder.

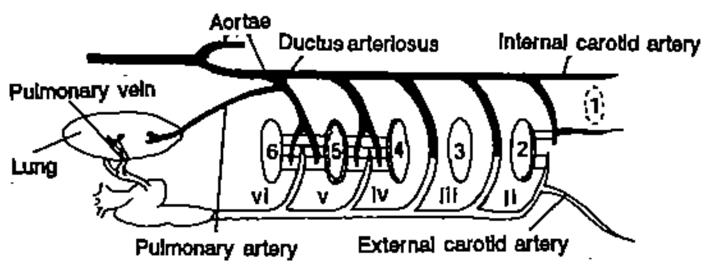


Fig. 8.18 : Aortic arches of *Protopterus* (lung fish).

8.3.4 Amphibians

In amphibians, with the reduction in the number of aortic arches and non development of gill lamellae, there is no further break up into afferent and efferent portions. Amphibians possess external gill filaments, atleast during early development but they are not homologous with the internal gill lamellae of fishes, nor are they supplied with blood in the same manner. In amphibians, generally the first two aortic arches (I, II) disappear early in the development. The pattern of remaining arches differs between larvae and metamorphosed adults. The frog larva has last four aortic arches (III-VI) that deliver to the internal gills. The embryonic pulmonary artery buds from the arch VI. During metamorphosis the gills and arch V are lost.

So in adult frog, aortic arches I, II and V disappear (Fig. 8.19). The anterior continuation of the ventral aorta becomes external carotid arteries. The third arch becomes the internal carotid artery, and both of these carotid arteries arise from the common carotid which is the section of ventral aorta that lies between III and IV arches. At the base of the internal carotid lies the carotid body which is an enlarged portion of the carotid arteries and is formed at the point of branching of carotid arteries.

The fourth aortic arches persist to become the systemic arches which unite posteriorly to form the dorsal aorta. Arch VI on each side sends a branch to the developing lung and another branch to the skin, thus becoming the pulmocutaneous artery. The portion of arch VI present initially between the pulmonary artery and the radix of the aorta (Fig. 8.15) is the ductus arteriosus, or duct of Botallus; it disappears at the time of metamorphosis. Fig. 8.20 shows the arterial system of the adult frog.

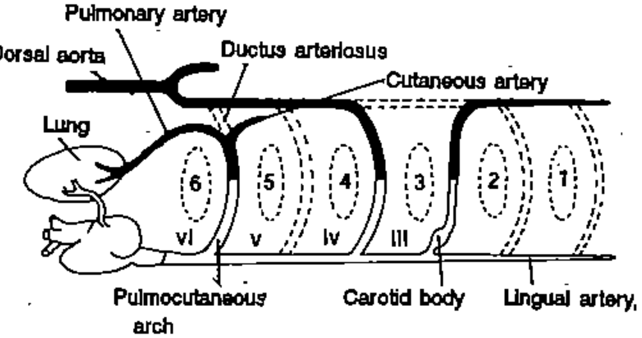


Fig. 8.19 : Diagram showing modification of aortic arches as found in adult frog.

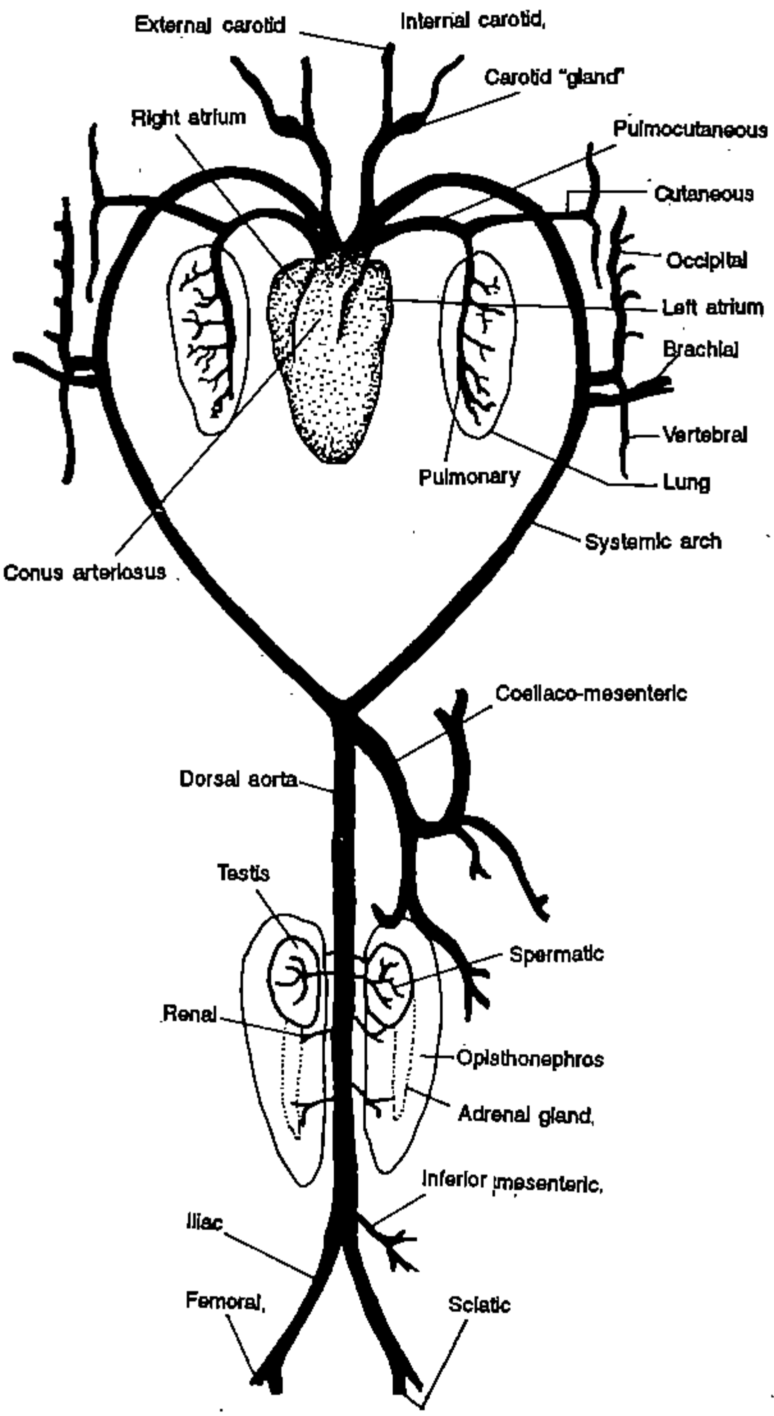


Fig. 8.20 : Diagram of arterial system of adult frog : ventral view.

In salamanders (Caudates) the fifth arch may persist in a very much reduced form. Frequently the radix between arches III and IV fails to degenerate completely. The ductus arteriosus also persists in caudates.

The external gills of larval caudates are supplied with vascular loops connected to aortic arches. In caudates, at the end of metamorphosis gills degenerate and atrophy of the vascular loops i.e. capillary net work surrounding the gill lamellae and collecting loop occurs (Fig. 8.21).

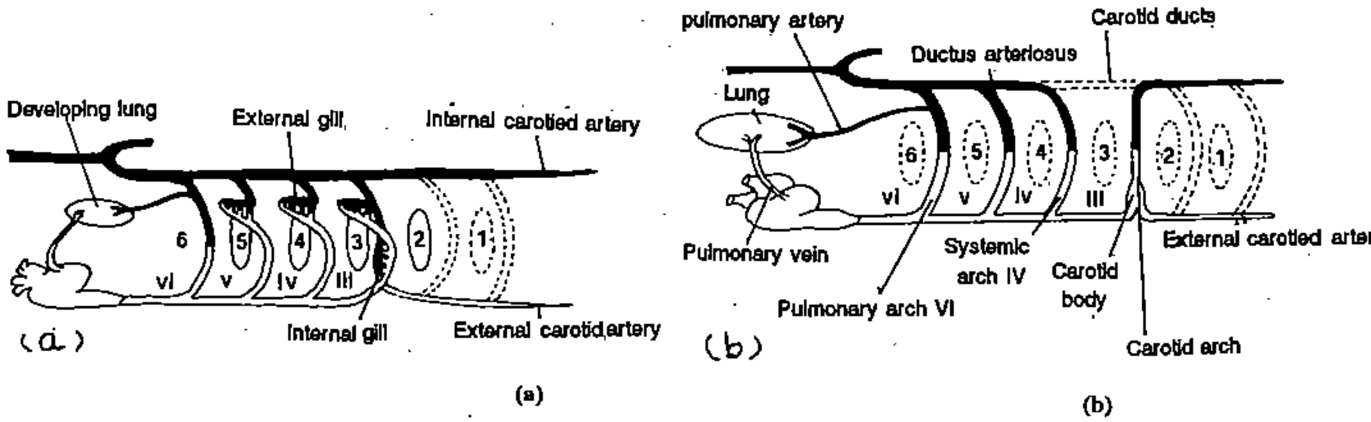


Fig. 8.21 : **Diagram showing modification of aortic arches as found in most caudate amphibians, (a) Salamander (larval); (b) Salamander (adult).**

Certain caudates, such as neotenic salamander *Necturus* are called perenni branchiates since they retain gills throughout life and fail to metamorphose. In this amphibian, the fifth aortic arch persists and the pulmonary artery arises from the fifth arch rather than the sixth, the ventral portion of which is lacking. Blood going to the lungs in *Necturus* has already been oxygenated. The lungs, therefore, under normal conditions are unable to function as respiratory organs, and the gills are retained. Now try the following SAQ to assess your programme.

SAQ 3

Match the items given in column I with those in column II.

	Column I		Column II
i)	Basic embryonic pattern in vertebrates	a)	Supply blood to jaws and face.
ii)	External carotid artery	b)	Generally in amphibians.
iii)	Reduction/modification of I and II aortic arches	c)	Occurs in caudates.
iv)	Disappearence of I and II aortic aiches during early development	d)	Characteristic of teleosts
v)	Atrophy of vascular loops at the end of metamorphosis	e)	Six pairs of aortic arches.

8.3.5 Reptiles

Just as in amphibians, reptiles retain aortic arches III, IV and VI. The fifth arch may also be retained in reduced form in certain lizards, and a remnant of the radix between arches III and IV may persist in some snakes.

In most reptiles, further modifications occur in the aortic arches (Fig. 8.22). These consist mainly in splitting of the distal portion of the conus arteriosus and part of the ventral aorta into three vessels – left systemic arch, right systemic arch and the pulmonary trunk. Thus, the modifications of the aortic arches give rise to one pulmonary circuit and two systemic circuits each of which arise independently from the heart. The sixth arch on each side gives off a pulmonary artery to the lung and in most cases loses its connection with the radix. The two pulmonary arteries, therefore, arise from a common trunk, the pulmonary aorta, coming from the right side of the ventricle and continuing as sixth arch. The fourth aortic arch on the left side establishes a separate connection with the right side of the partially divided ventricle. It together with a portion of the radix on the left side, becomes the left arch of the aorta. The remaining vessel derived from the truncus arteriosus connects to the left side of the ventricle and as it courses forward and after going off the fourth aortic arch on the right side finally divides into two common carotid arteries with external and internal branches. The right fourth aortic arch, together with a portion of the radix on that side, becomes the right arch of the aorta, which joins the posterior continuation of the left arch behind the heart to form the dorsal aorta proper i.e. common dorsal aorta. Since the right aorta bears mostly oxygenated blood and the left mainly deoxygenated blood, mixing occurs in the dorsal aorta proper. Some mixing may also occur through the foramen of Panizza. Mixing of oxygenated and deoxygenated blood seems to be associated with the poikilothermous mode of life. (Poikilotherms are those animals which cannot adapt themselves to the changing temperature e.g. fishes and amphibians).

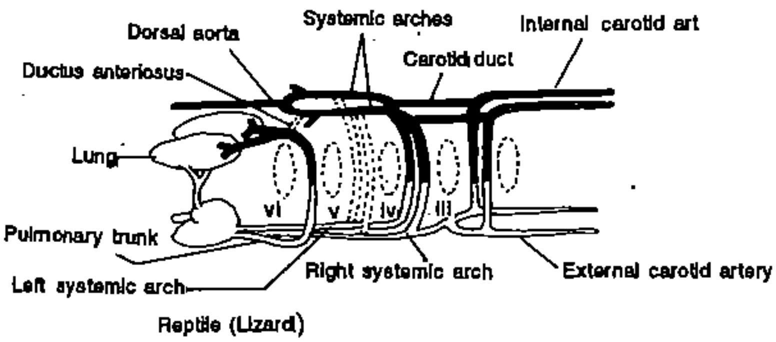


Fig. 8.22 : Diagram showing modification of the aortic arches as found in reptiles. The ventral aorta has split into three vessels.

8.3.6 Birds

The ventral aorta splits into two portions, a systemic aorta and a pulmonary trunk or aorta. The systemic aorta is connected to the left ventricle, and the pulmonary aorta to the right. The fourth aortic arch on the right side leaves the right systemic aorta and together with the radix, leads to the dorsal aorta proper, which supplies the entire body with oxygenated blood. The left systemic aorta does not develop fully. The pulmonary trunk leading from the right ventricle gives off the pulmonary arteries, which are actually outgrowths of the sixth aortic arch. Until the time of hatching there is a ductus arteriosus on each side, representing the portion of sixth aortic arch between pulmonary artery and radix (Fig. 8.23). These serve as shunts from the right ventricle to the dorsal aorta until the lungs become functional. They close at the time of hatching, and the blood from the right ventricle is then sent to the lungs for aeration.

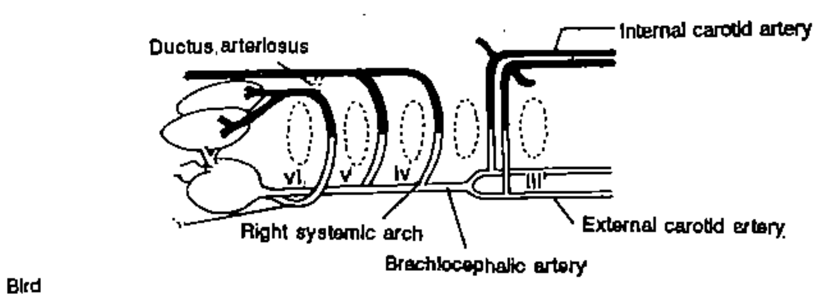


Fig. 8.23 : Diagram showing modification of aortic arches as found in birds.

8.3.7 Mammals

Changes in the aortic arches of mammals are rather similar to those of birds except that the radix on the right side loses its connection with the aorta. The fourth aortic arch on the left side together with its radix becomes the arch of the definitive aorta and therefore is the left systemic arch in mammals. The fourth arch on the right and a portion of the right radix together become the right subclavian artery. The left subclavian develops as an enlargement of one of the intersegmental arteries coming off the aorta (left systemic arch) in this region (Fig. 8.24). The pulmonary arch is formed from the paired sixth arch and its branches. In mammalian embryos there is at first a ductus arteriosus on each side, but the one on the right persists for only a short time. The left one, which serves as a shunt between pulmonary and systemic aortae, persists until birth, when it finally becomes occluded. The carotid arteries are formed from the paired third arch.

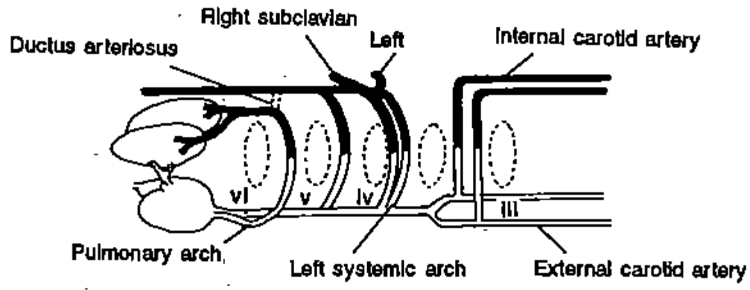


Fig. 8.24 : Diagram showing modification of aortic arches as found in mammals.

8.3.8 Overview of Evolution of Aortic Arches

The aortic arches in most of the fishes deliver the deoxygenated blood to the respiratory surfaces of the gills and from there distribute the oxygenated blood to the head region through carotid arteries and to the rest of the body through the dorsal aorta. In lung fishes and tetrapods the aortic arches form two types of circuits – arterial circuit to lungs through pulmonary arch and arterial circuit to rest of the body through systemic arches. Blood to the head in tetrapods is supplied by carotid arteries that arise from the systemic arch. The left and right arches are present in reptiles also. However, these are reduced to single systemic arch, the right arch in birds and the left arch in mammals. You can see in figure 8.25 the evolution of aortic arches.

8.3.9 Types of Arteries

Most of the vertebrate body is supplied with blood through branches of the aorta which for convenience sake may be grouped under two divisions: somatic arteries supplying the body proper, and visceral arteries, distribute blood to various portions of the digestive tract and associated structures.

I) **Somatic arteries:** They supply portions of the body derived from the embryonic epimere, being distributed to the dorsal musculature and vertebral column, where they are referred to as parietal, or segmental arteries. In higher forms in which the body is divided into more or less definite regions, terms such as intercostal, dorsolumbar, and sacral are used. The vessels going to the pectoral appendage are called subclavians and those to the pelvic are iliacs, which may be composed of a union of several segmental arteries.

II) **Visceral arteries:** The arteries supplying the viscera are of two kinds: paired and unpaired. The paired arteries are segmentally arranged and supply the body parts that are derived from the embryonic mesomere from which the urogenital organs and their ducts arise. These are termed as renal, genital, ovarian, spermatic and urogenital arteries. Renal and genital arteries are numerous in the lower vertebrates, but the number is much reduced in higher forms.

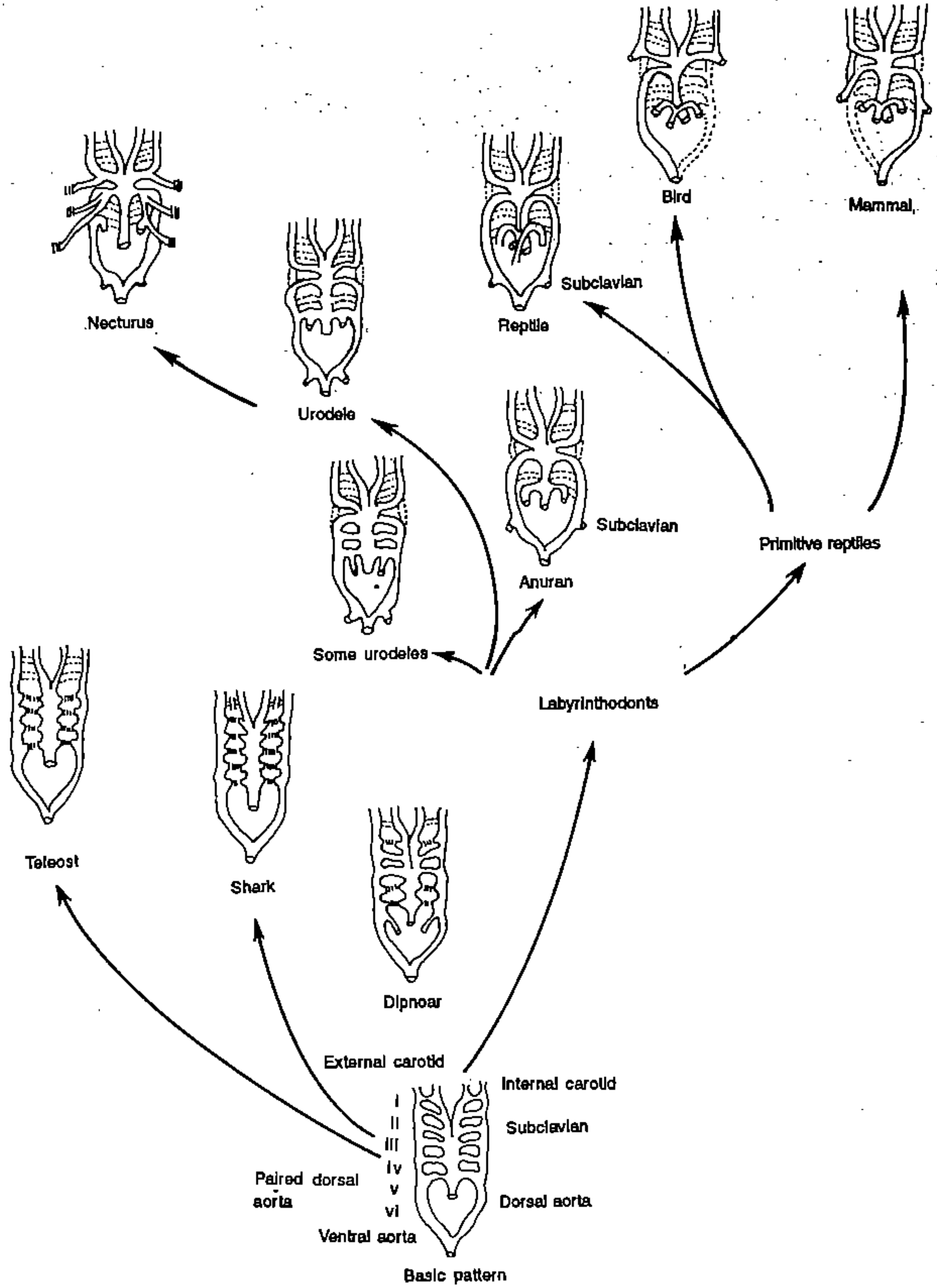


Fig. 8.25 : Evolution of aortic arches. Ventral view of the basic six arch pattern that includes a ventral aorta, paired aortic arches, and paired dorsal aortae. Modification of this basic pattern leads to the derived aortic pattern of adult vertebrates. Vertical lines on the aortic arches represent gills. Dashed lines are the arches lost from the basic pattern in the adult. Abbreviations : dorsal aorta (Da), external carotid (Ec), internal carorid (Ic), paired dorsal aorta (Pa), subclavian (Sc), ventral aorta (Va).

The unpaired visceral arteries supplying spleen, and the digestive tract with its derivatives, are vessels which course through the dorsal mesentery of the gut. There are usually three unpaired visceral arteries in vertebrates. The most anterior of these is the coelic artery, supplying the anterior viscera, including stomach (gastric), spleen (splenic) pancreas (pancreatic), liver (hepatic), and duodenum (duodenal). The second unpaired visceral artery is the superior mesenteric, which supplies the entire length of the small intestine, with the exception of the pyloric end of the duodenum, which is taken care of by the coelic artery. The third unpaired artery is the inferior mesenteric, supplying to the posterior part of the large intestine and rectum.

SAQ 4

Give short answers to the following questions.

i) What is the major modification that occurs in reptilian aortic arches?

....

....

....

ii) What is the role of ductus arteriosus in bird's circulatory system?

....

....

....

iii) How does right subclavian develops in mammals?

....

....

....

iv) What is one difference between somatic arteries and visceral arteries?

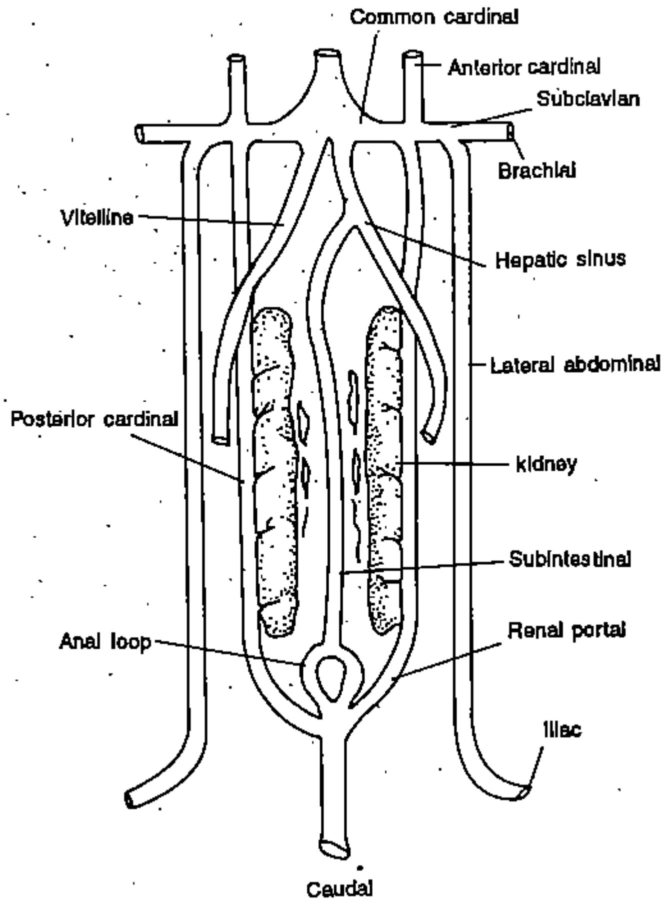
....

....

....

8.4 VENOUS SYSTEM

As in the case of the arterial system, a comparative account of veins in various vertebrate groups shows that they are arranged according to the same fundamental plan and that the variations form a logical sequence as the vertebrate scale is ascended. In its development venous system of higher forms passes through certain stages common to the embryos of lower forms (Fig.8.26). Basically three major sets of paired veins are present in the early developmental stage – vitelline veins from the yolk sac, cardinal veins from the body of the embryo and lateral abdominal veins from the pelvic region. Vitelline veins include the hepatic sinusoids and hepatic veins. Hepatic veins collect the blood from hepatic sinusoid network and enter the sinus venosus. The cardinal veins consist of anterior cardinal veins that collect the blood from the head region and, posterior cardinal vein that collect blood from the rest of the body of the embryo. Both these veins meet at common cardinal veins also called as duct of Cuvier that open into sinus venosus. The lateral abdominal veins are present in fishes but are normally absent or merged in tetrapods. We will discuss about these veins while discussing the venous system of fishes. The vein that carries the absorbed end products of digestion from the digestive tract to the vascular sinusoids in liver is called the hepatic portal vein. It is present in all vertebrates and is developed from the embryonic subintestinal vein originating in the caudal vein. The subintestinal vein loops around the anus, extends along the ventral wall of intestine, passes through the liver and finally joins the left vitelline vein. The structural variations in the venous system of different vertebrates is described below:



Basic embryo pattern,

Fig. 8.26 : Diagram of basic embryonic venous complex from which the venous system of vertebrates are derived.

8.4.1 Amphioxus

The vertebrate venous system is reduced to its simplest form in these chordates (Fig. 8.27).

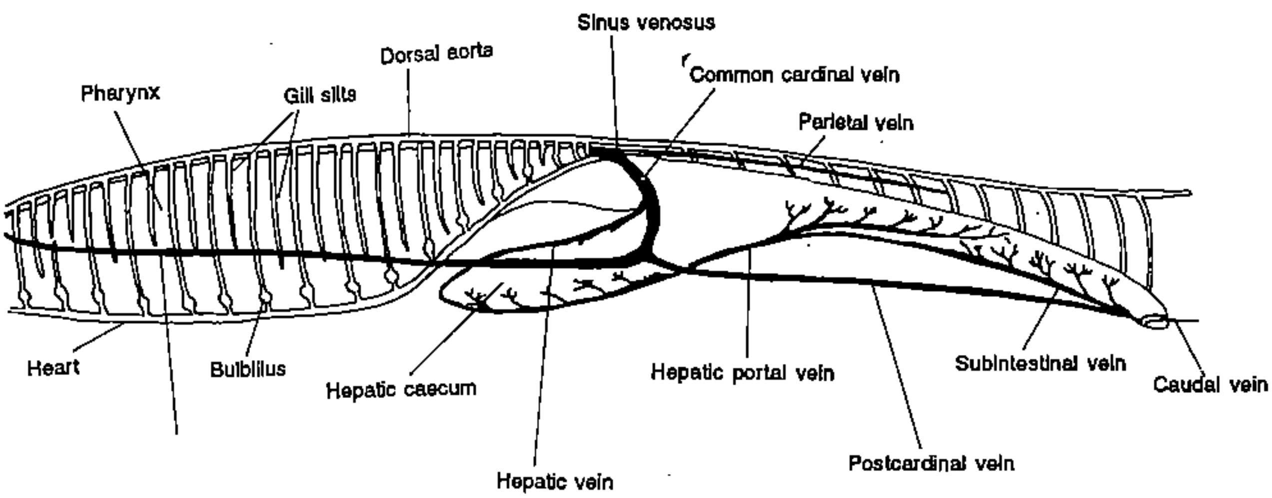


Fig. 8.27 : Diagram showing the essential features of the circulatory system of *Amphioxus* : lateral view.

8.4.2 Fishes

Many primitive features are retained by the venous system of fishes, but important advances over conditions in *Amphioxus* are evident (Fig. 8.28).

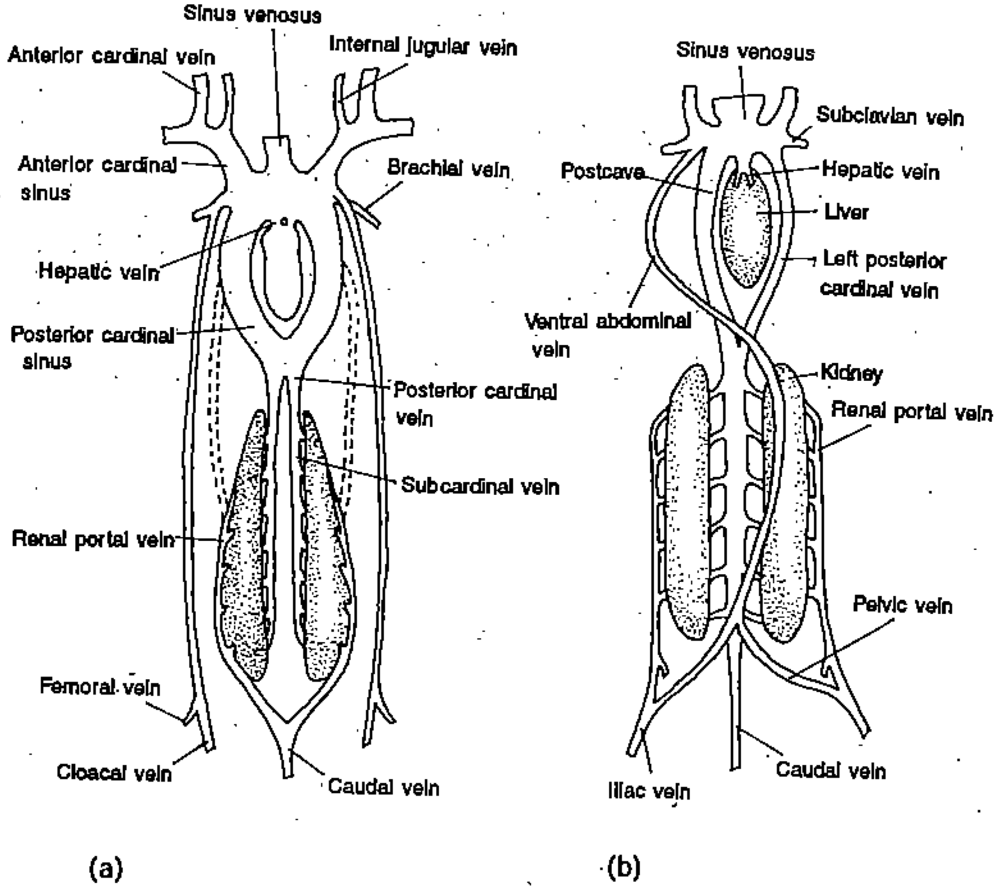


Fig. 8.28 : Diagrams, a) lung fish and b) shark, illustrating the changes over the primitive condition which occur in the venous system of fishes.

The sinus venosus receives a duct of Cuvier on each side. An anterior cardinal, or jugular vein brings blood to the duct of Cuvier from the dorsal side of the head region. In many fishes a pair of inferior jugular veins from the ventrolateral part of the head also enters the common cardinal veins. These are lacking in *Polypterus* and fused in *Lepisosteus*. Each common cardinal also receives a postcardinal vein from the posterior end of the body. Since fishes are the first vertebrates to possess paired appendages, subclavian and iliac veins, bringing blood from the pectoral and pelvic fins, respectively, make their appearance first in this group. The iliac veins join the lateral abdominals which course in the body wall to join the common cardinal. The posterior wall of the sinus venosus usually receives two hepatic veins, which return blood from the liver to the heart. The subintestinal vein has, in most cases, lost its connection with the caudal vein.

With the development of the opisthonephric kidneys (The adult kidney formed from the mesonephros and additional tubules from the posterior region of the nephric ridge. You will study more about this in the unit entitled Excretory System) and their posterior elongation, the postcardinals grow backward dorsal to the kidneys, ultimately to unite with the caudal vein. A pair of subcardinal veins develop ventral to the kidneys, i.e. between opisthonephric kidneys. Small blood vessels connect the postcardinal and subcardinal veins. They are not associated with glomeruli, which receive arterial blood. Blood in the caudal vein has now two alternative routes through which it may pass on its way to the heart. It may either go into the postcardinals directly or indirectly through the subcardinals renal veins. The next advance involves an interruption in the course of each postcardinal vein so that anterior and posterior portions are no longer continuous. Blood from the tail now travels only by one route. It passes through the kidneys, i.e. the renal portal veins to enter the subcardinal veins thus, establishing the renal portal system. The blood courses anteriorly via the postcardinals, which join the duct of Cuvier. The postcardinals usually receive veins from the gonads. The blood passing through the renal veins, flows in a direction reverse of that occuring during an early stage of development, after the renal portal circulation is established. These changes are evident upto elasmobranch fish stage.

In teleosts, lateral abdominal veins are not present. The subclavians enter the common cardinals, and the iliacs join the postcardinal. Veins from the swim bladder (derivative of the gut) usually join the hepatic portal vein. However, in certain forms the connection is with the postcardinal veins. In *Polypterus* they join the hepatic veins directly. In dipnoans, the pulmonary veins from the swim bladder enter the newly formed left atrium of the heart, and the double type of circulatory system appears for the first time.

Lung fishes show the characters as connecting link between amphibians and fishes. In *Epiceratodus* a single, midventral, anterior abdominal vein, similar to that of amphibians, makes its appearance. The lateral abdominal veins have fused to form the anterior abdominal vein, which courses forward to enter the sinus venosus. Iliac joins with renal portal and the pelvic vein is a branch of iliac which joins the anterior abdominal. The right postcardinal, including its posterior portion, has become much larger than its counterpart on the left side. The connection with the caudal vein on both sides is retained. The larger vessel on the right side is now called the postcaval vein. It passes through the liver and enters the left duct of Cuvier. The venous system of *Protopterus*, except for the lack of an anterior abdominal vein, resembles more closely with that of amphibians than that of *Epiceratodus*.

8.4.3 Amphibians

In amphibians, the renal portal and hepatic portal systems are brought into close association, since blood from the hind limbs must pass through one or the other.

Pulmonary veins from the lungs enter the left atrium, as in *Dipnoi*. In lungless salamanders, of course, pulmonary veins are absent and the left atrium is reduced in size.

The ducts of Cuvier, which originally received the subclavian, jugular, and postcardinal veins, are further consolidated in amphibians and are now called the precaval veins. These enter sinus venosus on each side. The jugular vein has external and internal tributaries. Since cutaneous respiration has developed to a high degree in amphibians, exceptionally large cutaneous veins are present which join the subclavians to enter the sinus venosus.

Although both urodele (caudates) and anurans (salientians) are similar in the above respects, they exhibit certain differences in regard to the arrangement of the postcaval postcardinal complex. In most caudates and a few salientians the anterior portions of the postcardinals persist in reduced form (Fig. 8.29 and 8.30), connecting the middle portion of the postcava with the duct of Cuvier on each side. In most adult anurans however, the anterior portions of the postcardinals usually disappear and furnishes the only route through which blood from the kidneys and gonads may return to heart.

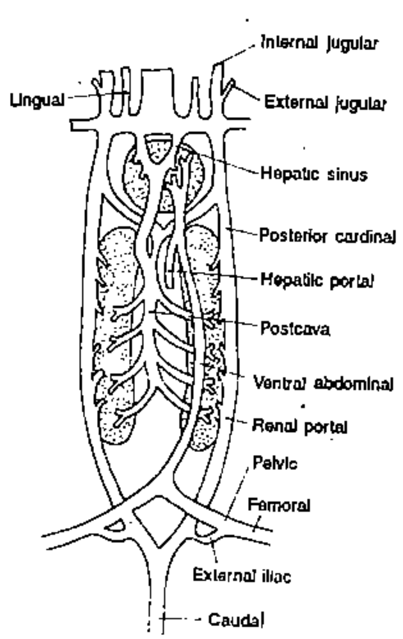


Fig. 8.29 : Diagram of venous system of a typical urodele amphibian : ventral view.

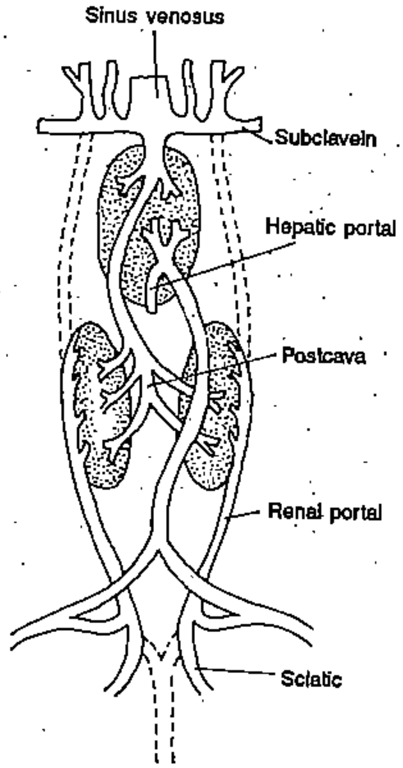


Fig. 8.30 : Diagram of venous system of a typical anuran amphibian : ventral view.

SAQ 5

Answer the following questions in short.

i) What are the three sets of paired veins present in the early embryonic stage?

....

....

....

ii) What are the veins in fishes that bring blood from the fins?

....

....

....

iii) What is the fate of lateral abdominal veins in teleosts and lung fishes?

....

....

....

iv) What are precaval veins?

....

....

....

v) Why large cutaneous veins are present in amphibians?

....

....

....

8.4.4 Reptiles

In this group following further partitioning of the heart the large systemic veins entering heart have shifted more to right (Fig. 8.31). Two precavae are the original ducts of Cuvier, which receive jugular, subclavian, and postcardinal veins. The anterior portion of the jugular, subclavian, and postcardinal have degenerated into two small vertebral veins. In snakes the subclavians are lacking. More blood from the posterior part of the body now courses through the anterior abdominal vein which joins the hepatic portal veins anteriorly. The importance of the renal portal vein has diminished, and in some forms direct channels may even pass through the kidneys, connecting renal portal and postcaval veins. Since cutaneous respiration does not exist in reptiles, pulmonary circulation has assumed greater importance.

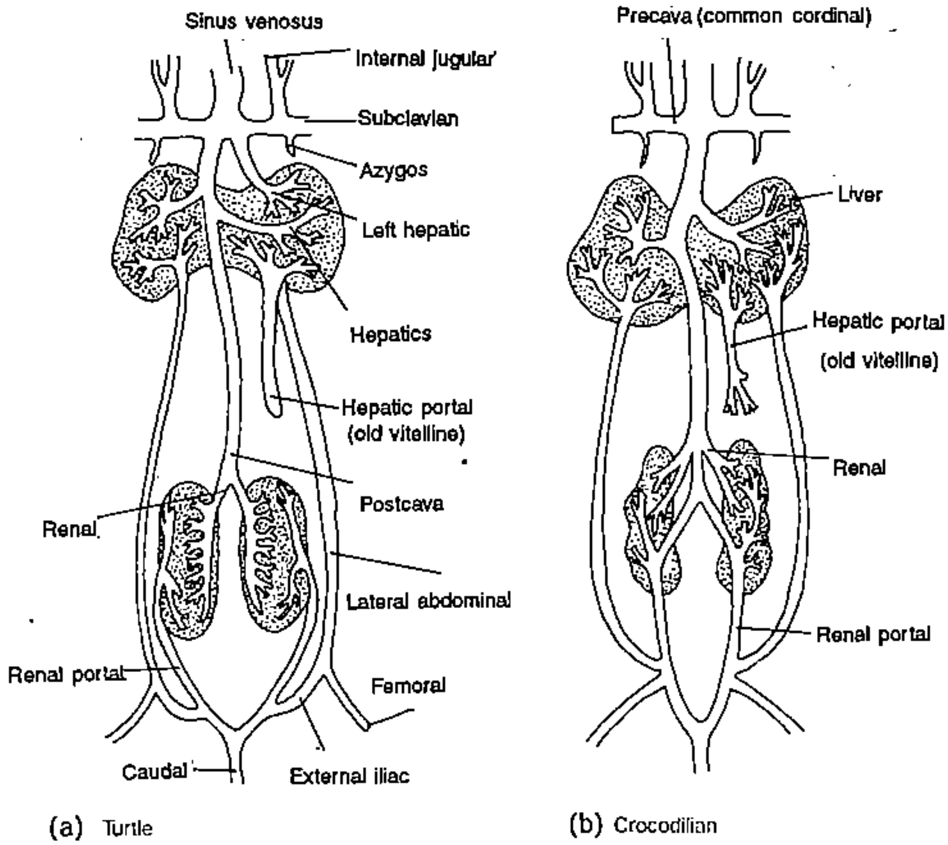


Fig. 8.31 : Venous channels in reptiles a) turtle, b) crocodile. A strong branch of the renal portal vein in coocodilians continues directly to the postcava. The pelivic vein occurs in turtles but has been omitted to facilitate identification of the basic pattern.

Depending upon the degree of asymmetrical development of the respiratory organs, pulmonary veins from the two lungs show discrepancies in size in various forms. One pulmonary vein may even be entirely absent in certain snakes in which the left lobe of the lung is absent. The reptilian postcava, as in amphibians, is derived partly from the subcardinals and partly from the vitelline veins. The postcardinals have practically disappeared.

8.4.5 Birds

The sinus venosus has been incorporated in the wall of the right auricle, so that the two precavae and single postcava enter the right auricle directly. Each precava is formed by the confluence of subclavian and jugular veins. The original postcardinal connection is no longer in existence. The postcava is the chief pathway for the return of blood from the posterior part of the body. The posterior end of the postcava receives blood directly from the limbs via the renal portal veins. The hepatic veins of birds join the postcava as it nears heart. The caudal vein in birds is greatly reduced. A vein variously known as the inferior mesenteric, cocygeomesenteric, and caudal mesenteric, connects the caudal vein with the hepatic portal vein. A small epigastric vein carries blood from the great omentum to one of the hepatic veins (Fig. 8.32).

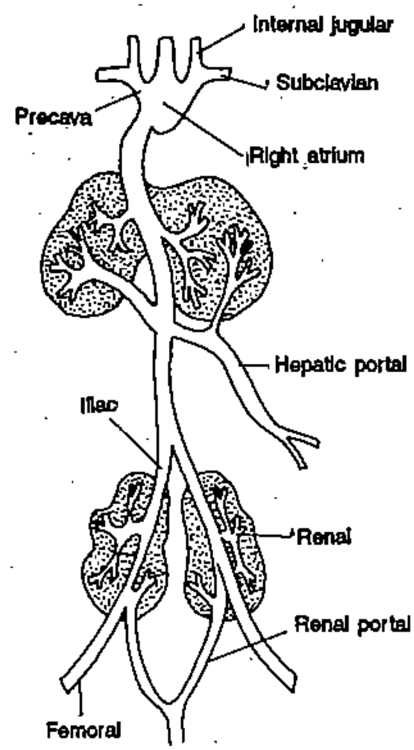


Fig. 8.32 : Diagram of venous system of bird, ventral view.

8.4.6 Mammals

The shifting of the main venous channels to right side is more clearly indicated in mammals than in other vertebrates. In some mammals two precavae are present, but in others they are joined. The vessel on each side which receives jugular and subclavian vein is then called the brachiocephalic (innominate) vein. In mammals a portion of the anterior end of the right postcardinal persists as the azygos vein. This drains the intercostal muscles and enters the precava. The greatest change in the venous system of mammals occurs in the postcava, which has become considerably simplified. No trace of a renal portal system is found in adults and all blood from the posterior end of the body is collected by the postcava. The embryonic development of mammalian postcava is complicated by the appearance of new vessels called the supracardinal veins. The anterior abdominal vein has disappeared in mammals, being found only in the monotreme, *Echidna*. Usually only the left umbilical vein persists, passing through the liver as the ductus venosus to join the postcava before it enters the heart. The hepatic portal vein usually referred to as the portal vein, is similar to the hepatic portal vein of lower forms (Fig. 8.33).

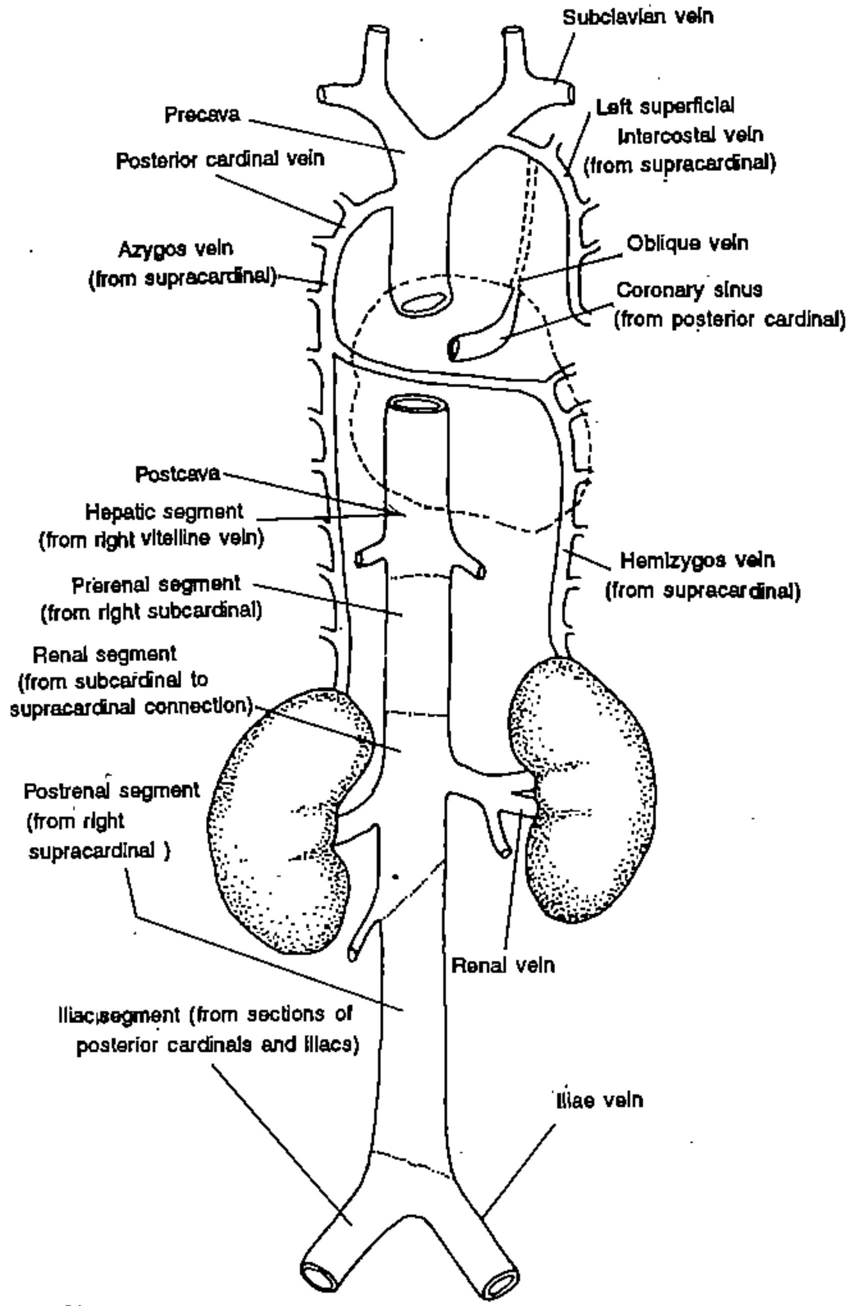


Fig. 8.33 : Diagram of venous system of cat, ventral view.

8.5 EMBRYONIC DEVELOPMENT OF THE CARDIOVASCULAR SYSTEM

Most blood vessels arise within embryonic mesoderm (or from mesenchyme) almost as soon as this germ layer becomes established. Small clusters of mesodermal cells called **blood islands** mark the embryonic debut of the cardiovascular system. Embryonic blood islands yield both blood vessels and blood cells, so they are involved in **angiogenesis** (blood vessel formation) and **hemopoiesis** (blood cell formation). Blood islands merge, forming a connected vascular network that eventually links parts of the embryo to each other and connects it to its nutrient supply and respiratory organs. The embryonic heart is tubular.

Early on, it has autonomous, rhythmic beats that drive blood through the developing vascular network. As in the adult, the cardiovascular system of the embryo assumes an active and essential role in respiration, metabolism, excretion, and growth.

When first formed, the embryonic vertebrate heart is already contractile and includes four major adjoining chambers. The **sinus venosus** is the first chamber to receive returning blood. Blood flows next into the **atrium**, then into the **ventricle**, and finally into the fourth chamber, the **bulbus cordis**. From the bulbus cordis, blood leaves the heart to enter arteries departing for the body of the embryo. In most tetrapods, splanchnric mesoderm forms the basic four chambered, tubular heart. Development of the heart begins when cells leave the splanchnic mesoderm to form a medial pair of **endocardial tubes**. Cells remaining in the splanchnic mesoderm proliferate, producing a thickened lateral region, the paired region, the paired **epimyocardium**. Cells of the endocardial tube and epimyocardium grow toward the midline and fuse into the single, centrally located, tubular heart. Specifically, the fused endocardial tubes from the endothelial lining of the heart, called the **endocardium**, and the epimyocardium gives rise to the extensive cardiac muscle of the heart wall, the **myocardium**, together with the thin visceral peritoneum covering the heart's surface. With these fusions, the basic four-chambered embryonic heart is established.

Flexions and expansions of the tubular heart twist the heart into different configurations, but the internal path of blood flow remains the same. In most fishes, adults retain this basic four-chambered embryonic heart. However, in lungfishes and tetrapods, varying degrees of internal subdivisions cordon off additional compartments within the heart, and some of the original chambers may become reduced or appropriated by other parts of the adult vascular system (Fig. 8.34).

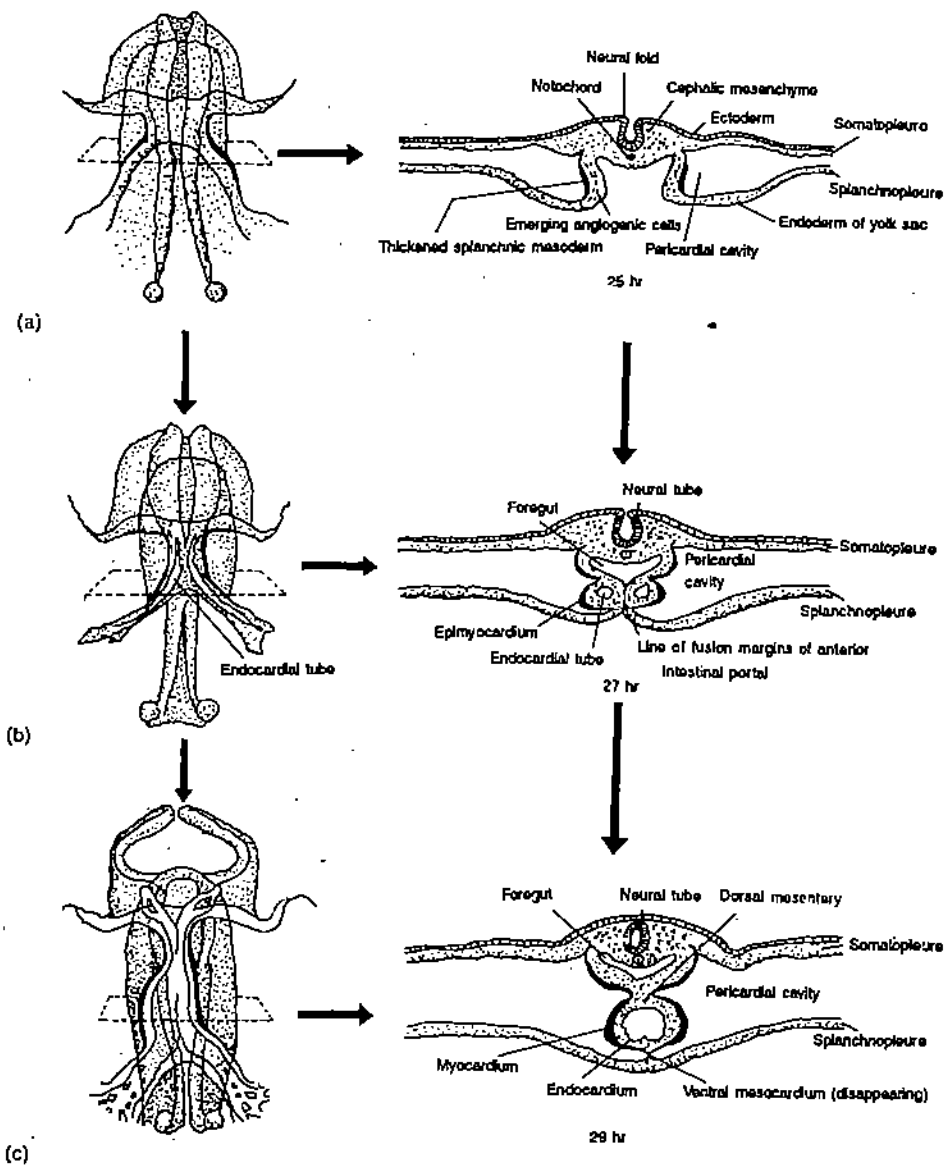


Fig. 8.34 : Embryonic heart formation. Chick embryo in successive stages of incubation (25, 27, 29 hr, respectively). Ventral (left) and corresponding cross-sectional (right) views of heart formation are illustrated. (a) Angiogenic cells emerge from the epimyocardium, a thickened splanchnic mesoderm. (b) Angiogenic cells differentiate into a pair of primordial endocardial tubes. (c) This pair of endocardial tubes fuses medially into the single endocardial tube, the future lining of the heart. The thickened epimyocardium forms the thin peritoneum on the surface of the heart and the extensive myocardium, the muscular wall of the heart.

SAQ 6

Fill in the blanks with appropriate words.

i) Subclavians are absent in ________ .

ii) The reptilian postcava is derived partly from ________. and partly from ________.

iii) The ________ brings the blood from the posterior part of the body.

iv) The caudal vein is greatly reduced in ________.

v) The ________ ________ transports blood from great omentum to hepatic vein.

vi) In ________ the azygos vein brings the blood from intercostal muscles.

vii) The anterior abdominal vein has disappeared in mammals, except in ________.

viii) ________ is the process of formation of blood vessels.

ix) The basic four chambered heart in most tetrapods is formed from ______., _____

8.6 BLOOD

Blood may be described as a specialized connective tissue in which there is liquid intercellular substance known as plasma, and formed elements, the red blood cells, the white blood cells and the platelets suspended in the plasma.

8.6.1 Composition of Blood

The general composition of the whole blood is summarized below :

Diagram

Blood
- Cells
  - Red blood cells
  - White blood cells
  - Platelets
- Plasma
  - Water 91-92%
  - Solid 8-9%
    - Inorganic constituents 0.9%
      - Sodium
      - Potassium
      - Calcium
      - Magnesium
      - Phosphorus
      - Iron
      - Copper
    - Organic constituents 7.5%
      - Proteins
        - Serum albumin
        - Serum globulin
        - Fibrinogen
        - Prothrombin
      - Non protein substances
        - Urea
        - Uric acid
        - Xanthine
        - Hypoxanthine
        - Creatin
        - Ammonia
        - Acids
      - Fats
        - Neutral fats
        - Phospholipids
        - Cholesterol
        - Cholesteroid
      - Carbohydrates
        - Glucose
      - Others
        - Internal secretions
        - Antibodies
        - Enzymes
        - Amylase
        - Protease
        - Lipase
        - Phosphatase
      - Colouring matters
        - Bilirubin
        - Careteus
        - Xanthophyllin

The red blood cells or erythrocytes are the containers of haemoglobin, the respiratory pigment. The erythrocytes in all the groups of animals, except for mammals have nuclei. Red blood cells vary in size for example, B µm in humans, 9 µm in elephants and 80 µm in some salamanders. The life of the erythrocytes is three to four months in the circulating blood before being broken down and replaced. White blood cells, the second major cellular component of the blood defend the body from infection and disease. The third type of blood cells are the platelets that help in the formation of clot at the site of tissue damage. Blood has important roles to play in body processes such as respiration, protection against diseases, nutrition, excretion, regulation of body temperature, maintenance of water balance, transport of hormones etc. You can read about the structure and function of blood in detail in Unit 3 of LSE-05 (Physiology) course.

8.6.2 Respiratory Pigment

Haemoglobin is the only respiratory pigment among vertebrates. This combines with far greater amounts of oxygen than any of the other respiratory pigment.

Haemoglobin is made up of an iron prophyrin compound associated with a protein, globin. This heme component of the molecule is a constant feature of all haemoglobins, but the globin portion varies in different vertebrates. The oxygen carrying capacity of haemoglobin in various vertebrates is given below:

Pigment	Colour	Site	Animals	Oxygen carrying capacity in volume per cent
Haemoglobin	Red	Corpuscles	Mammals	15-30
			Birds	20-25
			Reptiles	7-12
			Amphibians	3-10
			fishes	4-20

8.7 LYMPHATIC SYSTEM

Lymphatic system resembles the blood vascular system in that it consists of vessels, fluids in transit, and associated organs. A major difference is that lymph flows in only one direction that is towards the heart. The lymphatic system of all vertebrates consists of thin walled vessels called lymphatics. The walls of lymphatic vessels are like that of veins and like veins they also contain one way valves. The lymphatics penetrate nearly all the soft tissue of the body and commence as blind-end lymph capillaries that collect interstitial fluids. Once inside the lymph capillaries, the fluid is called lymph, a colourless or pale-yellow fluid containing metabolites and secretions, which constantly collect in the intercellular spaces. The lymph from any area mirrors the metabolic activities of that area from moment to moment.

Lymphatic system also includes lymphatic tissue which consists of connective tissue and free cells, the leucocytes, plasma cells and macrophages. Lymphatic tissue can be found almost anywhere in the body as diffusely distributed tissue, in patches or encapsulated in lymph nodes. A lymph node is a collection of lymphatic tissue wrapped in capsule of fibrous connective tissue. Lymph nodes are located within channels of lymphatic vessels. Lymph nodes occur in mammals and some water birds only.

The lymphatics in the villi of the small intestine collect globules of fat absorbed from the intestine after a meal. If the meal has been particularly fatty, the lymph in these vessels is milky. For this reason, the lymphatics of the intestinal villi are called lacteals, and the lymph therein is called chyle (juice). Some of the lymphatics in cyclostomes, cartilagenous fishes and even in man contain red blood cells as well as lymph. The fluid in these vessels is called hemolymph. In addition, lymphatic tissue helps in removal and destruction of harmful material like bacteria and dust particles. Plasma cells produce antibodies that circulate in the blood. Macrophages and leucocytes destroy the bacteria. Lymphatic tissue also intercepts the cancer cells that migrate through the lymph nodes. However, the rapidly dividing cancer cells fill up the lymph nodes. If such a case is detected in the tests all the cancer affected nodes should be removed.

Several factors that are instrumental in propelling the slow moving lymph through lymphatic vessels and nodes are as follows.

i) Muscular activity of various parts of the body.

2) Pressure built up in the smaller vessels by osmosis and absorption of tissue fluid.

3) The action of pulsating lymph hearts which consists of enlargements in lymphatic vessels with contractile walls, usually situated near a point where lymph enter the venous system. Lymph hearts are not true hearts because they lack cardiac muscles. The straited muscles in their walls slowly develop pulses of pressure to drive the lymph.

Let us discuss the lymphatic system in different vertebrates.

8.7.1 Fishes

Lymphatic vessels in fishes are extensively developed, peripherally located extend into head, tail and fins. Deeper channels follow the course of some of the larger veins.

Lymph hearts are usually not present, but in some forms they are present near the point of junction of lymphatic vessels and veins. Eel has a lymph heart in the tail. The European catfish has two caudal lymph hearts. Lymph nodes seem to be lacking in fishes.

8.7.2 Amphibians

Two main sets of lymphatic vessels are present in caudate amphibians. Superficial vessels beneath the skin carry lymph to cutaneous and postcardinal veins. Between 14 and 20 lymph hearts have been observed along their course in various forms. Deeper channels follow the dorsal aorta on each side and enter the subclavian artery. In anurans, with large lymph sacs, most of the lymph flows towards heart. Two pairs of lymph hearts are usually present in adult animals. First pair near the third vertebra, pumping lymph into the vertebral vein, and a second posterior pair, located near the end of the urostyle pumps blood into the transverse iliac vein. Lymph hearts are more numerous in larval and tadpole stages. More than 200 lymph hearts are present in caecilians, lying beneath the skin along the intersegmental veins.

8.7.3 Reptiles

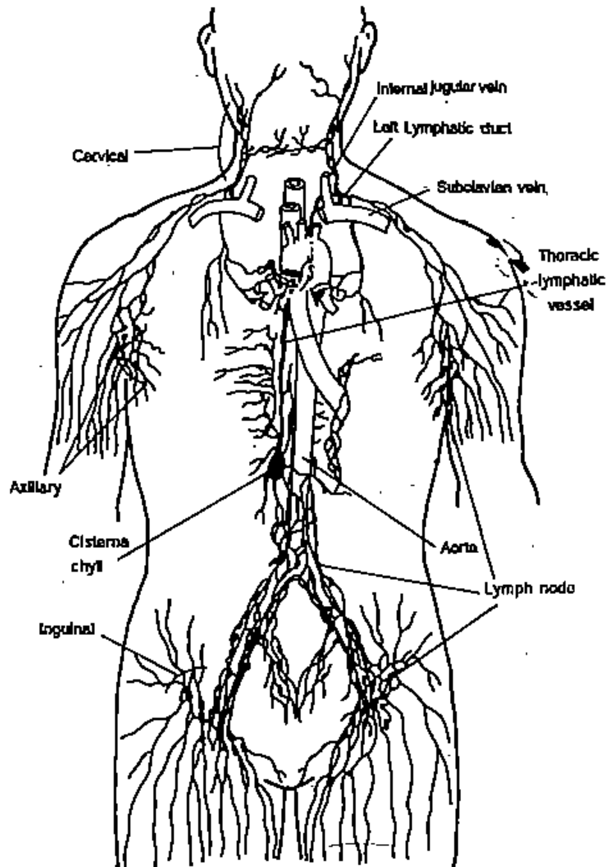
The lymphatic system is well developed. A large subvertebral trunk divides anteriorly to enter the precaval veins. In snakes lymphatic vessels and sinuses are exceptionally large and numerous. A posterior pair of lymph hearts pumps lymph into the iliac veins.

8.7.4 Birds

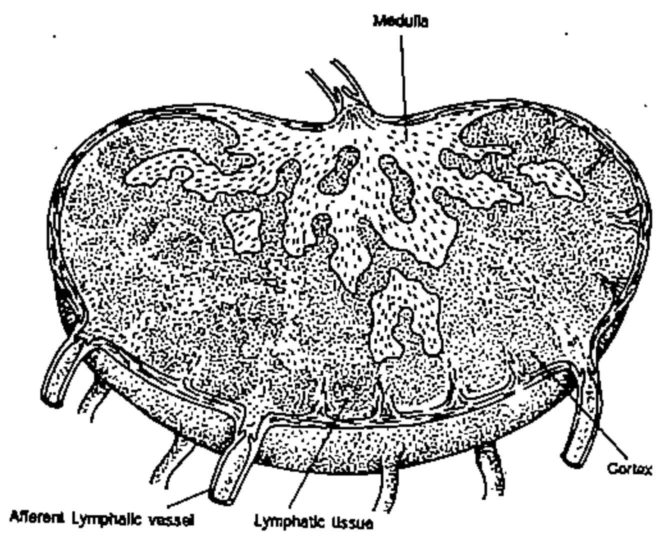
The lymphatic vessels of birds ultimately enter two thoracic lymph ducts which join the precaval veins. Transitory lymph hearts, not found in adult birds, may be observed in the pelvic region during embryonic development.

8.7.5 Mammals

Lymph hearts are altogether lacking in mammals. A main trunk, the thoracic duct drains all the lymphatic vessels of the posterior part of the body, as well as those coming from the left side of the head, neck and thoracic regions. In mammals lymph nodes are numerous in superficial regions of the head and neck, axillae, and groin. Many lie within the body cavity large and numerous in the mesentery of the intestine. In all those localities they serve to prevent the invasion of the body by bacteria (Fig. 8.35).



(a) Lymphatic circulation



(b) Lymph node

Fig. 8.35 : Lymphatic circulation and lymph nodes. (a) Lymphatic vessels returning from all parts of the body join to form major lymphatic vessels, the largest being the thoracic duct, which empties lymph into the postcaval or subclavian veins, (b) Cross section of a lymph node. In mammals and in a few other species, small swellings or nodes occur along lymphatic vessels. These lymph nodes house lymphatic tissue, which functions to remove foeign materials from the lymph circulating through them. Lymph nodes have cortex and medulla bounded by a fibrous connective tissue capsule. Notice the entering and departing lymphatic vessels.

8.7.6 Other Lymphatic Organs

Some organs of pharyngeal origin usually considered to belong to lymphatic system include tonsils, adenoids and thymus glands. Tonsils and adenoids guard the body by forming antibodies against antigenic substances. They filter the tissue fluid and produce lymphocytes. Thymus gland has a role to play in some of the immunological reactions in the body. Peyer's patches are nodules of lymphoid tissue in the small intestine especially numerous in the region of the ileum. Some other organs related to circulatory system in the body are as follows.

Hemolymph glands: These glands of the body closely resemble lymph glands except that they enclose blood vessels rather than lymphatics. Blood, rather than lymph, filters through them. They are also called hemal nodes. They are believed to play a role in the destruction of old and worn-out corpuscles and also erythrocyte formation. Ruminating mammals have numerous hemalnodes but their occurrence in man is doubtful.

Spleen: The largest lymphoid organ in body is the spleen. It is sometimes considered to be a hemolymph gland since it is interposed in the blood stream rather than in lymphatic vessels. The blood vessels are peculiarly arranged in the spleen so that the blood comes in contact with the phagocytes (macrophages) that engulf the fragments of disintegrating red corpuscles. Lymphocytes and plasma cells originating in thymus are later formed in large number in spleen. The spleen also serves as a storehouse for erythrocytes. Spleen also produces antibodies serving in the defence machanism of the body.

Spleen enlargement is a feature of malaria and in some other conditions in which the organ may assume relatively much larger size.

Pharyngeal tonsils present in reptiles, birds and occasionally in mammals appear in the mucous membrane on the roof of the pharynx and come to lie behind the choanae. It is possible that they are homologous with some lymphoid masses in the roof of the pharynx of amphibians. The enlarged pharyngeal tonsils in man are called adenoids. Other kinds of tonsils that are found in mammals only are palatine tonsils and lingual tonsils. Palatine tonsils are lymphoid masses derived from the second pair of visceral pouches and are located on either side where mouth and pharynx join. Palatine tonsils are often the site of infection and, therefore, can be removed. Lingual tonsils are lymphoid masses that develop in relation to lingual glands and are situated at the base of the tongue. Thymus gland was earlier believed to be an endocrine gland, however, evidences now indicate that it belongs to lymphatic system. In lampreys small primordia that arise from the dorsal angles of all the seven gill pouches and become separated from the pharynx are possibly the thymus tissue. In hagfishes the lobular structures posterior to gill region may be the thymus tissue. Lampreys exhibit most generalised condition of the vertebrates in respect to the thymus development. In teleosts it is represented by a single lobulated mass. In urodeles the gland is lobulated mass of tissue on each side of neck. In adult frog it lies behind the tympanic membrane and under the mandibular muscle and is smaller than in tadpole. In reptiles and birds there is variation in the origin of thymus. In some reptiles they originate as separate elements but show a tendency towards fusion into elongated lobular strands along the sides of the neck. In mammals thymus develops from the ventral portions of the pharyngeal pouches rather than dorsal. It lies along the ventral side of the trachea and extends back to the base of the heart.

SAQ 7

i) a) Name two blood proteins

....

b) Name two non-protein substances of blood.

....

c) Name three inorganic constituents of blood.

....

d) Describe the composition of respiratory pigment present in vertebrates.

....

....

....

ii) Match the items given in column I with those given in column II.

Column I	Column II
a. Arteries	i. Lymph
b. Unidirectional flow	ii. Blood
c. Collection of interstitial fluid	iii. Lacteals
d. Chyle	iv. Lymph capillaries
e. Absence of lymph nodes	v. Birds
f. Transitory lymph heart	vi. Mammals
g. Absence of lymph heart	vii. Fishes
h. Production of lymphocytes	viii. Tonsils
i. Lymphoid nodules in ileum	ix. Spleen
j. Phagocytosis of disintegrating red corpuscles	x. Peyer's patches

8.8 SUMMARY

- The circulatory system includes blood vascular and lymphatic systems. Blood vascular system consists of heart, arteries, capillaries, and veins. Lymphatic system is composed of lymphatics (including lacteals), lymph capillaries, lymph sinuses, lymph nodes in mammals and birds. Lymph hearts are present in lower vertebrates, but absent in birds and mammals. Lymph is transported from tissue spaces, and chyle, which is also a form of lymph, is transported from intestinal villi to certain major venous channels.
- An aortic arch is a blood vessel connecting the ventral and dorsal aortae and located, in the embryo at least, in a visceral arch. Typically, six pairs of aortic arches develop in each vertebrate embryo. During ontogeny the aortic arches are reduced in number, the most highly evolved vertebrates retaining fewest arches.
- A sinus venous occurs in fishes, amphibians, and reptiles. It is absent in adult birds and mammals, having been incorporated in the right atrial wall during embryonic development.
- There is no mixing of oxygenated and deoxygenated blood in fishes. Considerable mixing occurs in tailed amphibians, and less occurs in frogs and reptiles. Mixing occurs in fetal birds and mammals but not in adults.
- Major venous channels in the basic pattern of vertebrate circulation are anterior cardinal (internal jugular) veins from the head, postcardinal veins from the trunk and kidneys, and subclavian vein from the anterior appendages – all flow into common cardinal veins; abdominal veins from the hind limbs; renal portal system from the tail; and hepatic portal system from the chief digestive organs. Hepatic sinuses drain the liver, coronary veins drain the musculature of the heart, and pulmonary and postcaval veins are added in lung-breathing forms.
- The renal portal system drains only the tail in fishes. It acquires a connection (external iliac) with the hind limb drainage in amphibians and reptiles. In crocodilians and birds the connection may bypass the kidneys and go directly to the postcava. The renal portal system is absent in adult mammals, except monotremes, and the hind limbs and tail are drained solely by the postcava.
- Blood may be described as a specialized connective tissue in which there is intercellular substance known as plasma, and formed elements, the red blood cells, the white blood cells and the platelets suspended in the plasma. Specific gravity varies 1.055 to 1.060.

- The lymphatic system of all vertebrates consists of thin walled lymphatics. In birds and mammals, the lymph nodes are interposed along the course of the lymphatics. The lymphatics penetrate nearly all the soft tissue of the body and commence as blind-end lymph capillaries that collect interstitial fluid which is pale yellow fluid containing metabolites and secretions which collect in the intercellular spaces.
- Lymphatic vessels in fishes are extensively developed. Peripherally located channels extends into head, tail and fins. Lymph hearts are present in amphibians in which two main sets of lymph vessels are present. In reptiles and birds, lymphatic system is well-developed. In mammals, there are no lymph hearts; but several lymph nodes are present. The largest lymphoid organ in body is spleen.

8.9 TERMINAL QUESTIONS

Answer the following questions in 4-5 lines.

1) Write short notes on the general structure of heart wall.

....

....

....

....

2) Name different stages in the evolution of heart.

....

....

....

....

3) What is pace-maker?

....

....

....

....

4) Write short note on foramen of Panizza.

....

....

....

....

5) Comment on duct of Botallus.

....

....

....

....

8.10 ANSWERS

Self Assesment Questions

1. i) peristaltic waves

   ii) atrium

iii) tuberculate

iv) interatrial septum

v) cutaneous

2) i. a) reduced

b) initiates

c) partialy, completely

d) squamates and crocodiles

e) choanichthyans

f) mammalian

ii) Heart beat originates in a bundle of typical muscle fibres located in the wall of the sinus. This is called as "Sinoauricular node' (SA node). The heart beat further spreads to another as of a typical muscle fibres, in the wall of right atrium.

3) i - e
ii - a
iii - d
iv - b
v - c

4) i) Formation of right and left aortic arches, pulmonary trunk and a part of ventral aorta.

ii) It serves as shunt from right venticle to the dorsal aorta until the lungs become functional.

iii) The fourth arch on the right and a portion of the right radix together become the subclavian artery.

iv) Somatic arteries supply blood to the body parts derived from the embryonic epimere and visceral arteries supply to digestive tract and other organs derived from embryonic mesomere.

5) i) Vitelline veins from yolk sac, cardinal veins from the body of embryo and lateral veins from pelvic region.

ii) Subclavian and iliac veins bring the blood from pectoral and pelvic fins, respectively.

iii) Lateral abdominal veins are absent in teleosts but in lung fishes they fuse to form the anterior abdominal veins which enter the sinus venosus.

iv) The ducts of Cuvier which originally received the subclavian, jugular and postcardinal veins are further consolidated in amphibians and are called precaval veins.

v) It is because the cutaneous respiration has developed to the higher degree in amphibians.

6) i) snakes
ii) subcardinals, vitelline veins
iii) postcava
iv) birds
v) epigastric veins
vi mammals
vii) *Echidna*
viii) Angiogenesis
ix) splanchnic mesoderm

7) i) a) Fibrinogen, prothrombin

b) Creatin, Urea

c) Sodium, potassium, calcium

d) Haemoglobin is made up of an iron porphyrin compound, hence associated with a protein, globin. The heme component is a constant feature of all haemoglobins, but the globin portion varies in different vertebrates.

ii) a-ii; b-i; c-iv; d-iii; e-vii; f-v; g-vi; h-viii; i-x; j-ix.

Terminal Questions

1) Heart wall consists of 3 layers viz.

   a) Endocardium - the inner wall consisting of endothelium and elastic tissue.

   b) Myocardium - muscular portion in between endo- and epicardium.

   c) Epicardium - Outer fibrous tunica, covered by visceral pericardium (subdivision of coelom).

2) The following are the different stages in the evolution of heart.

   a) The protochordate stage without alimentary pharynx.

   b) The piscine stage with branchial pharynx.

   c) The early tetrapod stage with primitive lungs.

   d) The later tetrapod stage of higher ectotherms.

   e) The stage of endothermic tetrapods.

3) The excitation tissue which is responsible for the initiation of the heartbeat and embedded in the wall of the right atrium is called sinoauricular (SA) node or sinuatrial node. This is also called the pacemaker (myogenic centre) of the heart.

4) The crocodiles, which have a left aortic arch, do not receive blood from its own (right) ventricle, since the semilunar valves actually prevent flow from ventricle to aorta except under unusual stress situation. The left arch receives blood through a foramen of Panizza, connecting the right and left arches where they cross a short distance.

5) In salientian amphibians, the portion of aortic arch present at first between the pulmonary artery and the radix is known as ductus arteriosus or duct of Botallus. It disappears at the time of metamorphosis.

GLOSSARY

Abomasum : the last of four chambers in the complex ruminant stomach, homologus to the stomach of other vertebrates.

Afferent : conducting inward.

Antler : a branched, bare bone that grows outward from skull bones on some artiodactly species; usually grows annually in mature males and is shed during the non-reproductive season.

Apnea : temproary cessation of breathing.

Artery : blood vessel carrying blood away from the heart.

Auricle : blood receiving chamber of heart also the external ear.

Baleen : keratinized straining plates that arise from the integument in the mouth of some species of whales.

Bolus : soft mass of food in the mouth or stomach; compare with chyme.

Brachyodont : pertaining to teeth with low crowns. Compare with hyposodont.

Bunodont : pertaining to teeth with peacked cups. Compare with lophodont and selenodont..

Carnassials : sectorial teeth of carnivores including upper premolars and lower molars.

Caecal fermentation: process by which micro oganisms digest food in the caeca of the intestines. See intestinal formentation.

Caecum : a blind-ended out pocketing from the intestines.

Cementum : cellular and acellular layers that usually form on the roots of teeth, but in some herbivores, these layers may contribute to the occused surface.

Chyme : the liquified bolus of partially digested food after it leaves the stomach and enters the intestine. Compare with bolus.

Crop : a baglike expansion of the oesophagus.

Cutaneous respiration : direct gas exchange between blood and environemtn through skin.

Dentin : a material that forms the bulk of the tooth and is similar in strucutre to bone but harder, yellowish in colour and composed of inorganic hydroxypatite crystals and collagen, secreted by odontoplasts of neural crest origin.

Dentition : a set of teeth.

Dermal papilla : the part of the tooth-forming primordium that is derived from neural crest cells, becomes associated with the enamel organ, and differentiates into odontoblasts that secrete dentin. See enamel organ.

Dermis : the skin layer that lies beneth the epidermis and is derived from mesoderm.

Digestion : the mechanical and chemical breakdown of foods into their basic end products, usually simple carbohydrates, proteins, fatty acids, that are absorbed by the bloodstream.

Diphyodont : a pattern of tooth replacement involving only two sets of teeth, usually milk teeth and permanent teeth.

Ectotherm : an animal that depends on the environmental source of heat to regulate its body temperature.

Efferent : conducting outward

Emulsify : to break up fats into smaller droplets. Compare with digestion.

Enamel : forms the occlusal cap on most teeth; hardest substance in vertebrate body consisting almost entirely of calcium salts as apatite crystals:

secreted by ameloblasts of epidermal orgin. See dentin and cementum.

Enamel organ : the part of the tooth-forming primordium that is derived from epidermis, becomes associated with the dermal papilla, and differentiates into the ameloblasts that secrete enamel. See dermal papilla.

Endocardium : lining of the cavities of heart.

Endotherm : an animal that is capable of maintaining elevated body temperatures with the heat produced inside the body as a result of metabolic processes.

Epicardium : visceral peritoneum enveloping the heart

Foregut : anterior embryonic gut that gives rise to the pharynx, esophagus, stomach, and anterior intestine, Compare with hindgut.

Gill slit : pharyngeal slit associated with gills.

Hemibranch : a gill arch with lamellae on only one face.

Hepatic : related to liver.

Heterodont : denitifion in which the teeth are different in general appearance throughout the mouth.

Hypoxia : inadequate levels of oxygen to support metabolic demands.

Keratin : fibrous protein.

Keratinization : the process by which the skin forms proteins, especially kertain.

Omasum : the third of four chambers in the complex ruminant stomach; a specialization of the esophagus. See abomasum, reticulum, and rumen.

Pseudobranch : embryologically the first gill slit that is reduced to a small opening the spiracle. It carries a much reduced hemibranch know as pseudobranch.

Reticulum : the second of four chambers in the complex ruminant stomach; a specialized region of the esophagus. Compare with abomasum, omasum, and rumen.

Rumen : the first of four chambers in the complex ruminant stomach; an expanded specialization of the esophagus. Compare with abomasum, omasum, and reticulum.

Ruminant : a placental mammal with a rumen, a specialized expansion of the digestive tract that processes plant material; Ruminantia.

Selenodont : teeth with crescent-shaped cusps; as in artiodactyls. Compare with bunodont and lophodont.

Sinus : space in organ or tissue (sinus venosus in heart).

Veins : blood vessel carrying blood towards the heart.

FURTHER READING

1. The Life of Vertebrates J.Z. Young (Third Edition) ELBS. Oxford University Press.

2. The Vertebrate Body A.S. Romer and T.S. Parson (Sixth Edition) CBS College Publishing.

3. Chordata Anatomy and Evoultion D. Jacob, A Sharma and K. Nandchahal (1994). Ramesh Book Depot, Jaipur.

NOTES

NOTES

NOTES

Ir Uttar Pradech
Rajarshi Tandon Open University

UGZY -02
ANIMAL DIVERSITY-II

Block

3

FUNCTIONAL ANATOMY OF CHORDATES – II

- give a comparative account of the vertebrate brain and correlate its evolution with its functions,
- describe the basic and specialised sensory organs in vertebrates,
- describe the location structure, functions and secretions of different endocrine glands in vertebrates,
- explain the advantage of endoskeleton and their modifications in different vertebrates.

BLOCK 3 FUNCTIONAL ANATOMY OF CHORDATES - II

In the earlier tv ..ocks you have learnt that the chordate body is much more than just a sum of its parts performs a number of vital functions related to body-environment boundaries, support and movement, food processing and nutrition, gaseous exchange, water balance and body fluids, internal transport, sensory mechanisms, coordination and integration and reproduction. Block 3 is a continuation of the previous block which dealt with some of these system, in this block we discuss the other chordate systems namely, urinogenital, nervous, skeletal and endocrine.

Unit 9 – Urinogenital System, gives a comparative account of the excretory and reproductive systems in chordates. Evolutionary survival of animal . depends on their reproducing successfully which is the primary biological role of the genital system. On the other hand, urinary system is concerned with quite different functions, namely, to eliminate waste products and to regulate the water and electrolyte balance. Although excretory and urinary functions are quite different, we have included them in urinogenital system as both share many of the same ducts and embryonically the concerned organs arise from the same or adjacent mesodermal tissue and maintain a close anatomical association.

Structural support is necessary for normal function and becomes especially critical for organisms of relatively greater mass. Support is more than simply preventing an animal from falling down. Openings must be supported to permit passage of materials and to prevent them from collapsing under operational forces. The soft mass of delicate organs of the body must be protected and reinforced by structural material. All chordates have an endoskeleton which in the lowest form may consist of only the notochord, but as the animals evolved the internal skeleton composed of cartilage and bone or a combination of both, gave structural support necessary for normal functioning. Unit 11 – Skeletal System gives a comparative account of the axial as well as appendicular skeletons of vertebrates alongwith the modifications in the skeleton of limbs.

Some means of integration have to be established to provide coordinated and meaningful responses to the external and internal stimuli by the total form of the organisms or from the parts that are affected. The nerve cells of the nervous system and the endocrine glands are the two major components of this integrating system. The nervous system exerts its control through the nerves distributed to all parts of the body in fractions of seconds and the endocrine gland are slower coordinators that send their secretions through the blood and lymph vessels causing effects that may last over days or several weeks. The integration of these two systems is very complex and difficult to separate. For convenience sake we have discussed them in two units – Unit 10 and Unit 12.

Unit 10 – deals with Nervous System and Sense Organs. We have discussed the organisation of the nervous system and the brain in relation to function in different vertebrate groups. Associated with the nervous system are certain sensory receptor organs, capable of responding to stimuli and transmitting them to the central nervous system. In the higher centres of the brain the stimuli are perceived as sensations. We have discussed the basic sense organs and some of the specialised sense organs that have evolved in vertebrates in relation to their habitats.

Unit 12 – gives an account of the other part of the integrating system the endocrine glands in various vertebrate phyla. It is important to know the fact that with minor variations the several endocrine glands are similar in all classes of vertebrates. The organs that makeup the endocrine system are found distributed throughout the body, vary widely in embryonic origin and are often parts of other organ systems. Though each gland has its particular and specific function the hormones secreted by them show functional interrelationship.

Objectives

After studying this block you will be able to:

- give a comparative account of the urinogenital system of chordates,

- give a comparative account of the vertebrate brain and correlate its evolution with its functions,
- describe the basic and specialised sensory organs in vertebrates,
- describe the location structure, functions and secretions of different endocrine glands in vertebrates,
- explain the advantage of endoskeleton and their modifications in different vertebrates.

UNIT 9 URINOGENITAL SYSTEM

Structure

9.1 INTRODUCTION

Excretion and osmoregulation as you are aware (Refer LSE-05 Unit 4) are two homeostatic processes performed by the kidneys and urinary ducts, which form the **urinary system**. This system is intimately associated both anatomically, and in terms of embryonic origin with the **genital system**. The genital system includes the gonads which generate gametes and the genital ducts that serve as passages for the gametes – sperms in males and ova in females. Though functionally different the two organ systems the urinary and the genital system are treated together as the **urino-genital system**, since both develop from the same segmental blocks of trunk mesoderm or adjacent tissues and share many of the ducts. Thus although the two systems have nothing common functionally they are closely associated in their use of common ducts and are studied under the broad heading of urinogenital system. In this unit, you will learn about the embryonic development of the urinogenital system, the basic plan in vertebrates and the variations in different chordate groups. You will also study the adaptive variations of urinary system in vertebrate living in specialised habitats.

Objectives

After going through this unit, you should be able to:

- describe and illustrate the urinogenital system of the proto chordates – cephalochordates and urochordates,
- illustrate and describe the basic plan of urinogenital system in vertebrates,
- give a comparative account of the urinogenital system of fish, amphibians, reptiles, birds and mammals,

- describe the origin and embryonic development of kidneys, gonads and their associated ducts,
- discuss the morphological and physiological adaptations of the urinogenital system of vertebrates.

9.2 THE URINARY SYSTEM IN CHORDATES

9.2.1 Urinary System in Protochordates

The urinogenital system of protochordates such as the Cephalochordate [e.g. *Branchiostoma* (amphioxus)] and Urochordate, (e.g. *Herdmania*) is very different both in structure and origin from that of the vertebrates (Refer unit 1).

Cephalochordata

Despite the similarities to vertebrates in other aspects of its anatomy, the specialised organs of excretion in the cephalochordate, *Branchiostoma* (amphioxus) show no relationship to any part of the vertebrate kidney or other known fluid regulating structure.

The organs of excretion in *Branchiostoma* are the **protonephridia** – which are ectodermal in origin (unlike vertebrate kidneys which originate from the mesoderm). Protonephridia(Fig. 9.1) are segmentally arranged sac-like tubes which lie in coelomic spaces or atrium above the pharynx. Each protonephridium opens into the peribranchial or atrial space surrounding the gills so that its excretory products released into the atrium, can be flushed away by the outgoing stream of water. Internally, within the coelomic sac the protonephridium terminates blindly (not opening) into the coelom. (see also Fig. 9.17a in this unit)

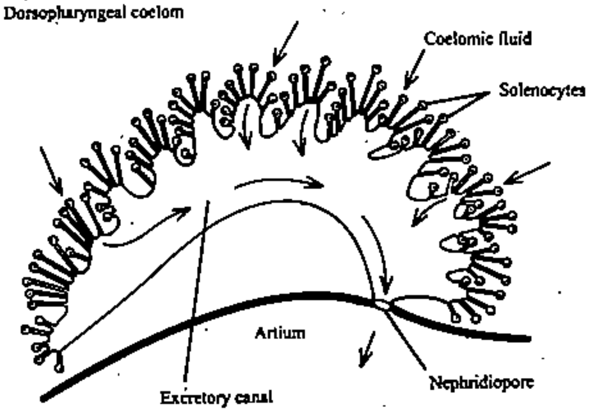


Fig. 9.1: The protonephridium of *Branchiostoma*. (Arrows show path of fluid flow)

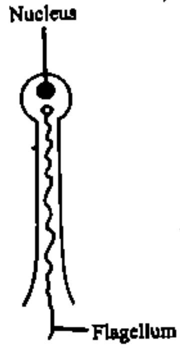


Fig. 9.2: Enlarged view of a single flame cell or solenocyte.

The protonephridial sac bears numerous, specialised tubular flame cells called the **solenocytes** (Fig. 9.2.). Each solenocyte has a single flagellum projecting downwards into the protonephridial tube or canal. Constant beating of flagella probably forces fluid into the protonephridia. The exact mechanism of functioning of solenocytes is still not clear. As the distal ends of solenocytes lie close to branchial (gills) blood vessels, the solenocytes probably help to filter blood fluids from the branches of branchial blood vessels. In the process some fluid components such as ions are probably returned to the body (Fig. 9.1).

Urochordata

In the urochordate, *Herdmania* , neural gland is supposed to be the excretory organ (Fig. 9.3) and lies embedded in the mantle above the nerve ganglion or brain. The neural gland consists of few central tubules from which arise peripheral tubules. The central tubules open into a longitudinal canal. The longitudinal canal opens by a ciliated funnel at the base of dorsal tubercle. The excretory cells are called **nephrocytes**. They are present in blood in order to collect waste which are in the form of xanthene and urates. The waste passes through the lumen of the neural gland and its duct and is finally discharged into the pharynx. Neural glands are endocrine in function as well, since they also control oviposition, development and metamorphosis.

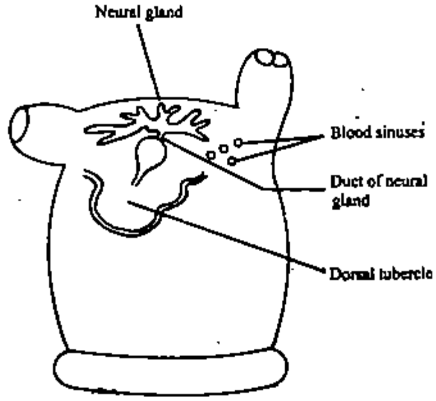


Fig. 9.3: Neural gland of *Herdmania*.

9.2.2 Urinary System in Vertebrates

The basic plan of urinogenital system is common to all vertebrates. The urinary organ-system lies in the abdominal region (Fig. 9.4 a and b) and consists of paired kidneys which are the principal organs of excretion and osmoregulation. These kidneys lie dorsal to the coelom, (retroperitoneal), one on each side of the dorsal aorta. The basic units of the kidney are the minute, uriniferous tubules that end blindly and receive filterate from the blood. The uriniferous tubule consists of two parts, the nephron and collecting tubule. The primary function of the uriniferous tubules is removing excess water, salts, waste metabolites and foreign substances from the blood. Numerous such tubules connect to form an urinary or excretory duct system called **ureter** which carries urine from the kidney. The ureter of each kidney opens into a urinary bladder which in most adult tetrapods is a single median structure. Urinary bladder acts as a reservoir which stores urine prior to its removal. The bladder develops as a ventral outgrowth from the cloaca. The bladder opens to the body surface through a short tube, the urethra. The urethra is thus a small tube which arises from the bladder and opens by a single urinary opening either into the cloaca or directly to the outside.

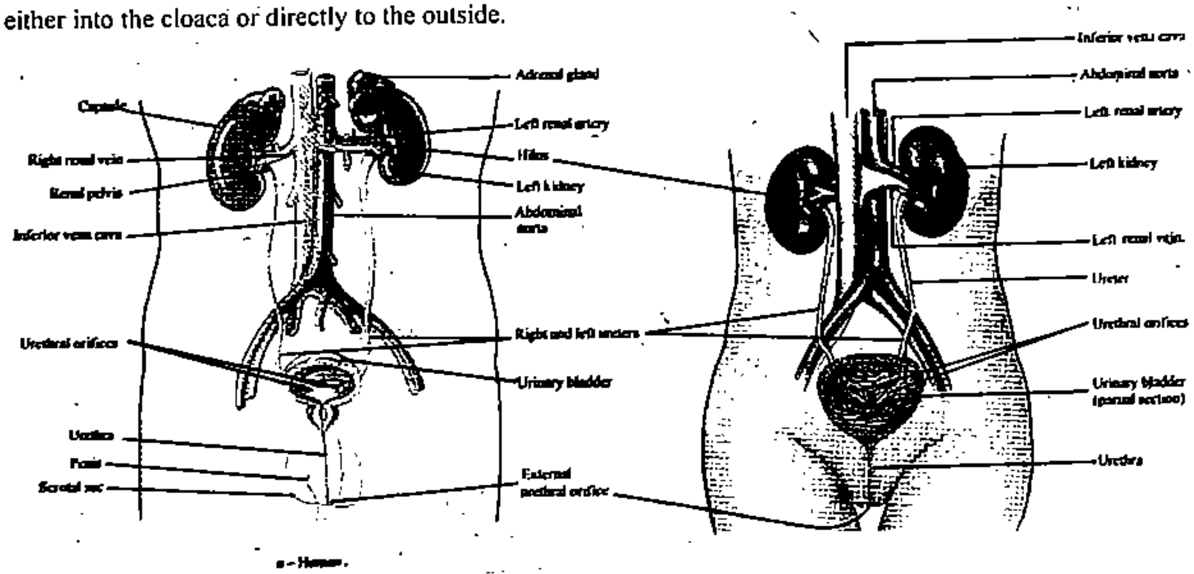


Fig. 9.4: Ventral view of the human excretory systems in (a) male, (b) female.

9.3 EMBRYONIC DEVELOPMENT OF URINARY SYSTEM

Urinogenital system is mesodermal in origin. The intermediate mesoderm which is located in the dorsal and posterior body wall of the embryo forms the kidney. At the onset of its differentiation this posterior region of the intermediate mesoderm expands to form a **nephric ridge** that protrudes slightly from the dorsal wall of the body cavity (Fig. 9.5 a). Next the paired nephrotome which are the embryonic fore runner of the nephric tubule (Fig. 9.5 b) are formed from the posterior part of intermediate mesoderm.

The nephrotome is often segmented and soon differentiates into a series of segmentally arranged tubules each of which contain a nephrocoel, which is a coelomic chamber that opens into the coelom by means of a ciliated peritoneal funnel. The medial end of the nephrotome then widens to form a thin walled renal capsule into which enters a tuft of arterial capillaries called glomerulus. From the lateral end of the nephrotome arise outgrowths. These outgrowth fuse to form a common nephric duct (Fig. 9.5 c). The nephrotome is now properly called a nephric tubule and may retain its connection with the coelom through the persistent peritoneal funnel. Thus the fundamental plan underlying the excretory system consists of p. ired and segmented nephric tubules that open on one end into the coelom and on the other end into the nephric duct with a glomerulus in between (Fig. 9.5 d). In most adult vertebrates, however, there is no connection with the coelom through peritoneal funnel.

In the development of the urinary duct of ureter, longitudinal ducts appear first at the anterior end of nephrogenous mesoderm as backwardly directed extensions of the excretory or nephric tubules. The extensions join to form the 'nephric duct' which opens into the cloaca. All the nephric tubules ultimately open into this duct.

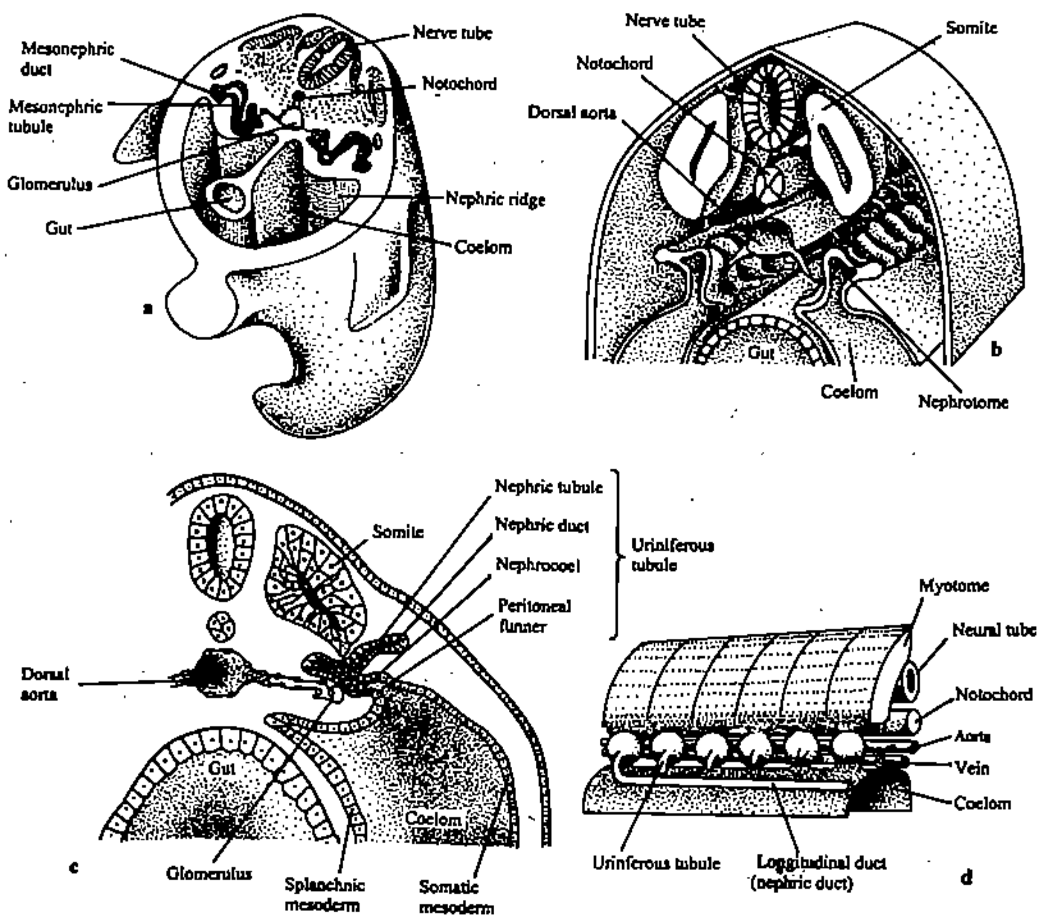


Fig. 9.5: Embryonic development of nephric tubules in vertebrates. (a) Embryo (lower part) showing location of developing kidney (nephric ridge); (b) section through embryo showing the appearance of segmental nephrotome in the posterior part of the intermediate mesoderm; (c) diagrammatic representation of developing kidney tubule and longitudinal nephric duct, note the segmental arrangements; (d) the medial end of the nephrotomes differentiates into the first part of the nephric tubule, the renal capsule into which the glomeruls grows. Arterial sprouts from dorsal aorta form the glomerules. The lateral ends of nephrotomes grow outward and fuse with each other to form the nephric duct. Sometimes the nephrotomes remain connected to the coelom by means of ciliated peritoneal funnel.

9.4 URINIFEROUS TUBULES

The number of uriniferous tubules vary from only a few hundred in the kidneys of cyclostomes to over a million per kidney in mammals, in whom the tubules of both kidneys combined constitute over 120 km of tubing.

The functional units of the kidney as mentioned before are the minute **uriniferous tubules** (Fig. 9.6). Each tubule is constituted of (i) **nephron** (nephric tubule which is the excretory unit) and the (ii) **collecting tubule** (Fig. 9.6) into which the nephron empties. Nephron (nephros: Gk Kidney); concentrates urine and passes it through the collecting tubule. The collecting tubule affects the concentration of urine and conveys it to the minor calyx, (see Fig. 9.9 a) which is the beginning of the excretory duct.

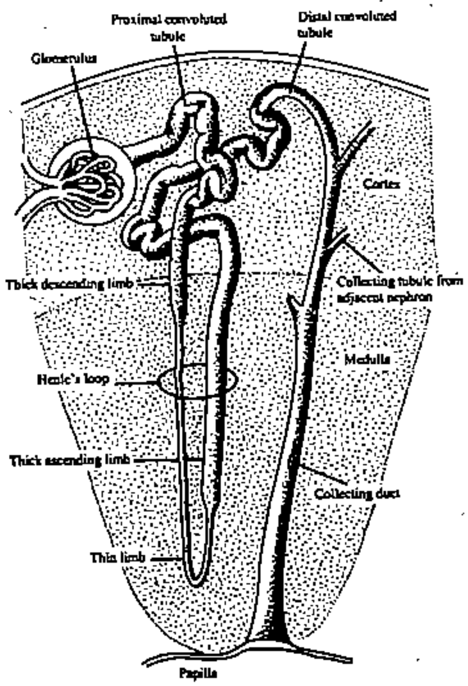


Fig. 9.6: Uriniferous tubule – the basic excretory unit.

I) Nephron

Each nephron has: a) a dilated portion – renal (Malpighian) corpuscle and b) the secretory tubule portion.

(a) Renal Corpuscle or Malpighian Corpuscle

The renal corpuscle is the proximal portion of each nephron and is made of (i) double walled squamous epithelial capsule called **Bowman's or renal capsule.** The outer layer of the capsule is called **parietal layer** and inner one is called the **visceral layer.** Between the layers of Bowman's capsule is a urinary space receiving fluid filtered through capillary wall and visceral layer. (ii) A tuft of **inter-arterial** capillaries called **glomerulus** is surrounded by the Bowman's capsule. Each glomerulus is formed by the subsequent branching of the renal artery (one of the major branches from the dorsal aorta) into a capillarity bed. The visceral or inner layer of the Bowman's capsule is made of stellate cells called podocytes. The visceral layer is in contact with blood vessels of glomerulus. The point of entry of the blood vessels forms the **vascular pole** and the entry point of the nephric filtrate from the Bowman's capsule into the proximal convoluted tubule is called the **urinary pole.** Fig. 9.7 shows a complete uriniferous tubules, surrounded by its blood vascular system.

(b) Tubular portion

The tubule portion is subdivided into (a) proximal convoluted tubule (PCT) (b) loop of Henle with thick and thin limbs and (c) distal convoluted tubule (DCT). The PCT begins at the urinary pole of renal corpuscle (Fig. 9.8) and is lined by simple epithelial cells which have microvilli forming a brush border and lots of mitochondria and the enzyme Na^+ K^+ ATpase . PCT has a wide lumen and is surrounded by peritubular capillaries.

Henle's loop is U-shaped with thick descending and ascending limbs. Initially thick (the thick part is the straight part or **pars recta** of the proximal tubule) the loop of Henle thins near the turns then thickens again as it becomes part of the distal convoluted tubule. Henle's loop has a large lumen lined by squamous epithelium but no brush border.

The distal convoluted tubule (DCT) is continued from the ascending limb of Henle's loop and forms the last segment of the nephron. It is lined by cuboidal epithelium which lacks brush border. At the vascular pole, DCT establishes contact with renal corpuscle of the parent nephron (see Fig. 9.7 a, b and 9.8).

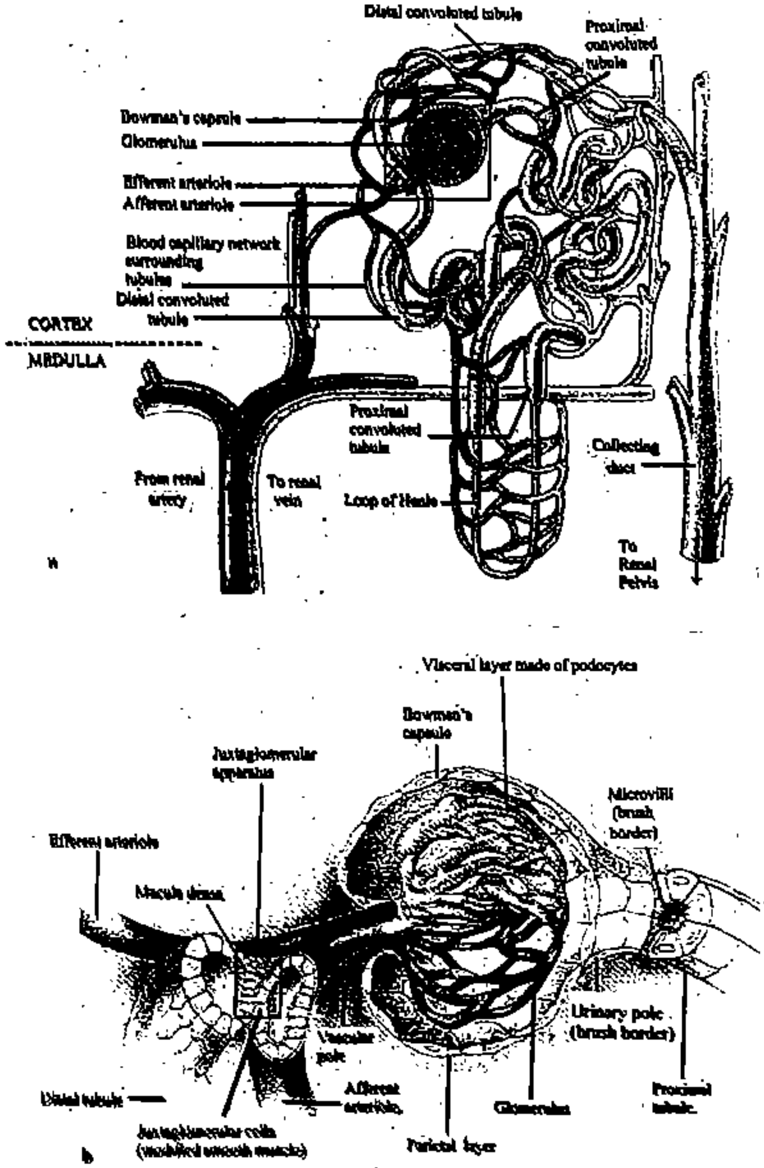


Fig. 9.7: The basic excretory unit : a) uriniferous tubule showing its relationship to its surr..unding blood vascular system, b) an enlargement of the boxed area in a showing the juxta glomerular apparatu

II) The Collecting Tubule and Collecting Duct

Urine passes from the distal convulated tubule to the collecting tubule. Collecting tubules of nephrons join together to form collecting ducts or papillary ducts of Bellini. These ducts widen near tips of renal or medullary pyramids of the kidney.

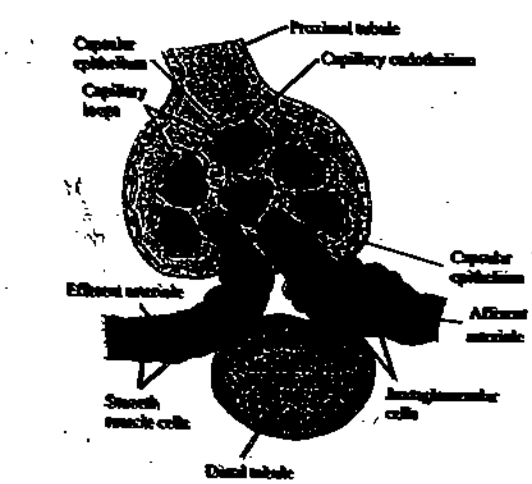


Fig.9.8: Magnified view of the Bowman's capsule showing noles the juxta glomerular cells and macula densa.

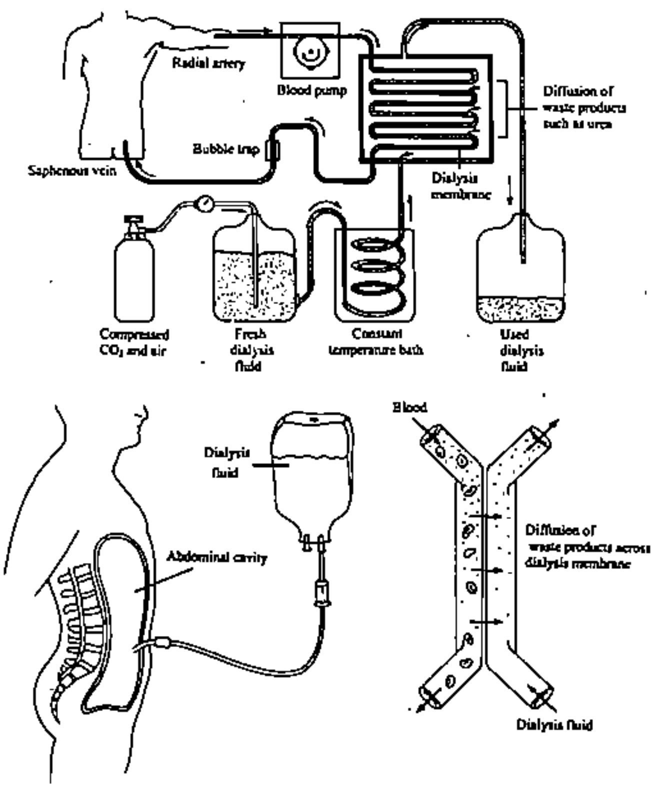
Juxtaglomerular Apparatus

The wall of afferent arteriole near the renal corpuscle is made up of modified smooth muscle cells called **juxtaglomerular cells** which contain lots of Golgi bodies. The secretion of these cells is Renin which helps to regulate blood volume. The wall of the distal tubule at this region is modified and looks dark under the microscope, hence it is called **macula densa**. The afferent arteriole juxtaglomerular cells and macula densa form the juxtaglomerular apparatus (Fig. 9.7 b).

9.5 THE KIDNEY

The kidneys are specialised for maintaining the appropriate levels of water and many solutes in the body and for eliminating wastes of protein metabolism and in carrying out osmoregulation. The kidneys of vertebrates are especially important in eliminating excess water and divalent ions and conserving solutes. In this section we will just deal with the kidney and the urinary system of vertebrates. Let us begin by examining the structure of the kidney, using the mammalian kidney as an example. This will familiarise you with the terminologies that are used to describe the anatomical complexity of the vertebrate kidney. When the kidneys fail in a human being, the person can be put on an artificial kidney temporarily. (See Box 9.1)

Box 9.1



In case of renal failure in humans, the patient has to be put on an artificial kidney. Haemodialysis or CAPD (Continuous Ambulatory Peritoneal Dialysis) are employed as the techniques. Artificial kidney is a mechanical device which can separate waste products from blood and works on the principle of dialysis. The process employed is called haemodialysis (GK: haeme – blood; lysis – 'separate'). A semipermeable membrane made of porous cellophane separates large non-diffusible particles like blood cells from small diffusible molecules of urea and other waste products.

9.5.1 Structure of Kidney

The mammalian kidney (Fig. 9.9) has a smooth external surface. The typical metanephric, mammalian kidney (Refer subsection 9.2.2) is a bean-shaped organ attached to the dorsal wall and is retroperitoneal in position. It has at its medial side a cavity or depression called hilum or hilus through which the ureter leaves the kidney. At the exit point of the ureter, a renal vein also leaves the kidney and a renal artery and nerve enters it.

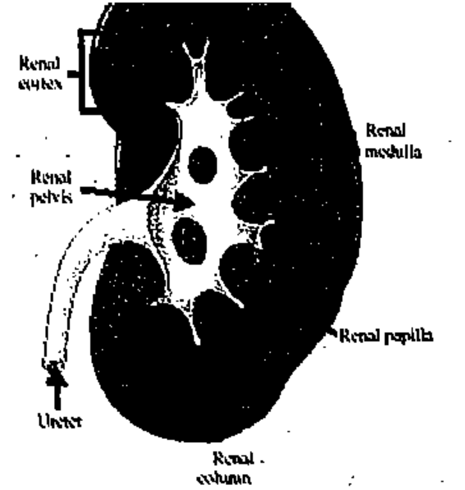


Fig. 9.9: Section of mammalian kidney showing cortex, medulla and departure of ureter.

A section of the kidney reveals that the kidney is surrounded by a capsule of connective tissue, under which lies the cortex. The renal corpuscles and the convoluted portions of the secretory tubules lie entirely in the cortex (Fig. 9.10). Immediately beneath the cortex is the medulla of the kidney which is striated in appearance and contains the loops of Henle and collecting tubules. The medulla is partially composed of large areas known as medullary pyramido or renal pyramids (Fig. 9.9). The medullary pyramids are made up of parallel tubules called medullary rays. Each **medullary** ray contains one or more collecting tubules and nephrons. Parts of the cortex between the medullary rays form the **renal column of Bertini**. The outer borders of the pyramids are subdivided into smaller units called lobules. The collecting tubules lie in the pyramids but may extend well up towards the cortex. The collecting tubules of nephrons join together to form collecting ducts or **papillary ducts of Bellini**. There ducts widen near tips of renal or medullary pyramids. The inner portion of each pyramid is in the form of a blunt papilla and projects into an out pocketing of the pelvis known as minor calyx (plural: calyces). Several minor calyces join together to enter the major calyx, which in turn opens into the renal pelvis. Urine produced by the kidney enters the minor and then major calyx. The pelvis leads to the ureter which empties into the bladder (cloaca in monotremes). Urine which is stored temporarily in the bladder passes to the outside through the urethera.

Mammalian kidneys have two types of nephrons and the ratio of each varies depending on the species (Fig. 9.10). One type **the cortical nephron**, has its glomerulus in the outer kidney cortex with a tubule that extends only in the outer region of the medulla. Cortical nephrons which predominate in the human kidney (90%) have short loops of Henle. The second type have their glomeruli in the deep cortex close to the edge of the kidney medulla and therefore are called **juxta medullary nephron**. These which predominate (100%) in mammals of dry habits have long loops of Henle that dip deeply into the medulla. Kidney tubules show tremendous variation in vertebrates.

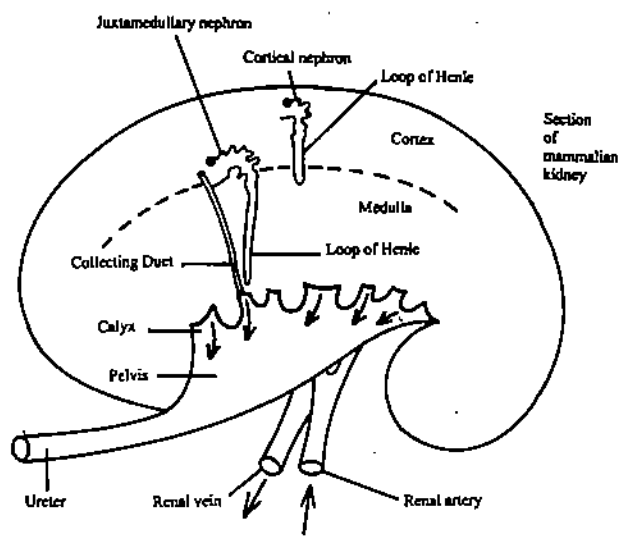


Fig. 9.10: A diagrammatic representation of section of mammalian kidney showing a cortical nephron and juxta medullary nephron.

Urinary bladder is present in all mammals. It is a muscular sac, derived from the ventral cloacal wall. The bladder narrows down and connects to the outside by the urethra. The lower ends of the ureters except in monotremes open directly into the bladder on its dorsal surface. In monotremes they open into the urethra through small papillae near the base of the bladder. At the junction of bladder and urethra there is an abundance of elastic tissue. Much of the bladder musculature in the form of bundles continues down to the urethra. Urine flow ceases when the length of the urethra is increased and diameter of lumen is reduced. In males the urethra passes through the penis to open at the tip of that organ through the external urethral orifice or urethral meatus. In females the condition varies. In some, as in rat and mouse the urethra opens independently to the outside, passing through the clitoris; in others it enters a urinogenital sinus or vestibule, which is the terminal part of the genital and urinary tract.

9.5.2 Blood Circulation in Kidney

Kidneys are highly vascular (Fig. 9.11). The **renal artery** delivers blood to each kidney. Before entering the kidney it divides into two branches – one going to anterior part of kidney and other to the posterior part. The branches give interlobular arteries which are located in the renal medullery pyramids. At corticomedullary junction, they form the arcuate artery. Fig. 9.11 shows the supply of blood to the nephron. Afferent arterioles arise from the interlobular arteries and supply blood to the glomerular capillaries. Blood passes from these capillaries into efferent arterioles. Efferent arterioles branch to form peritubular capillary network which nourish PCT and DCT. They also carry away absorbed ions and molecules.

The efferent arterioles associated with juxtamedullary nephrons form long thin capillary vessels which run straight into the medulla and loop back towards the corticomedullary boundary. These are called **vasa recta** or straight vessels. They provide nourishment and oxygen to medulla since they contain filtered blood.

Renal veins take the same course as renal arteries. Blood from interlobular vein form arcuate vessels. The interlobular vessels then converge to form renal vein through which blood leaves the kidney (Fig. 9.11).

Renal Interstitium: In both cortex and medulla, the spaces between the urinary tubules, contain cells called interstitial cells, which secrete prostaglandin.

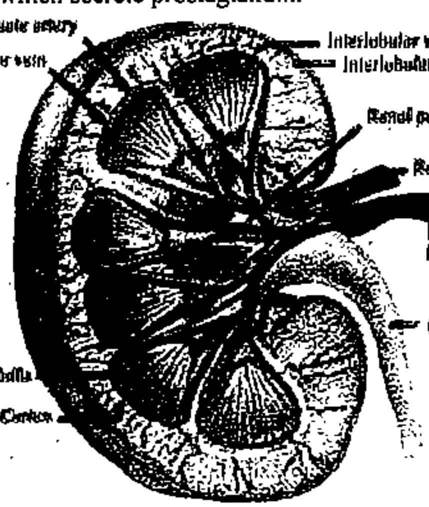


Fig. 9.11: Section of kidney showing blood circulation.

SAQ 1

Fill in the blanks with appropriate words.

i) The bench of capillaries surrounded by the Bowman's capsule is called ....

ii) A notch present on the medial side of human kidney is called ....

iii) .... artery delivers blood to each kidney.

iv) Urinogenital system is .... in origin.

9.6 PHYLOGENY AND SUCCESSION OF KIDNEYS

Comparative studies of vertebrate development indicate that the ancestral kidney called archinephros (ancient kidney) of the earliest vertebrates extended along the length of the coelomic cavity and was made up of segmentally arranged tubules, each resembling an invertebrate nephridium. Each tubule of the archinephros (also called holonephros) opened at one end into the coelom by a nephrostome (ciliated funnel) and at the other end into a common nephric duct called archinephric duct. The archinephric duct of each kidney runs along the dorsal side of the coelom and opens into the cloaca. A segmental kidney is found in the embryos of hagfishes and caecilians (Fig. 9.12 a).

Kidney of living vertebrates have developed from this primitive plan. During the embryonic life of the amniote vertebrates, the three types of kidneys pronephros, mesonephros and metanephros (Fig. 9.12) appear in succession. There is a succession of three developmental stages of kidneys, so that this is termed **'succession of kidneys'** or **'tripartite concept of kidney'** (Fig. 9.12 b). Some but not all of these stages are observed also in other vertebrate groups.

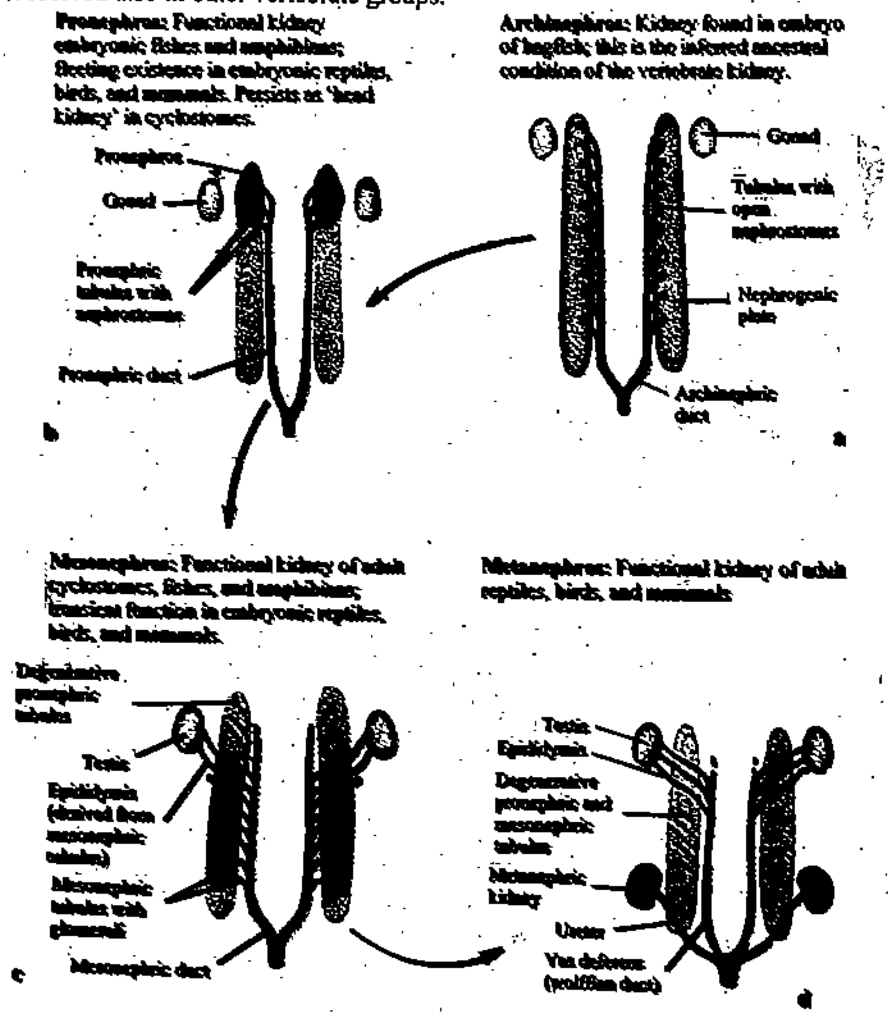


Fig. 9.12: Comparative development of male vertebrate kidney. (a) archinephros (b) pronephros (c) mesonephros (d) metanephros. (Light colour represents degenerated or underdeveloped structures and bright red the functional structures).

Pronephros

In all vertebrate embryos, the first kidney to appear is the pronephros. In it the pronephric tubules are anteriorly located and segmentally arranged. One end of these tubules open into the coelom by a nephrostome while other end opens into the archinephric duct which in this case is called pronephric duct. The two pronephric duct, one on each side extend posteriorly and open into the cloaca. Pronephros is located anteriorly in the body. Only in the adult hagfishes (anamniote) does the pronephros become part of the persistent kidney also called **"head kidney"** (Fig. 9.12 b). In all other vertebrates it degenerates during development and is replaced by a more centrally located mesonephros.

The term 'opisthonephros' of the embryonic anamniotes is not quite comparable to the mesonephros of the embryonic amniotes, even though the two are structurally similar. By convention the term mesonephros is used for the structure which appears during embryonic development in reptiles, birds and mammals.

Mesonephros

In the vertebrate embryo, tubules arising from the middle of the nephric ridge constitute the mesonephros (Fig. 9.12 c). Mesonephros is a sometimes known as the **Wolffian body**. Mesonephric tubules are segmentally or metamerically arranged in the beginning but as more tubules rise this metamerisms is lost. The tubules open into an already existing pronephric duct and no new duct is formed. When the pronephros degenerates the persistent pronephric duct is called mesonephric duct or the wolffian duct. The mesonephric duct may enlarge at its posterior end to form the (i) urinary bladder for storage of urine or (ii) the seminal vesicle for storage of sperms.

The term archinephric duct is applied to the kidney duct in anamniotes. The name wolffian duct is given to the duct in amniotes which forms in connection with the pronephros and mesonephros.

The mesonephros is the functional kidneys of **embryonic** amniotes (reptiles birds and mammals) and contributes to the **adult** kidney (called an opisthonephros) in anamniotes of jawless vertebrates, fishes and amphibians (Fig. 9.12 and Fig. 9.13).

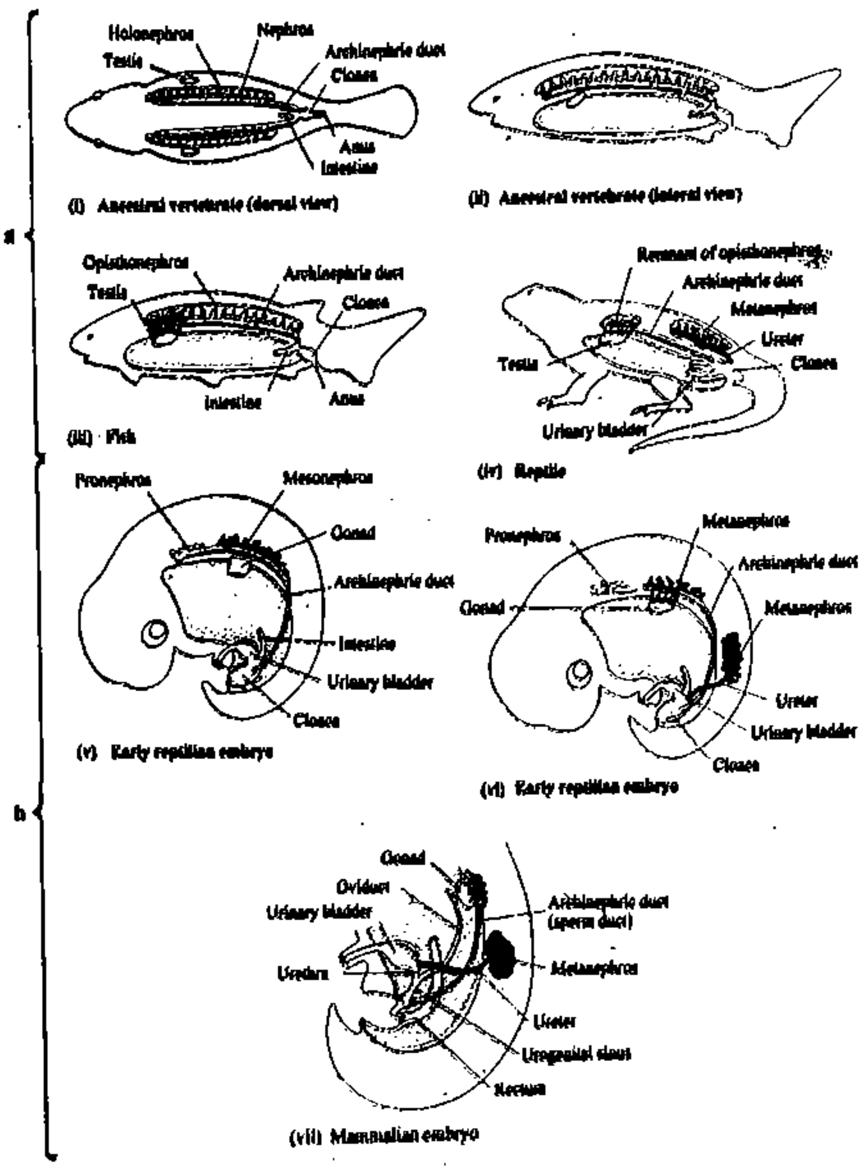


Fig. 9.13: Vertebrate excretory systems (a) comparison of the evolution (i-iv) and (b) embryonic development (v-vii) of the vertebrate kidney and its duct.

Mesonephros may persist after birth in reptiles, the egg laying mammals (Prototheria) and pouched mammals (the metatheria). In the adult amniotes, the functional kidney is the **metanephros**. As soon as the metanephros becomes functional, Wolffian duct (mesonephric duct) degenerates in females and persists in males as urinogenital duct.

Parts of the male genital ducts such as epididymis and ductus deferens as well as the seminal vesicles develop from mesonephric tubules.

Metanephros

During embryonic development of amniotes – (the reptiles, birds and mammals) the pronephros, mesonephros and metanephros appear in succession. The adult kidney of amniotes is the metanephros (Fig. 9.12 d). The metanephros develops as the posterior part of the nephric ridge and during development, it gets displaced anteriorly and laterally. The displaced metanephros develops its own new duct, the metanephric duct or the ureter. The dilated tip of metanephric duct becomes the renal pelvis (Fig. 9.9).

The metanephrosis is distinguished in several ways from pronephros and mesonephros. It is more caudally (posteriorly) located and is a much larger more compact structure containing a very large number of nephric tubules. It is drained by a new duct, the ureter, which develops when the old archinephric duct is relinquished to the reproductive system of the male for sperm transport. Thus the three successive kidney types – prosnephros, mesonephros, metanephros succeed each other embryologically and to some extent phylogenetically in amniotes (Fig. 9.13).

9.7 FUNCTIONS OF URINARY SYSTEM

The urinary system has several functions (Fig. 9.14):

1. The kidneys produce urine which contains metabolic waste products such as ammonia or urea or uric acid etc depending on the animal group. Urine passes through ureters to the bladder. It is temporarily stored in the bladder and is then released to the outside via urethra through urinary or urinogenital opening. Urine is formed by filteration, reabsorption and secretion (Fig. 9.14 a).

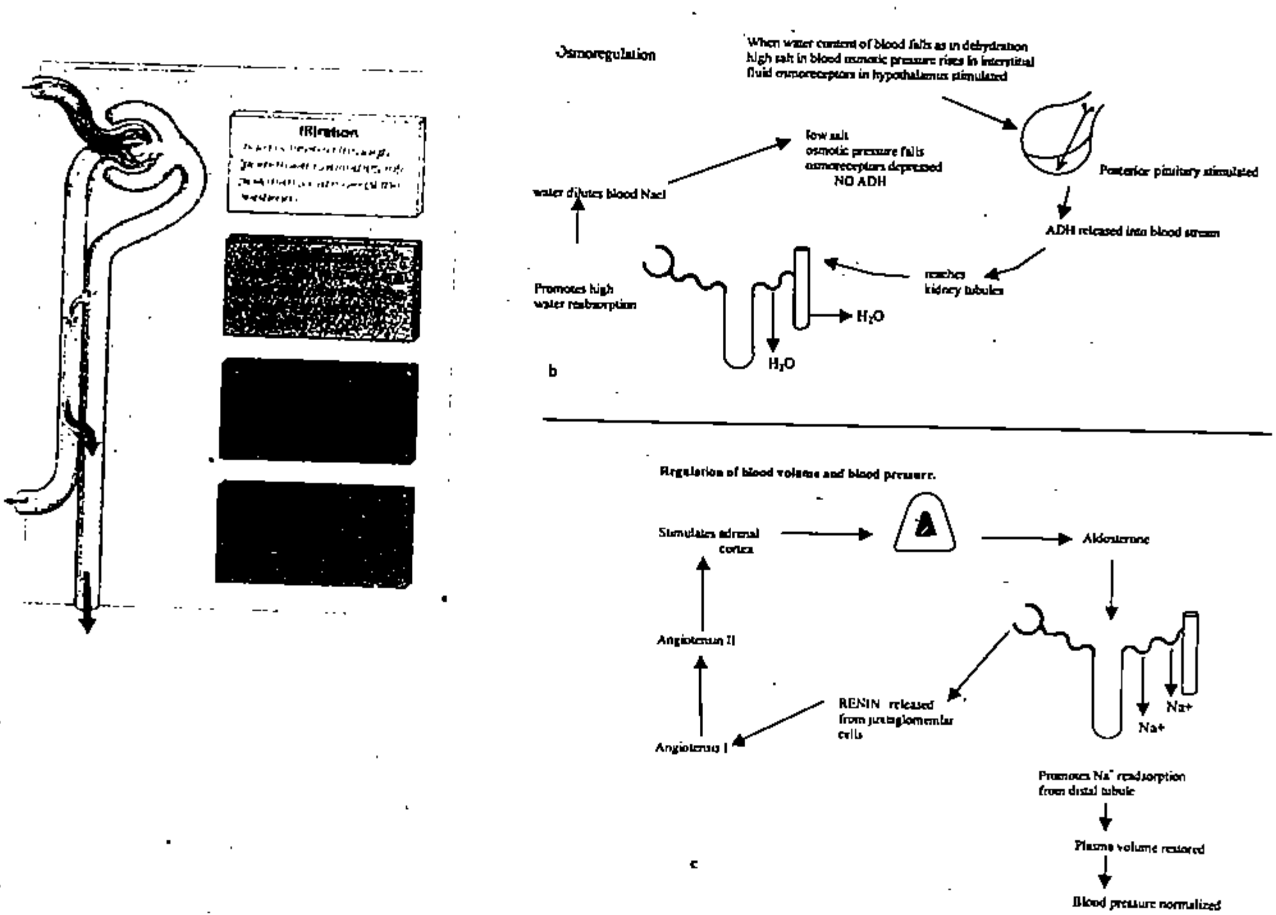


Fig. 9.14: Functions of urinary system (a) removal of metabolic wastes by filteration, reabsorption and secretion (urine formation) (b) osmoregulation (c) regulation of blood volume.

2. Kidneys regulate fluid and electroyte balance and hence serve in osmoregulation and water balance (Fig. 9.14 b).
3. Kidneys produce an enzyme **renin** which has a function in regulating blood pressure (Fig. 9.14 c).
4. The cortical cells of kidneys secrete a hormone **Erythropoietin** which is associated with production of blood cells. In case of loss of blood or hypoxia, erythropoietin formation is stimulated. Erythropoietin acts on bone marrow to promote formation of erythrocytes.
5. In certain male vertebrates, apart from carrying urine, the ducts from kidneys also carry sperms and are thus called urinogenital ducts. In female vertebrates, ureters act only as a passage for urine.

SAQ 2

i) Name the

a) Functional unit of the kidney.

....

b) Tuft of capillaries surrounded by renal capsule.

....

c) U-shaped loop between PCT and DCT.

....

d) Collecting duct.

....

ii) State the parts of the uriniferous tubule in its proper sequence.

iii) Tick the appropriate functions of the kidney.

a) Removal of metabolic waste.
b) Osmoregulation.
c) Transmission of gametes.
d) Secretion of renin and erythropoietin

iv) Match the following in column A with terms in column B.

	Column A		**Column B**
a)	capillaries of efferent arterioles	i.	Prostaglandin
b)	Renal interstitium	ii.	Juxtaglomerular apparatus
c)	macula densa	iii.	Red blood cells
d)	erythroporetin	iv.	vasa rectae
		v.	Sperms

9.8 VARIATIONS IN THE URINARY SYSTEM PLAN

You have already learnt in section 9.7 of this unit that the two major functions of the kidneys are (I) excretion of metabolic wastes and (ii) maintenance of water and electrolyte balance (osmoregulation). It has been observed that apart from the small variations in structure and function of kidneys that have evolved in the urinogenital systems of vertebrates due to living in different habitats the pattern of the renal system is fairly uniform and apparently simple both in the anamniotes and amniotes. However, study does show that there are great differences from group to group in the construction of the urinary system in different vertebrate groups these namely Agnatha, Fish, Amphibia, Reptiles and Mammals. This is due to difference in habitat.

9.8.1 Habitat Related Structural Variations

Vertebrates evolved in water. Some emerged on land. Life in freshwater and in the sea offered different problems of osmotic concentration. Since kidneys were the organs for osmoregulation, the kidney tubules underwent structural modifications to meet the regulatory needs of each vertebrate group in its own specific environment.

Kidneys of vertebrates are confronted with two kinds of problems:

1. **Water elimination** in the fresh water organisms and
2. **Water conservation** in the marine and terrestrial organisms.

Fresh Water Organism

In fresh water organisms, kidneys have (i) large well developed glomeruli which produce large volumes of glomerular filterate. (ii) Prominent distal tubules absorb salts and amino acids from the filtrate to retain them within the body and also absorb much less water. Lots of water is eliminated in the urine.

Marine Organism

Marine organisms face dehydration as the outside environment (sea water) has greater osmotic concentration. So water tends to move out of the body of the marine organism. The structural modifications in these organisms is adapted to retain water and are:

i) Loss of glomeruli (aglomerular kidney).
ii) Shortening or loss of distal segments of kidney tubules which are responsible for reabsorption of salts. Both the above modifications cause water retention and increased salt excretion so that homeostasis is maintained in these organisms.
iii) Marine fishes have extra renal structures for excretion of salts. Elasmorbranchs (cartilaginous fishes) have **chloride** secreting glands on the surface of gills and also rectal glands which secrete salts. Marine reptiles and birds have **salt** excreting – paired large nasal glands located in a bony socket with duct opening into nostril. Refer to unit 5 of LSE-05.

Terrestrial Organism

Terrestrial organisms also need to conserve water. Snakes have aglomerular kidneys for this purpose. In mammals, the Henle's loop of the nephron concentrates the urine by reabsorbing water from it. The length of loop of Henle's varies with the environment of the organism. For example beaver which have lots of water in their immediate environment have short, Henle's loops. Both long and short loops of Henle are present in rabbit and humans which have an intermediate capacity for concentrating urine (see Fig. 9.6 again). The sand rat, on the other hand which is found in arid conditions has very long loops of Henle's in order to reabsorb as much water as possible and so excretes a very concentrated urine.

9.8.2 Variations in Urinary Systems of Vertebrates belonging to Different Groups

The vertebrate kidneys themselves are varied in structure; the ducts vary as does the urinary bladder. These variation are due to two major causes: (I) The kidney unlike many organs must start functioning at an early stage of development in order to remove the metabolic wastes of the rapidly growing embryo. The kidney is however, subject to modification or replacement in the later developmental stages and adult existence (ii) as the gonads (testis and ovary) lie adjacent to the kidneys. These organs specially the testis tend to take over part of the tubes and tubules of the urinary structures as a conducting system for their products. As a result of this the urinary organs have been markedly modified in most vertebrate groups. In this subsection we will survey the construction and hence normal variations of urinogenital systems in various vertebrate groups (Fig. 9.15 a to g).

Agnatha (Cyclostome) or Jawless Vertebrates

The adult kidney of jawless vertebrates lamprey *(Petryomyzon)* is opisthonephros or Mesonephrons and the tubules are derived from the posterior mesomere. The tubules have lost all connection with the coelomic cavity but form a close association with the glomerular blood vessels at the blind-ended kidney capsule. The absence of connection between kidney tubules and coelom makes it evident that "coelomic fluid filter" was replaced by "blood filter system" early in vertebrate evolution. This may be because possibly coelomic fluid pressure is too low and variable to keep up with the fluid balance demands of vertebrates which have high metabolic rates.

In adult lamprey the kidney is elongated and flattened. The kidneys lie on either side of the mid-dorsal line and each is suspended by a mesentery like membrane. The archinephric duct courses along the free edge of the kidney. The pronephros exists above the mesonephros as the non functional "head kidney".

In the adult hagfish the opisthonephros consists simply of a series of tubule arranged in a segmental manner along most of the length of the trunk, each tubule draining directly into the archinephric duct or pronephros. In hagfish adults the archinephros becomes modified to form a persistent head kidney. The remainder of the kidney, however is separated from the head kidney and becomes the opisthonephros. The hagfish has only forty glomeruli, each connected to the collecting duct (archinephric duct) by a small neck segment. (Fig. 9.15 a)

Fish

The kidneys of fishes are opisthonephric or mesonephric and though they exhibit great variation in shape, they are however fundamentally similar in structure (Fig. 9.15 b and c). In all species they are dorsal in position. In some species they extend almost the entire length of coelom. In other fishes they may be more voluminous and the two sides may show various degree of fusion. In still others they are short and confined to the posterior part of the body cavity. Peritoneal funnels are only retained in a few forms, notably *Amia*, *Sturgeons* and certain elasmobranchs. In some marine teleosts no external or internal glomeruli are present, and so such kidneys are called as aglomerular kidneys.

Generally the kidneys of male fish are longer than those of females, since the anterior ends in male are appropriated by the reproductive system. In males of some groups small modified kidney tubules now called efferent ductules, connect the testes with the archinephric duct. This archinephric duct is termed as the ductus deferens and serves as the passage for sperm transport. It may, in addition continue to carry wastes. However, in such cases there is a marked tendency for the posterior portion of the opisthonephros to take over the greater part of the excretory function, with one or more accessory ducts developing which are responsible for carrying wastes directly to the cloaca or to the outside. In Selachians, Chondrosteans and some others the conncection of the testis and archinephric duct usually occurs at the anterior end of the opisthonephros. In teleosts however the testes and opisthonephric kidneys are not connected. In them the duct from the testes either join the archinephric ducts near the posterior ends or open independently to the exterior.

In some fishes the dilation of the archinephric duct may form a bladder like enlargement for temporary storage of urine (Fig. 9.15 c). In those fish where archinephric duct functions as ductus deferens, enlargements called **seminal vesicle and sperm sac** may develop to serve as temporary storage places for spermatozoa.

Amphibians

The amphibian kidney is opisthonephric or mesonephric and the anterior tubules of the opisthonephros functions as the sperm duct. The primitive archinephric type of kidney is found in the larval caecilians of the amphibians. The kidney is similar to the larval kidney of the hagfish and consists of the distinct metameric arrangement of kidney tubules, renal corpuscles and nephrostome. In the adult the kidney is opisthonephros. The opisthonephros is lobulated and extends the greater part of the length of the coelom. In many larval amphibians a small head kidney with peritoneal connection may be present but it does not persist in the adult.

The urodele amphibians have opisthonephric or mesonephric kidneys that are similar to the elamobranchs (cartilaginous fish). The kidneys have two regions (i) anterior narrow region which in males is more genital than urinary in function and is referred to as epididymis and (ii) posterior expanded portion which is the main part of the opisthonephros and is called the 'kidney proper'. The archinephric ducts run along the lateral edge of the kidney a short distance from the kidney proper. Numerous collecting ducts or tubules which are more developed in males than females join at intervals to the archinephric duct from the opisthonephros. The archinephric duct now called mesonephric ducts serves in the male as a ductus deferens as well as transports wastes but in females is concerned only with transporting wastes. The mesonephric ducts in both sexes open into the cloaca on either side, through a small papillia (Fig. 9.15 d).

In the anurans the opisthonephric kidneys are dorsoventrally flattened have a more posterior concentration of tubules. They are confined to the posterior part of the abdominal cavity and so are retroperitoneal and dorsally located. Unlike in the urodeles the anterior and posterior regions of the kidney are not clearly distinguished. An yellowish, orange adrenal gland is closely attached to the ventral side of the kidney. In females the kidneys and reproductive system have no connection to each other. However, in males they are intimately connected. In males certain anterior kidney tubules become modified into efferent ductules that connect the testis to the kidney while the mesonephric duct serves to transport spermatozoa as well as urinary wastes. In these animals unlike the urodeles the archinephric duct is located within the kidney along its lateral margin. It leaves the opisthonephros near the posterior end and passes to the cloaca (Fig. 9.15 e).

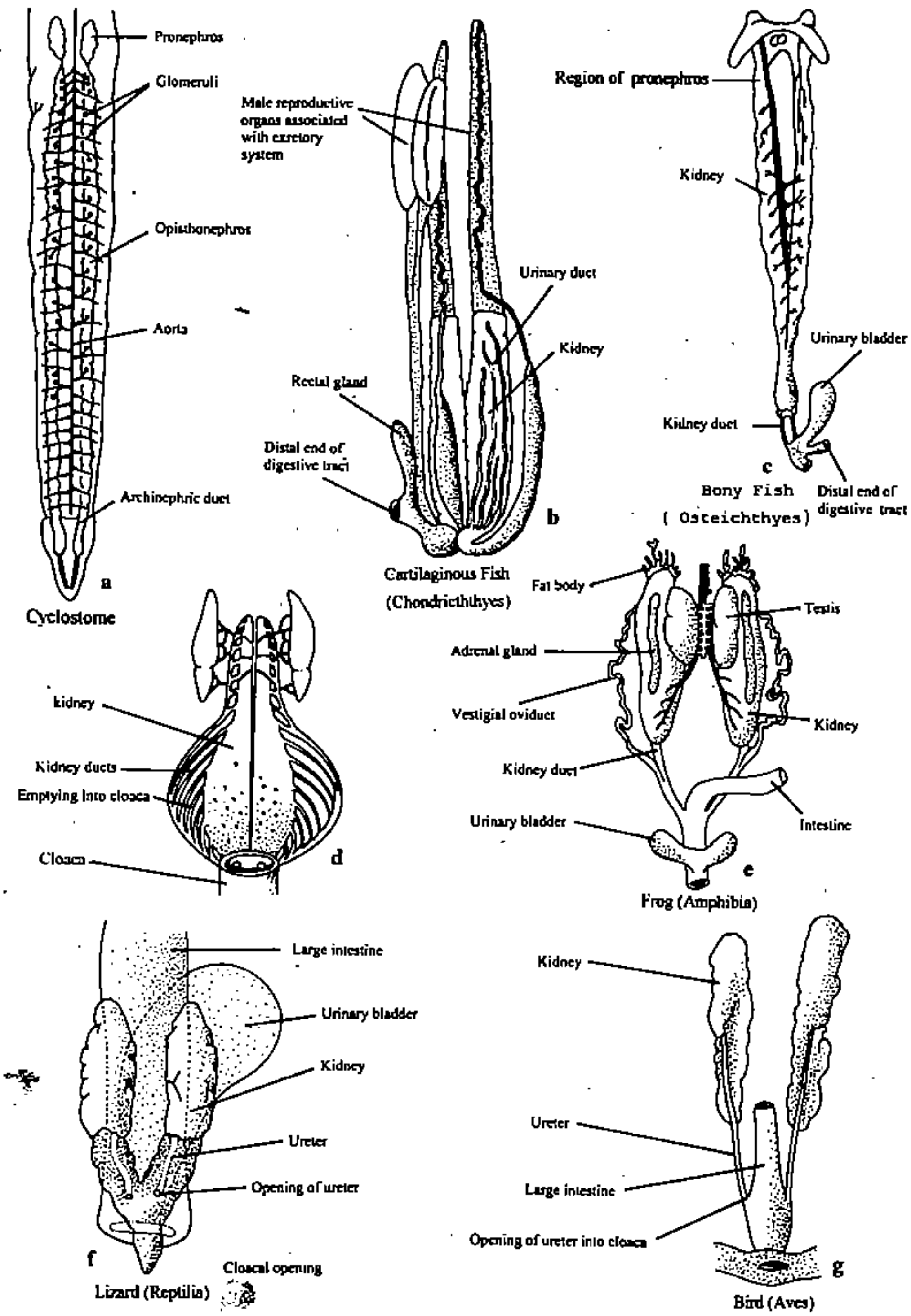


Fig. 9.15: Urinary systems of vertebrates (a) cyclostome (b) cartilaginous fish (c) bony fish (d) salamander (amphibian), (e) frog (amphibian), (f) lizard (g) bird.

A thin walled, bilobed bladder which is thought to be endodermal in origin and homologous with the urinary bladder is present. It is derived from the cloacal wall and opens into the amphibian cloaca a short distance beyond the openings of the archinephric ducts. The archinephric duct and bladder are not connected directly, and so the thin, watery urine first passes directly into the cloaca.

Reptiles

Reptiles are the first completely terrestrial vertebrates adapted to fresh water, estuarine and even marine habitats. Kidney in reptiles are metanephric. In reptiles the kidneys are usually small and compact with lobulated surface and confined to the posterior half of the abdominal cavity, generally to the pelvic region (Fig. 9.15 f). The posterior part of the kidney narrows down on each side and in some lizards the hind parts may even fuse. The degree of symmetry varies in reptiles especially in case of snakes and limbless lizards who due to their elongated body shape possess excessively lobulated, long, narrow kidneys; often one kidney may be entirely posterior to the other.

In snakes and crocodilians a urinary bladder is absent. Most turtles and lizards however have well-developed and usually bilobed bladders which open into the cloaca. Except in turtles the ureters open separately in the cloaca. In turtles the ureters are connected to the bladder. In some turtles a pair of accessory urinary bladders is also connected with the cloaca. These functions as accessory organs of respiration. In females they may be filled with water, which is used to soften the ground when they prepare their nest.

Living reptiles have only about a few thousand nephrons in which loops of Henle are absent and renal corpuscle are poorly developed. The glomeruli are small in order to conserve water.

Birds

The kidneys in all birds are situated in the pelvic region of the body cavity and their posterior ends are frequently united. They are complex, lobed structures with short ureters, which open independently into the cloaca (Fig. 9.15 g). The kidneys contain some mammalian-like kidney tubules with loops of Henle (some short and some long loops) that parallel collecting ducts. Birds mostly, however have reptilian type tubules that do not have loops. Urinary bladder is absent in all birds except for ostrich. Urinary wastes are mainly in the form of uric acid and are eliminated via the cloaca along with the faeces. The ability of kidney to concentrate urine and thereby conserve water is not as good as in mammals, but is better than in reptiles. The cloaca and even the posterior large intestine may further modify and concentrats urine by resorption of water and ions.

The mammalian urinary system has already been dealt is the previous sections. Refer subsection 9.2.2, sections 9.4, 9.5 and fig. 9.4 for details.

SAQ 3

i) Tick the correct alternative:

a) Marine organisms possess

1) short distal tubule
2) long distal tubule
3) very long distal tubule
4) short proximal tubule.

b) Snakes have aglomerular kidney in order:

1) to conserve water
2) to remove water
3) to conserve protein
4) to remove protein.

c) The desert kangaroo rat in order to combat dehydration :

1) has long Henle's loop for reabsorption

2) utilises metabolic water
3) eats waterladen vegetation
4) all of the above.

9.9 THE GENITAL SYSTEM

The genital system is the reproductive system and is made up of the **gonads, gonoducts** and **genital openings**. The gonads as you have read are mesodermal in origin. They are called testes (sing testis) in males and ovaries in female. Both the testes and the ovaries produce gametes and secrete hormones and are termed **primary sex organs.**

The gonads are usually paired structure, though unpaired gonads occurs in some forms such as cyclostomes (jawless fish), certain fish as well as female birds of most species. This is the result of either fusion of paired gonads or the unilateral degeneration of one gonad. Evidence of metamerism of gonads in chordates is only found is the primitive amphioxus – cephalochordate.

You will recall that ananmniotes include cartilaginous and bony fishes and amphibians while amniotes include the reptiles, birds and mammals.

In vertebrates the ovaries and testes come to be attached to the dorsal body wall by mesentery like bands of tissue, the **mesorchium** in the male and **mesovarium** in the female. In most vertebrates the gametes (ova in females and spermatozoa in males) produced by the gonads are transported outside the body by means of the deferens ducts (vas deferens) in males and by oviducts in females. In a few forms like cyclostome ducts are absent in both sexes. Eggs and sperm escape from the body cavity through genital pores. The deferent ducts as you will recall are usually the mesonephric or the Wolffian ducts which also serve to transport urinary wastes from the opisthonephric or mesonephric kidneys in those animals in which these kidneys function either during embryonic or adult life (in male anaminotes). In amniotes in which the metanephros is the functional kidney and in which the mesonephros degenerates, the Wolffian duct of the male on each side persists to become the ductus deferens (male genital duct).

In most vertebrates in both sexes when the reproductive ducts first develop they open posteriorly into the cloaca. This relationship persists throughout life in many vertebrates, but in others the cloacal region becomes modified so that the reproductive ducts either open separately to the outside or in the males atleast, join the excretory ducts to emerge by a common opening or urinogenital opening.

In many aquatic vertebrates fertilisation is external while in all terrestrial vertebrates except for anuran amphibians and even in many aquatic species it is internal. In some animals transport of spermetazoa from male to female is brought about by apposition of the cloaca (cloaca:sing) of the two sexes in most animals, however, males have copulatory organs which are used in an intromittent manner to deposit the spermatazoa into the reproductive tract of the female. Various types of copulatory organs are found in the vertebrate groups.

In both sexes all the structures or organs which help to bring the germ cells or products of the primary sex organs together are termed as **accessory sex organs**. These include the reproductive ducts, associated glands and intromittent organs. **Secondary sex characters** are indirectly concerned with sex but play a part in the reproductive scheme. Sexual differences in such secondary sex characters like plumage, body size and strength, as well as vocal apparatus are only indirectly related to reproduction.

Cloaca (Roman term for sewer) is present in a variety of vertebrates. It occurs as a ventral pocket, at the back end of the trunk of the animal, and opens to the exterior. The orifices of the digestive, genital and urinary systems open into it. The cloaca appears to be a primitive vertebrate feature. Primitively, the gut, urinary duct and genital ducts all terminate in a common, short chamber, the cloaca that empties to the outside.

Most tetrapods (amphibians, birds reptiles, egg laying mammals) have retained a distinct cloaca, although most mammals have not.

SAQ 4

Fill in the blanks with appropriate words.

i) The primary sex organs are the .... and ....

ii) Mammary glands are .... sex organs.

iii) .... duct becomes the ductus deferens.

iv) The ....are attached to the dorsal body wall by the mesovarium.

v) When reproductive ducts first develop, they open into ....

vi) The tissue that suspends the testis from the dorsal body wall is called ....

vii) Copulatory organ is an .... organ.

9.9.1 Embryonic Origin of Gonads and Gametes

The sex of an individual depends basically upon the nature of its chromosomal inheritance. The early development of the embryo is mainly because of the organisation already present in the unfertilised egg, the influence of the sperm and the hereditary features it introduces, all which are not obvious until a relatively late stage. We thus observe that for some time the sex organs of the embryo remain in an **indifferent stage** during which the development of the gonads and their ducts proceed considerably far without any indication of whether the embryo would develop into a male or female. Finally the embryo develops its specific sex features, presumably due to hormonal activity.

In amphibian males, the cloacal glands are present which secrete scent in order to attract the female for mating. In them clocal glands also secrete a jelly like substance which holds together a package of sperms which is called **spermatophore**. The female picks up the spermatophore in her cloaca for fertilisation of her eggs.

Embryonic origin of Gonads

Maleness in chordates develop basically on a female plan. Both the gonads and kidneys develop from the intermediate mesoderm (mesomere) of the embryo (Fig. 9.16 a).

In vertebrates there is a great difference in the rapidity with which different organ systems develop. The nervous system for instance, grows very rapidly in early stages while the genital organs are one of the slowest to develop. The gonads make their appearance only at a stage when most of the other organ systems have been blocked out and the coelomic cavities are well developed. Paired longitudinal swellings the genital ridges develop along the roof of the coelom, medial to the embryonic kidney and on either side of the dorsal mesentery (Fig. 9.16 b). These ridges gives rise to the gonads.

The gonads developing from such ridges are elongate to begin with but often in later stages become short and compact with a usual tendency for anterior concentration of tissue. The germinal epithelium of the ridges are continuous with the mesodermal lining of the rest of the coelom and form the more important structural parts of the gonad.

Mesenchyma lying beneath the epithelium forms the connective tissue and in higher vertebrates at least gives rise to the special interstitial tissues that are thought to be a source of gonad hormone.

Before the end of the indifferent stage, the gonad generally develops in many cases into a swollen structure which extends out into the coelomic cavity from its dorsal wall in the neigbourhood of the developing kidney and is often supported by a special mesentry. From the germinal epithelium that cover the gonad surface, finger like structures called the **primary sex cords** grows inward into the underlying mesenchyma of the gonad (Fig. 9.16 b).

The gonads of both sexes initially contain germ cells. These germ cells do not arise in the genital ridge nor even in the adjacent mesoderm. In fact they do not arise in the embryo at all. They first rise in remote sites outside the embryo in the extra-embryonic endoderm. From here they migrate to the indifferent gonad where they get located permanently. In females the germ cells establish residence in the cortex while in males they get located in the medulla.

As gonads mature they enlarge and are pushed downwards where they lie suspended by a dorsal mesentry termed **mesorchium** in males and mesovarium in females.

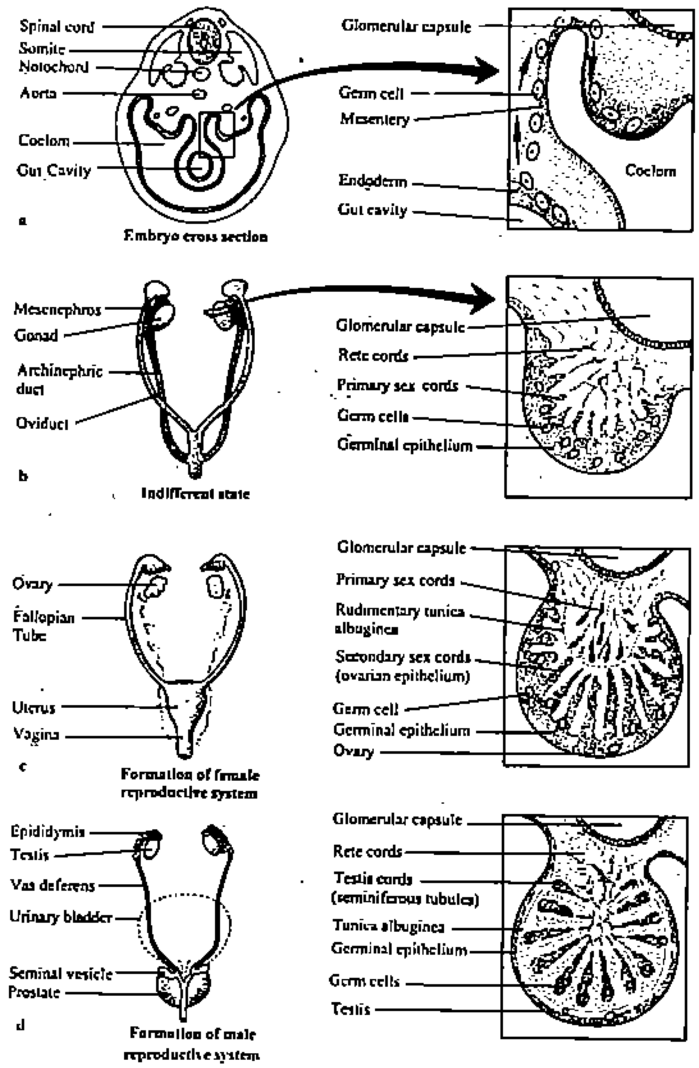


Fig. 9.16: Development of gonads in vertebrates showing modification of the indifferent gonad into ovary or testes. The gonadal structure, whether primary cortex or medulla is derived from embryonic mesoderm (a) the primodial germ cells which give rise to spermatozoa or egg are initially located in the beginning, within the embryonic endoderm and then migrate through the mesenteries during development into the indifferent gonad (b) the germ cells arrange themselves between the medullary and cortical cells of the indifferent gonad (c) the cortical tissues predominate in the formation of the ovary while (d) the medullary tissues predominates in the for motion of testes.

9.9.2 Functions of the Genital System

- The primary function of the genital system is production of gametes, the sperms and the eggs respectively by the male and female gonads under the influence of hypothalamo – pituitary hormones.
- Gonoducts of the genital system transmit gametes to the place most suitable for fertilisation. It may be water in which eggs are laid by the female and sperms dropped on them by the male (external fertilisation) or sperms may be discharged just as far into the female tract where egg and sperm can meet (internal fertilisation).
- Transport of sperms into female body is specially performed by accessory reproductive organs or intromittent organs, to ensure fertilisation.
- The female gonoduct is different from that of the male. It is specialised for retention of: (i) egg (in case of egg laying or **oviparous** organisms), e.g. fish, amphibia, reptiles and binds (ii) the fertilised egg with the developing embryo (in case of **ovoviviparous** organisms which lay the egg after embryo has developed to a certain stage) e.g. certain snakes or (iii) the developing embryo (in case of **viviparous** organisms which deliver full fledged young ones) e.g. mammals.

- Gonads secrete sex hormones which are steriod in chemical nature. The male hormone secreted by the testis is **testosterone**. The female hormones are mainly **estrogen and progesterone**. The sex hormones control the production of secondary sex characters, difference in structure, physiology and behaviour by which male and female can be distinguished. The secondary sex characters are especially prominent during breeding season.

SAQ 5

Choose the correct alternatives from the parenthesis.

i) Reproductive organs develop from the embryonic (mesoderm/ectoderm) germ layer.
ii) The finger like process developing from germinal epithelium are called (primary/secondary) sex cords.
iii) Organism that lay eggs in which the embryo develops are called (viviparous/ oviparous).
iv) Mammals are (ovoviviparous/viviparous).
v) Estrogen is a (male/female) hormone.

9.9.3 Genital System of Protochordates

Branchiostoma is a dioecious chordate. The gonads of both male and female are similar in arrangement, with distinctly segmented gonads (i.e. is many gonads) that are arranged below the muscle segments or myomeres (Fig. 9.17 a). Approximately 26 pairs of gonads on either side of the atrium also called peribranchial space project into it from the inner surface of the body wall. The most anterior gonads are located around the middle of the pharyngeal region. Each gonad (or segment) is a hollow sac which is lined with an (1) outer coelomic epithelium and an (2) inner germinal epithelium. Gametes develop within the cavity of the gonad and are expelled through the wall into the artrial cavity by means of temporary pores. From this cavity the gametes pass directly to the outside through the atriopore. In these animals fertilisation is external. Overall, the reproductive organs of the *Branchiostoma* are not similar to those of vertebrates. The ovarian follicle also appears to differ from the vertebrates because a follicular epithelium is absent.

Urochordates (Tunicates) are hermaphrodites, that is, they have both sex organs in the same individual. In other words they are hermaphrodite. Ducts from gonads enter the atrium, a space surrounding the viscera (organs of the body) and then to the outside by the atriopore (Fig. 9.17 b).

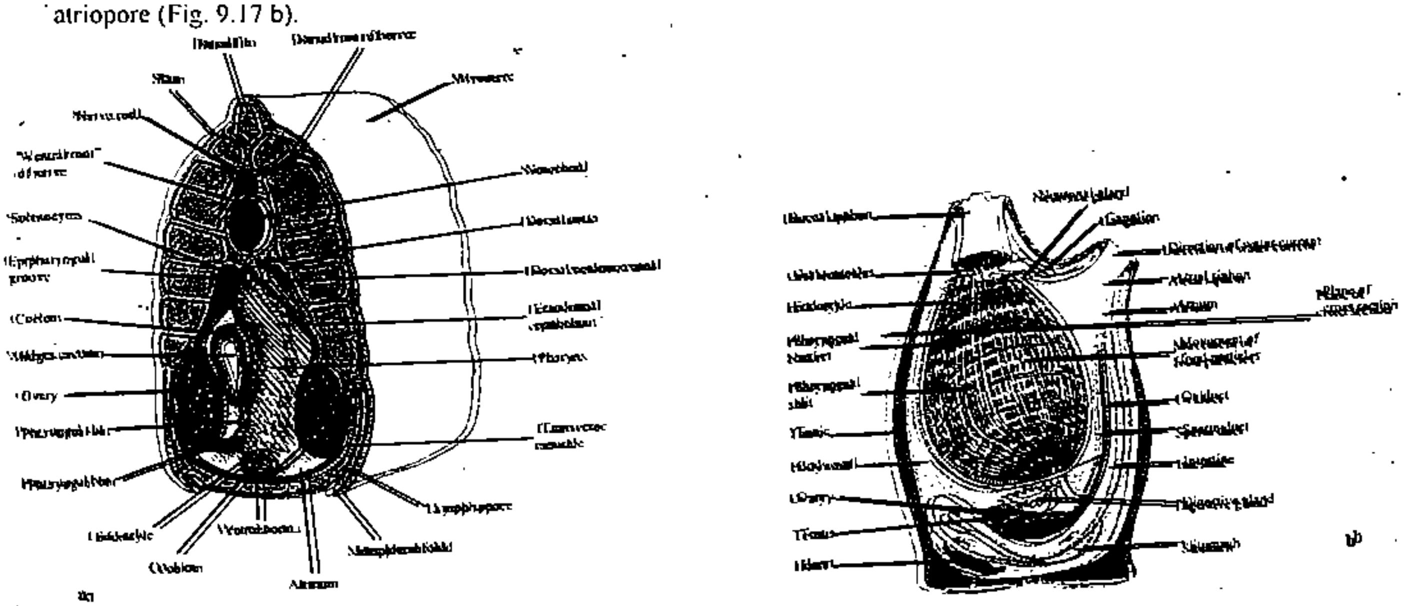


Fig. 9.17: Genital systems of protochordates (a) cross section of *Branchiostoma*, showing segmental gonads (b) saggital section of a tunicate showing its reproductive systems.

9.10 MALE GENITAL SYSTEM OF VERTEBRATES

The genital system of male vertebrate composed of

1. Paired gonads – testes (singular - testis)
2. Paired urinogenital ducts

3. Single urinogenital opening

Let us begin our study of the male genital system with the anatomy of the testes.

9.10.1 Testes

Testes of all vertebrates have similar construction. The typical testis is a compact organ whose shape however varies in members of different vertebrate classes. In some forms, testis is composed of: (i) elongated tubules called the seminiferous tubules in which the primordial germ cells develop into mature sperm and which connect by means of ducts to the outside e.g. anuran amphibians and amniotes. (ii) in others, the testes consists of rounded cavities called seminiferous ampullae or spermatic ampullae or spermatic cysts – e.g. cyclostomes, fish and urodeles. Both the rounded ampullae and elongated tubules, at first consist of solid masses of cells which later develop the cavities or lumina.

Seminiferous Tubules

The testes in anurans, amniotes (reptiles, birds and mammals) and even some teleosts, are composed largely of seminiferous tubules which are coiled tubes and whose walls contain cells that produce sperm (Fig. 9.18 a).

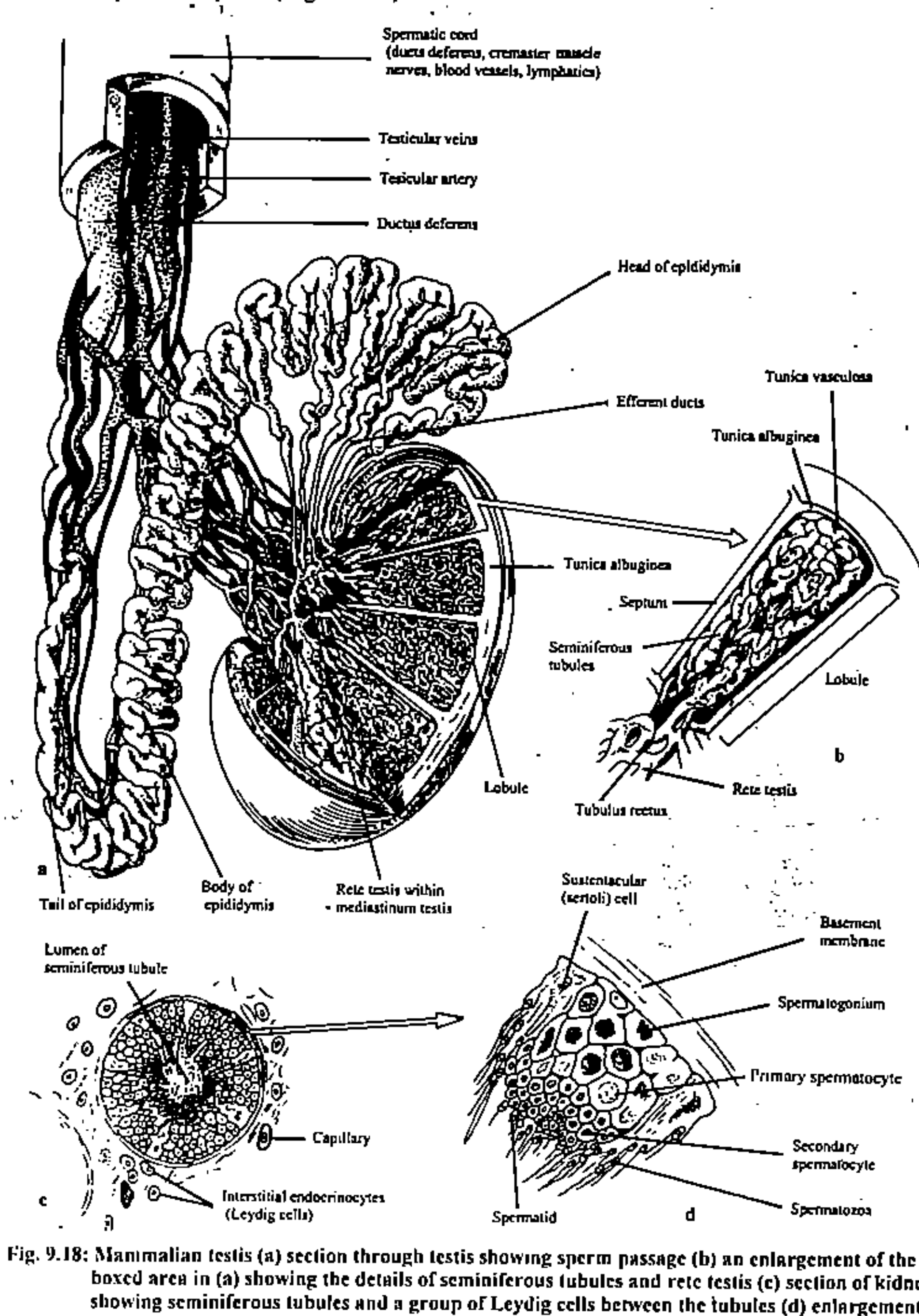


Fig. 9.18: Mammalian testis (a) section through testis showing sperm passage (b) an enlargement of the boxed area in (a) showing the details of seminiferous tubules and rete testis (c) section of kidney showing seminiferous tubules and a group of Leydig cells between the tubules (d) enlargement of the boxed area in (c) showing developing sperms and sertoli cell.

The testes are surrounded by a capsule, the **tunica albuginae.** Seminiferous tubules may constitute upto 90 per cent of the testis. The tubule walls consist of a multilayered germinal epithelium containing spermatogonic cells and **Sertoli cells** which are nutritive in function and in which the heads of the maturing sperms are embedded. Sertoli cells probably also produce, most of the fluid in which the sperms are suspended, while leaving the testis by means of active filteration from blood plasma (Fig. 9.17 b). Seminiferous tubules may end **blind** at the tunic or outermost tissue layer, and pass toward the centre, becoming tortuous, that is, full of twists and bends, before emptying into a system of collecting tubule, the **rete testis**. Such an arrangement is characteristic of frogs. In certain amniotes like the rat for example the tubules may be open ended, running a zig-zag course from the rete to the periphery and back again. The average length of such tubules is 30 cms, and they seldom communicate with each other. In many mammals, the tubules are grouped into lobules separated by connective-tissue septa, or walls. This arrangement allows the packing in of an extensive quantity of germinal epithelium into a small space (Fig. 9.18 a). The tubules are inconspicuous and epithelium is inactive in immature males and between breeding season in the adult males of those species which have specific breeding seasons.

In some species however, spermatogenesis or production of sperms in adult males proceed at a variable pace throughout the year. An active epithelium may exhibit all stages of developing sperms. The lumen or tubule cavity contains the tails of many sperms whose heads are embedded in the Sertoli cells, free sperms and fluid that is resorbed. In mammals in any single zone along a tubule, all sperm are at the same stage of maturation; adjacent zones contain different generation of sperms and a period of sperm formation and discharge is followed by interval of inactivity.

Seminiferous Ampullae

Cyclostomes, most fishes and tailed amphibian have seminiferous cysts also called **spermatogonial cysts, spermatocysts** or **sperm follicles** or **ampullae** or **crypts** or **sacs acini** or **capsules** in which sperms develop but in which the epithelium is not germinal. Sperms mature within the ampullae, among cells called the **Sertoli cells**. The Sertoli cells appear to be partially nutritive in function. Once the sperms mature, the walls of the ampullae break down and release the sperm into the coelomic cavity. The arrangement of the germinal epithelium is different from that of seminiferous tubules. Spermatogenic cells migrate into the cysts from a permanent germinal layer, which depending on the species may be among cysts at the periphery of the testes or in a ridge along one margin of the testis. The spermatogenic cells after invading the thin, non- germinal epithelium of the cells, multiply producing a large number of sperms. The cysts become swollen and whitish in colour and the entire testis swells up as well becoming granular in appearance. When sperms mature they separate from the epithelium and move freely in the cystic fluid. Finally the cysts burst and the sperms are shed into the duct. In the case of cyclostomes and a few teleosts the sperms are released into the coelom. The cysts collapse on becoming totally empty. They are then either replaced by new ones or become repopulated by additional spermatogenic cells.

The spaces between the seminiferous tubules or spermatogenic cysts in the testes are filled with **testicular stroma** which consist chiefly of connective tissue, blood, lymphatic vessels and nerves. Stroma is more abundant in some vertebrates than in other. Glandular **interstitial** cells called **Leydig cells** are also present in most if not all vertebrates. The Leydig cells are thought to be a primary source of **androgens** or male hormones. These cells are not always easily distinguishable. The capillary system of the rat testis and probably that of many other vertebrates is such that blood which bathes the Leydig cells flows to the tubules. In most vertebrates however the adult gonads retain a position in the upper part of the coelomic cavity. In vertebrates except mammal the testis lie within the body. This is also the case in many and sometimes in all members of the mammalian orders Monotremata, Insectivora, Hyracoidea, Edentata, Sirenia, Cetaceae and Proboscidiea.

In some male mammals like in most marsupials, ungulates, carnivores and primates after infancy the testes descend into special pouch called scrotum where they are lodged permanently. The scrotum or scrotal sac is a temperature regulating device. The scrotal sacs are paired structures which project externally from the floor of the abdominal cavity, each connected to the abdominal cavity by a **inguinal canal** lined with peritoneal membrane. During development the testis move backward and downward from their original position into these sacs each accompanied by its duct, blood vessels, lymphatic vessels and by a fold of its proper **mesentery** called **gubernaculum**. A few mammals have a pouch into which the testes descend and from which they can be retracted by the action of the muscle (cremaster) in the scrotal sac. These include a few rodents such as ground squirrels, most bats and some primitive primates (loris, potto). In some cases the sacs remain in open connection with the abdominal cavity, and the testes may be withdrawn into the body between breeding season through the iguinal canal which acts as path of descent and retraction of the testes to the sac. In descending, the testes carry along a spermatic duct, blood and lymphatic vessels and a nerve supply wrapped in peritoneum which collectively constitute the spermatic cords. In rabbits, most rodents and some insectivores the scrotal sacs are absent instead they have a wide inguinal canal into which the testes may be withdrawn and from which they are retracted when in danger of injury. In these mammals, the descended testes cause a temporary bulge in the perineal region (i.e. between the anus and urinogenital opening). In a small number of mammals the testes permanently occupy the perineal location. In some mammals including man (Fig. 9.4 a) the sacs may be permanently closed off, but sometimes a weak spot in the abdominal wall of this region may rupture leading to a condition known as iguinal hernia.

9.10.2 Male Genital Duct

The male gonoducts or genital ducts which in most vertebrates serve to transport spermatozoa to the outside of the body are the archinephric ducts or the Wolffian ducts, that are formed in connection with the developing kidneys. You will recall that the name archinephric duct is used for the kidney duct in anamniotes. Although the male genital ducts are similar to the female genital ducts, the male genital ducts have a more complex history and organisation.

The original function of these ducts as you will recall, is elimination of urinary wastes. In a number of fishes and amphibians certain modified kidney tubules are employed in carrying spermatozoa from the testis to the archinephric duct. They are known as **efferent ductules** and the archinephric duct is then termed as the **ductus deferens**. Even in the amniotes in which the mesonephros degenerates, its duct persists to become the **ductus deferens** and **epididymis (ductus epididymidis)**. This ductus epididymidis establishes connections with the testis via **efferent ducts** or **ductules** (Refer Fig. 9.18 a) which in this case are the modified and persistent mesonephric tubules. Reproductive ducts are lacking in amphioxus and modern jawless fish, the cyclostomes.

In modern jawless fish the testicular ampullae rupture to release sperm into the coelom from where they pass out of the body by means of the genital pores (Fig. 9.19). In most vertebrates however the sperms never enter the coelom but go directly into genital ducts. In all jawed vertebrates the testes are joined to one or more ducts called the sperm ducts through which the sperm leave the body. All sperm ducts include parts of the kidney ducts and so they are called urinogenital ducts. The exception are the teleost fish in which the ducts are not derived from the kidney but from the testis itself. In most vertebrates the sperms mature as they pass through the genital ducts but in teleosts they seem to be fully mature at the time they leave the testis. The genital ducts terminate at the urinogenital sinus which often empties into the cloaca. Uninogenital ducts may also carry urine from the adjoining kidney though that part of the kidney stops functioning in some species. From the testis is formed a tubular network called the **rete tubule** or **rete testis**. The rete testis within the testis forms a network of thin walled ductules or minute ducts that collect sperms from the seminiferous tubules (Fig. 9.18 a).

The rete is drained by a number of small ducts called the efferent ducts or **vasa efferentia**. The vasa efferentia are usually modified kidney tubules and are usually less than 10 in number. The kidney tubules or vasa efferentia drain into the archinephric or mesonephric duct called the deferent duct in male which empties into the urinogenital sinus. The efferent and deferent ducts are collectively termed as epididymis and may be used primarily for sperm transport (Fig. 9.18 a).

The epididymis of amniotes which is a highly coiled duct that drains the vasa efferentia usually serves as a temporary storage place for sperm. In mammals the first part of the epididymis consists of a head, body and tail that wrap around the testis and then gradually straightens out to become the spermatic duct. The epididymis secretes substances that prolong the life of the stored sperm and increase their capacity for motility.

9.10.3 Male Accessory Sex Glands

Vertebrates males, especially of terrestrial species may have several accessory sex glands. Some amphibians (salamanders) have cloacal and pelvic glands which secrete a jelly package to enclose sperm thus forming the spermatophore. They may also have other functions as well. In mammals a number of relatively large and complex accessory glands occur. The testis and epididymis secrete fluids that form part of the semen. Other glands are the prost ate gland, vesicular glands, bulbourethral glands, urethral glands (or Littre's gland) and coagulating glands. All of these open into the urethral part of the urinogenital sinus. Not all the glands are present in every species. However, the major mammalian sex glands are the **prostrate, the bulbourethral** and the **ampullary glands** and the **seminal vesicles** all of which are the outgrowths of the spermatic duct or of the urethra and all four occur in elephants and horses and in most moles, bats, rodents, rabbits, cattle and primates.

The prost ate is the most widely distributed mammalian accessory sex gland. It empties into the urethra by multiple ducts. Many rodents, insectivores and lagomorphs have three separate prostatic lobes. In a few mammals which include some carnivores and primates, the prostrate is a single mass with lobules and encircles the urethra at the base of the bladder. In many rodents as well as in some other mammals, the semen coagulates quickly after ejaculation due to secretion from a male coagulating gland which is usually considered part of the prostatic mass. **Coagulated** semen forms a vaginal plug that temporarily prevents copulation.

Balbourethral or Cowper's glands arise from the urethra near the penis and are surrounded by the muscle of the urethra or penis. Usually there is one pair of Cowper's gland in the mammals, except for in some marsupials where as many as 3 pairs have been found.

An ampullary swelling on the spermatic duct near the urethra is present in many mammals. However in a small number of mammals a separate ampullary gland is formed as an outgrowth of the duct.

Seminal vesicles are paired, typically elongated and coiled fibromuscular sacs that empty into either the spermatic duct or the urethra. These vesicles contribute the sugar fructose and citric acid to the semen but do not serve as sperm reservoir.

9.10.4 Intromittent Organs

In most aquatic forms external fertilisation takes place and water provides the medium by which the spermatozoa reach the eggs. In terrestrial forms, however, a liquid environment is needed to transport the spermatozoans so internal fertilisation is the rule. The necessary fluids are produced by both male and female. In a number of terrestrial vertebrates spermatozoa are transferred from male to female by cloacal apposition but in most terrestrial forms, and even in many aquatic species where fertilisation is internal the males develop organs called **intromittent** or **copulatory organs** which are used by them during internal fertiliation to introduce sperms suspended in seminal fluid into the female tract.

A number of types of copulatory organs exists among vertebrates all of which are not homologous.

Intromittent organ in Anamniotes

Fish – Among fishes copulation with internal fertilisation occurs only in elasmobranchs, holocephalians and some teleosts. In elasmobranchs copulation is accomplished by means of clasping organs called claspers (Fig. 9.19 a) which are modifications of the medial portions of the pelvic fins of males. During copulation one clasper is inserted into the female cloaca. Sperms leave the male cloaca, enter a groove on the clasper and are flushed by water squirted from siphon sacs within the body wall of the male into the female cloaca. In the teleosts which have internal fertilisation the anterior border of the anal fin of the male may be elongated posteriorly to form an intromittent organ called the gonopodium (Fig. 9.19 b).

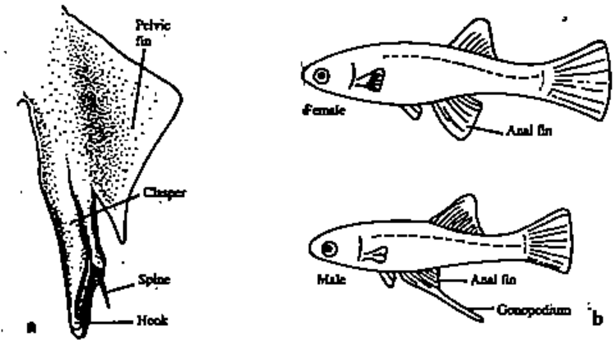


Fig. 9.19: Intromittent organs of fishes (a) clasper, a modified pelvic fin of male elasmobranch *Squalus acanthias* (dogfish) and (b) gonopodium, which is a modification of the anterior part of the anal fin in males, of those teleosts, who exhibit internal fertilisation.

Amphibians – Copulatory organs are absent in urodeles and anurans though internal fertilisation does occur in urodeles. In these animals the male deposits spermatophores, which are actually small packets of spermatozoa held together by secretions of cloacal glands. The female picks up the spermatophore by the muscular movements of the cloacal lips. A dorsal diverticulum of the cloaca, the spermatheca serves for storage of the spermatozoa which are thus available for fertilising the ova as they pass down the oviducts to the cloaca.

Intromittent organs of Amniotes

Intromittent organs are very well developed in reptiles and mammals and few birds like the ostrich, drakes and ganders. In the amniotes intromittent organs are of two kinds:

(1) **Hemipenes** are paired, saclike organs devoid of erectile tissues lying in pockets under the skin near the cloaca. Hemipenes can be everted or retracted eg. Snakes and lizards (Fig. 9.20).
(2) **Penis** is an unpaired erectile organ, eg. male turtles, crocodiles, few birds and mammals (Fig. 9.21 and 9.22).

Reptiles: The only reptile lacking copulatory organs is *Sphenodon*. In other reptiles as you have learnt, two types of structures occur. In snakes lizards the hemipenes is present. They are everted during copulation by propulsor and retractor muscles and filling of blood sinuses in the hemipenes (Fig. 9.20).

In turtles and crocodiles, the single penis is derived from paired thickenings or ridges in the anterior and ventral walls of the cloaca and is composed of connective and erectile tissues. The paired masses of erectile tissue are called **corpora cavernosa.** A groove along the dorsal surface serves as a passage for the spermatozoa. During the mating act, the corpora cavernosa are filled and distended with blood, making the penis firm and enlarged and erect. The penis can be extruded and retracted.

Fig. 9.20: Hemipenes of male reptile (lizard).

Birds: A penis occurs only in the males of ducks, geese, swans and ostriches. It is a single structure, built on the same plan as that of turtles and crocodilians. In the remaining birds sperms are transmitted through cloaca (Refer unit 16 of LSE-10).

Mammals: A single penis is typical of mammals. In monotremes, under normal conditions, the penis lies in the cloacal floor. It is similar to the organs of turtles, crocodilians and bird except that the groove on the dorsal side becomes a closed tube.

In addition the tube is surrounded by a single mass of erectile tissue the **corpus spongiosum** which is separate from another pair of erectile tissue mass called the corpora cavernosa. The canal in monotremes is supposed to carry only spermatozoa since the urethra has a separate opening into the cloaca (Fig. 9.21).

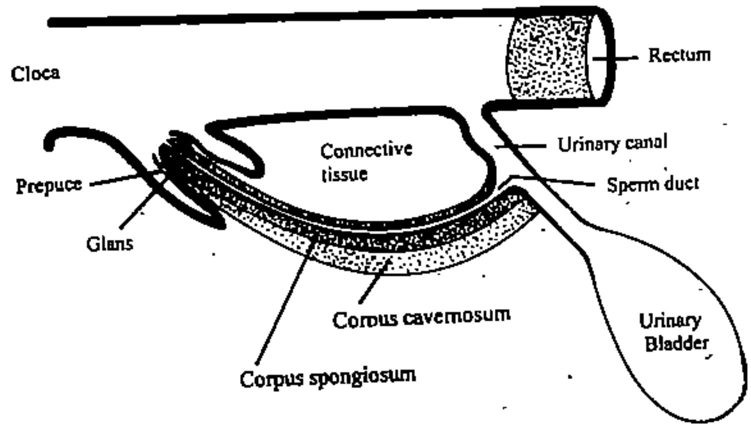


Fig. 9.21: Diagrammatic longitudinal section through cloacal region of male monotreme showing a retracted penis.

In the rest of the male mammals the openings are not separate (Fig. 9.22). The urethra in these animals and subsequent groups serves as a passage for both urine and seminal fluid. The two corpora cavernosa are separated by a septum and the corpus spongiosum surrounds the urethra. The end or tip of the penis is enlarged to form a sensitive swollen glass, containing erectile tissue and numerous nerve endings which make n extremely sensitive to certain stimuli. It is is continuous with the corpus spongiosum. The glans is covered by a thin and delicate skin called **foreskin** or **prepuce**.

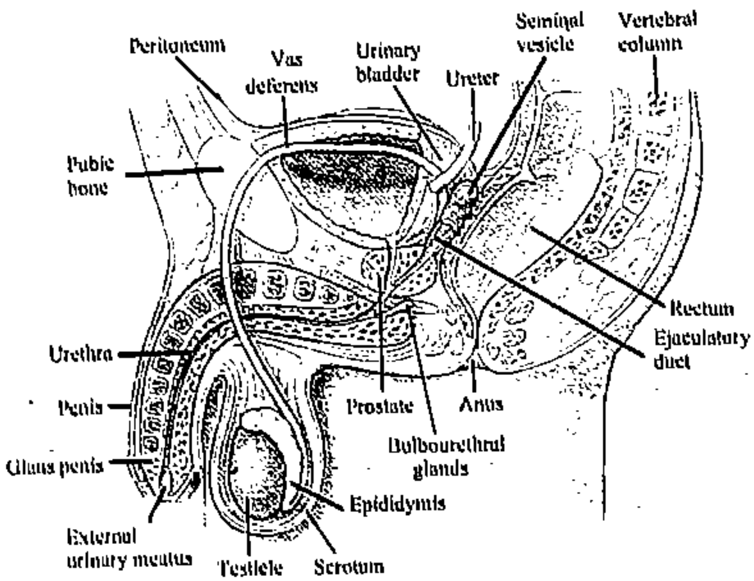


Fig. 9.22: Saggital view of pelvis of human male showing the urinogenital system and interior of testis and its duct.

SAQ 6

Correct the following sentences if necessary.

i) In cyclostomes, sperms develops in seminiferous tubules within the testis.
ii) Leydig cells secrete the hormone estrogen.
iii) The male genital ducts are called fallopian ducts.
iv) The accessory sex glands namely prostrate, Cowper's gland, Bulboutheral gland are found in female vertebrates.
v) The intromittent organ in lizard is called gonopodium.

9.11 FEMALE GENITAL SYSTEM OF VERTEBRATES

The genital system in vertebrate female consist of:

1. Paired gonads – ovaries (sometimes one due to degeneration)
2. Paired oviducts
3. Single female genital opening
   (Refer to Fig. 9.23 a and b)

9.11.1 Ovary

An ovarian follicle consists of an oocyt or immature egg enclosed in a epithelium. The cells of epithelium are referred to variously as follicular cell or nurse cell or granulose cells. In cyclostomes, teleosts and amphibians the epithelium is one layer thick. In the hagfish and in those vertebrates like elasmobranches, reptiles, birds and monotremes in which the oocytes have heavy yolk deposit, the epithelium appears to be two cells thick. In mammals above the level of monotremes, the follicular epithelium appears to be many cell thick.

Ovaries lie within the body cavity and are suspended by the dorsal mesentry, the mesovarium, through which pass blood and lymph vessels and nerves. Primitive vertebrate ovaries are found in hagfish, in which a mesentry-like fold of gonadal tissue stretches across nearly the entire length of the body cavity. In the hagfish, the unique feature is that the functional ovarian tissue occupies only the forward half of the gonadal mass while the rear part contains the rudimentary testicular tissue. In most fishes except in very primitive forms, the ovaries are similarly elongated. In tetrapods except for mammals the ovaries are usually confined to the middle third or half of the body cavity, particularly during the non breeding seasons. The ovaries of mammals underg· moderately caudal displacement in order to be located between the kidney and the pelvis (Fig. 9.23 a).

The shape of an ovary depends on many factors like whether one egg or thousands are discharged (ovulated), whether the eggs are immature or ripe; whether mature eggs are small or large, or whether pigments occur in the egg cytoplasm, such as those responsible for yellow yolk. The appearance of the ovary is also affected by other factors such as the season of the year in seasonal breeders. (as ovary enlarges during the breeding seasons and diminishes in size between seasons) the age of the animal (whether juvenile or reproductively active or senile especially in birds and mammals) and the fate of the ovulated egg follicles or sacs.

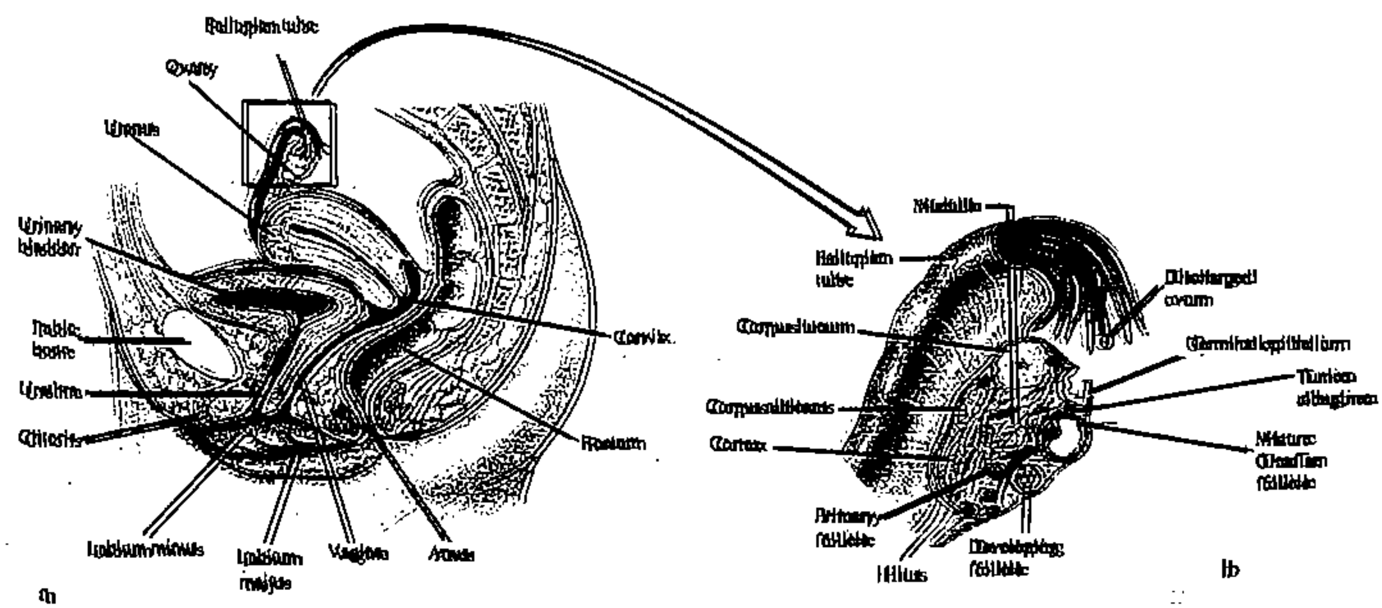


Fig. 9.23: Mammalian female reproductive system. (a) saggital view of pelvis of human females showing female reproductive system. (b) cut away of ovary showing internal structures.

Ovaries are characterised as saccular or hollow or lacunate (i.e. compartmented) or compact structures. However, most ovaries are similar in construction. They are covered with a **germinal epithelium** that is continuous with the peritoneum lining the body cavity. Beneath the epithelium the ovary has a layer of connective tissue called **tunica albuginea** which is considerably thinner than that surrounding the testis. Below this the ovary has an external cortex and internal medulla. The cortex which is the thick outer layer lies immediately internal to tunica albuginea and contains future eggs and at one time or another, eggs in ovarian follicles (developing eggs) (Fig. 9.23 b). The cortex also contains remnants of ovulated follicles and in mammals, and clusters of interstitial cells that in some species are glandular. The cortical components are embedded in a supportive frame work of connective, vascular and neural tissue that form the **stroma.** Internal to the cortex is the vascular, meso-dermal medulla which consists of blood and lymph vessels, nerves and connective tissue. The medulla lacks germinal elements and exhibits no significant cyclical activity. It is usually inconspicuous and is continuous with the dorsal mesentry. In the cyclostomes the medulla and dorsal mesentry are indistinguishable from each other. On the contrary in mammals the medulla is almost completely surrounded by the cortex and converges on the mesovarium at a narrow hilus, at which nerves and vessels enter the ovary. In the medulla of the mammalian ovary near the hilus are small masses of blind tubules or solid cords called the rete ovari. The **'rete ovari'** are homologous (of the same embryonic origin) with rete testis in the male. The rudimentary right ovary of the birds usually consists of only medullary tissue.

9.11.2 Female Genital Ducts

Eggs are released into the coelomic cavity. Once in the coelom, the mature eggs enter the female genital duct called **oviduct** which parallels the archinephric duct in its embryonic course. The oviduct usually joins the urinogenital sinus near the cloaca. Oviducts except in teleosts and some fishes are modifications of the mullerian ducts and develop in every male or female embryo (except in cyclostomes) as a pair of longitudinal ducts. In males, the Mullerian duct disappears or becomes rudimentary. In females, it grows larger to become the reproductive tract or gonoduct. Its smooth muscles and cilia of the ciliated cells, in its lining propel eggs along the tract.

In most teleost fishes with tubular ovaries, eggs do not enter the coelom at large but go directly into a special genital duct called gonaduct which is named so, because it is apparently derived directly from the gonad. The gonaduct encloses a small part of the main coelom (Fig. 9.24). In higher mammals the oviduct differentiates into three regions (i) Fallopian tube (ii) uterus and (iii) vagina. The oviduct of most other vertebrates is open at both ends, at the urinogenital sinus which may open into the cloaca and near the ovary by means of **infundibulum** which is also called **pre ampulla.** The end next to the ovary is ringed with mobile, finger like ciliated projections called **fimbriae** that actively envelops the ovary near the time of ovulation (see Fig. 9.24).

Oviducts may be long or short and may have glandular portions that are modified to be secretory in function. As a result along the course, the oviducts may differentiate into (i) a region that provide protective and nutrient material on the eggs, (ii) uterus (pl: uteri) to lodge the developing embryo in case of viviparous animals. (iii) the terminal segment of the female genital duct which is modified to receive the intromittent organ.

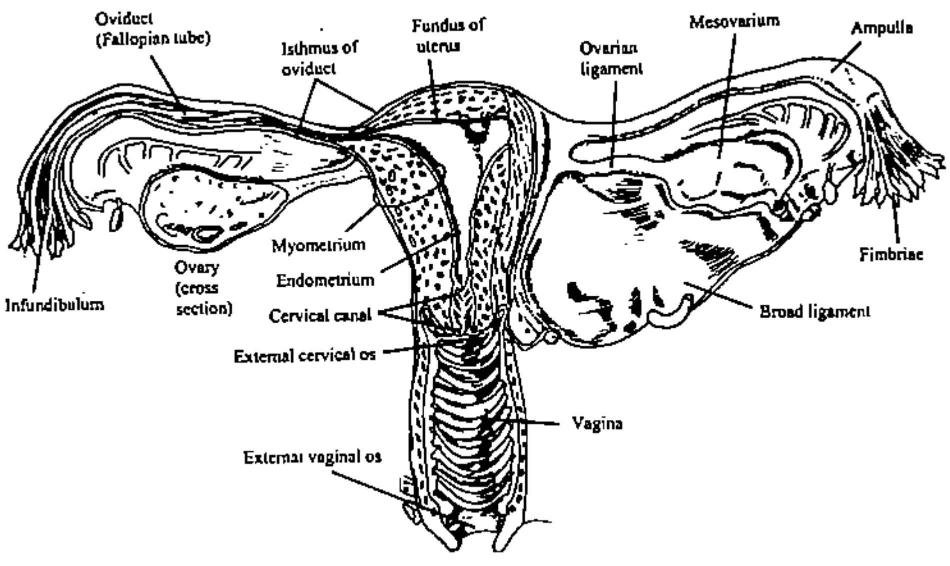


Fig. 9.24: The reproductive system of human female showing oviduct, ovary, uterus and vagina.

Uterus

Uterus is the muscular middle part of the oviduct (Refer to Fig. 9.23 a and Fig. 9.24 again). Its muscles form the **myometrium** and its inner lining is called **endometrium**. The endometrium becomes highly vascularised before the blastocyst stage (or developing embryo) implants.

In all mammals the uterus narrows to form the posterior **cervix** (Fig. 9.23 and Fig. 9.24). Lips of the cervix enclose the uteri opening or '**os uteri**' through which sperms rise upto the upper part of oviduct for fertilisation. The cervix dilates during delivery of the baby.

Uterus shows a number of variations in mammals. In primitive mammals like monotremes (egg laying mammals) and marsupials there are two uteri (**duplex uterus**). In most mammals however, the distal parts of the two uteri are fused together to give a **bipartite** or **bicornuate** uterus. In higher primates there is a complete fusion of the two uteri to form a single **simplex uterus** (Fig. 9.25).

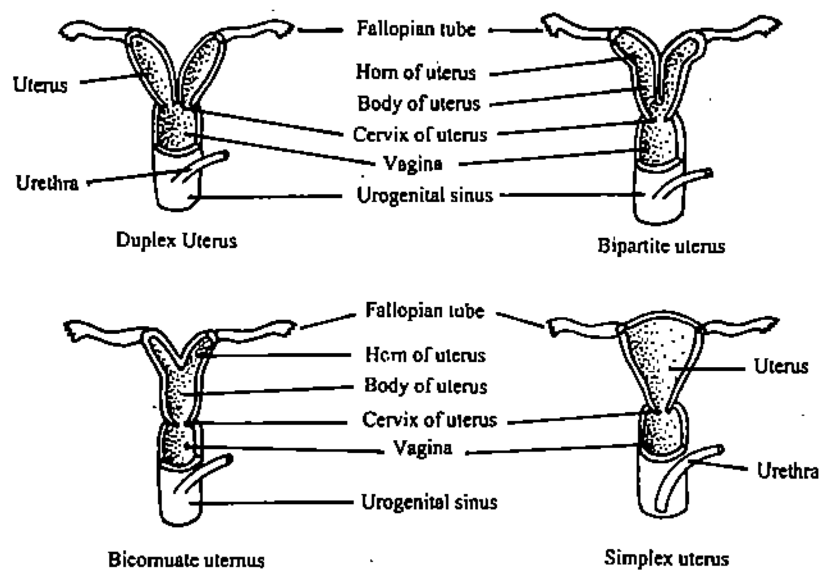


Fig. 9.25: Diagram showing the fusion of posterior ends of paired uteri in females of placental mammals. (The uterus and part of the vagina have been cut open.)

Vagina

The uterus leads through the narrow cervix into the **vagina**. Vagina is the fused terminal part of the Mullarian duct. It opens into urinogenital sinus (Fig. 9.22) or is extended to open directly to the outside. It is a muscular distensible tube which receives the penis during mating. It has convolutions on it which are called **vaginal rugae**. Vagina opens to the exterior by the female genital opening.

Vagina is absent in egg laying mammals. Marsupials, have paired vagina that opens into urinogenital sinus. To match the two vaginae, male penis is forked at the tip and one tip enters one lateral vaginal canal to discharge semen.

9.11.3 Female Accessory Glands

You have already read in subsection 9.10.3 about the various accessory glands associated with the male genital system. You will similarly find that the accessory glands are also associated with the female genital system of many vertebrates. Oviducts of many female vertebrates have glands in the oviduct called the albumin gland that coat the egg with albumin. Other glands associated with the oviduct are the shell gland or nidamental gland that cover the egg with shell material; mucous cell or oviducal tubular glands that secrete a jelly like material. Amniotes that lay large eggs may have in the oviduct mucous secreting glands called vaginal mucous gland that coat the egg prior to expulsion, possibly to lubricate it. Some fishes have adhesive glands that coat the eggs with a sticky secretion so that the egg scan adhere together or to appropriate objects. In some vertebrates that retain the developing embryos within the body, special glands of the oviduct evolve in order to nourish the young. These glands secrete into the oviduct so that young present there absorb or ingest the secretion. This secretion is called uterine milk or embryotrophe.

9.11.4 External Female Genitalia

In females the external genitalia in comparison to males is feebly developed. Maximum development of female genitalia is in the Order Primates of mammals. In human females it is well developed and is described below:

External Genitalia of Human Female

The external genital organs of the female are termed **vulva** (Refer to Fig. 9.24). The internal genitalia of the female consists of an outermost structure called **labia majora** which are a pair of skin folds and contain adipose tissue. Within the cleft formed by these folds are the **labia minora**, which are a smaller pair of skin folds that are highly vascularised but have no fatty tissue. At the anterior end of the vulva, these two interior skin folds partly enclose the **clitoris**, a small organ for sexual stimulation. The opening of the urethra is about midway between the clitoris and vaginal opening. The **vaginal opening** is located behind the urinary meatues and is much larger than the urinary opening. It is covered by a thin mucous membrane the hymen.

Bartholin's glands (or bulbovestibular glands) or **greater vestibular glands** are two bean shaped glands, one on either side of the vaginal opening. These secrete a lubricating fluid. The two glands open by a single duct between hymen and labia minora. Bartholin glands are homologous to male **bulbourethral glands.** A group of tiny mucous glands, the **lesser vestibular glands** also called **Skenes glands** open into the vestibule.

9.11.5 Mammary Apparatus

Mammals are named so because of the characteristic presence of the mammary apparatus, which includes (i) **mammary glands**, (ii) **elevated nipples** which are the outlets for secretion of these glands and (iii) **breasts** or **mammae** which are the integumentary swellings due to localised presence of these glands (Fig. 9.26).

Mammary glands are modified sweat glands. They are present in both male and female mammals but they become well developed only in females as their development is controlled during puberty by the ovarian hormones estrogen and progesterone.

Each mammary gland is divided into a number of lobes and each lobe has several **lobules**. Lobules are formed of connective tissue in which secretory cells called alveoli are embedded. **Alveoli** are arranged in grape like clusters around minute ducts. Progesterone stimulates the growth of alveoli and estrogen stimulates growth of ducts.

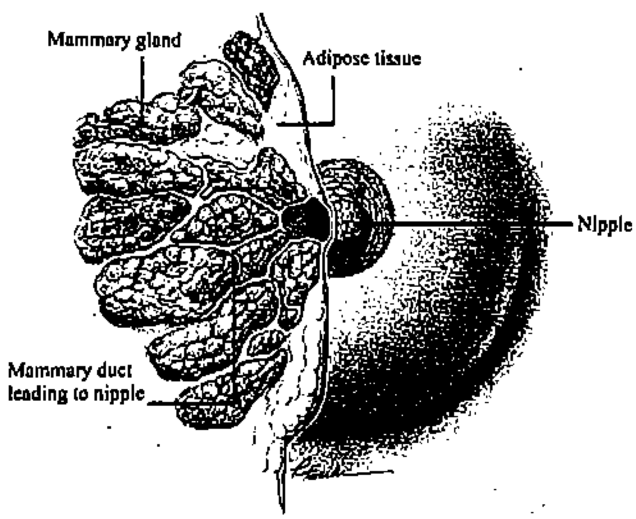


Fig. 9.26: Human female breast showing mammary apparatus.

Ducts from lobules units to form a single lactiferous or milk carrying duct per lobe. Each duct opens by a pore at the nipple. The nipple is bordered by a pigmented area called **areola** containing several sebaceous glands which appear as small nodules under the skin. The nipples vary in number and location in different mammals. The number depends on the number of offsprings born in a litter. The position of mammae depends on their availability to the suckling offspring. In monkeys and other primates which are arboreal, the mammae are pectoral. Humans, who have descended from arboreal ancestors also have pectoral nipples. In ruminants which suckle their young, while standing, the mammae are elongated and project downwards. In pigs they are arranged on the sides and so the mother lies down to suckle the young. The number of nipples vary Horse, bats, whales and humans have a pair of nipple.

9.12 SURVEY OF GONADS IN VERTEBRATES

Jawless vertebrates: In the jawless fishes the gonads begin as paired structures but fuse later in development into a medial gonad. Sperms form in the ampullae rather than in seminiferous tubules. In both male and female forms, special genital ducts are absent. The gametes that are released from the gonads pass through the coelomic cavity and out of the body via genital pores. The lack of genital ducts appears to be a primitive vertebrate feature. The complete separation of the anus from the urinogenital tube appears to be a specialisation.

Jawed vertebrates

Cartilaginous fish – Gonad structure, origin, as well as pattern of genital ducts of cartilaginous fishes are typical for jawed vertebrates in general (Fig. 9.27 a and b) and indicate a common origin of vertebrate genital ducts from archinephric tubules. The Mullerian duct originates as a new structure in jawed vertebrates. The testes are of primitive ampullary type. Modifications for internal fertilisation include pelvic fins called **claspers** (Refer subsection 9.10.4). The many variations on internal development among cartilaginous fishes indicate no common pattern or clearly defined relationship to other fishes or to tetrapods.

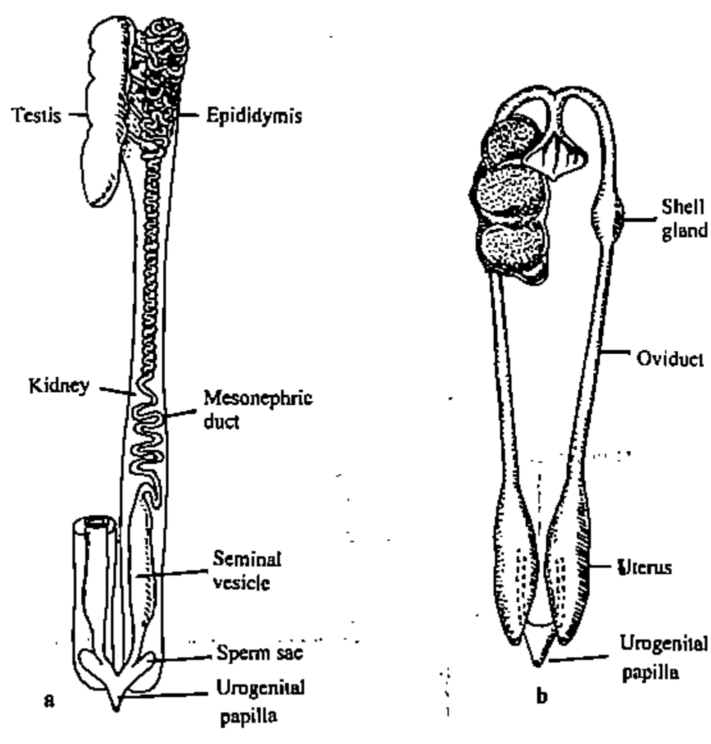


Fig. 9.27: Reproductive system of cartilaginous fishes (a) male urinogenital system of a shark (b) female reproductive system of shark *Squalus*. The left ovary has been removed.

Bony fishes: Most extant teleosts have specialised hollow ovaries and testes with genital ducts called gonoducts that are derived from the gonads (Fig. 9.28 a and b). However some bony fishes similar to jawless fish have coelomic transport. In them, extensions of the gonads in the adult produce hollow testes or ovaries that continue as tubes to transport the egg or sperm respectively to exit from pores through the posterior body wall. The testes may be (i) ampullary (or acinar) as in jawless fish and sharks or (ii) tubular as in most tetrapods. Tubular testes and the genital ducts associated with the kidneys seem to be primitive features of bony fishes.

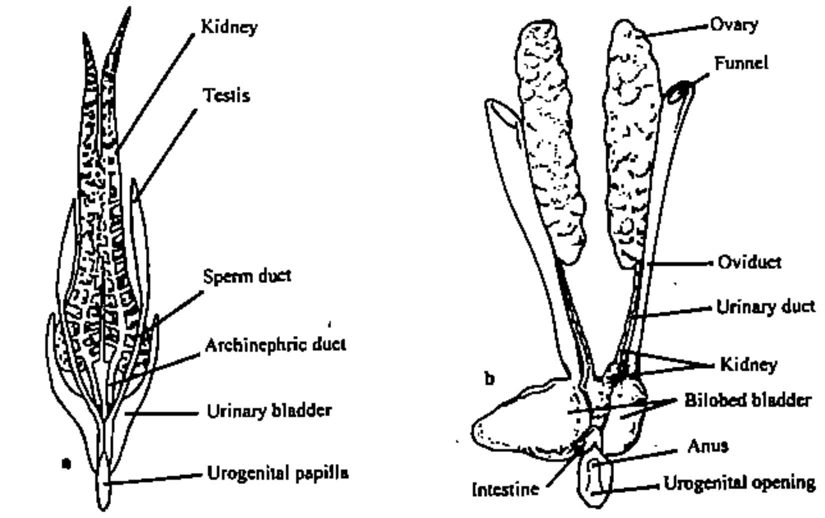


Fig. 9.28: Reproductive system of bony fishes (a) male urinogenital systems of male sea horse, *Hippocampus* (b) female reproductive system of bony fish *Amia*.

Amphibians: In amphibians the gonads and urinogenital ducts are basically like those of primitive bony fishes and tetrapods (Fig. 9.29). Some oviparous and all viviparous forms have developed internal fertilisation which may have originally been an adaptation for a terrestrial mode of life. Caecilians appear to be the most of terrestrial of the amphibians in terms of reproductive adaptation. They all have internal fertilisation and appear to have developed mechanisms to protect the egg, by brooding, egg retention or more complete viviparity. Living viviparous amphibians include several species of salamander, approximately five species of frogs and about 20 species of caecilians. The oviducts of females of some viviparous species of frogs, salamanders and caecilian produce nutrient secretions called uterine milk for the young. No placenta is however known to develop within the oviduct.

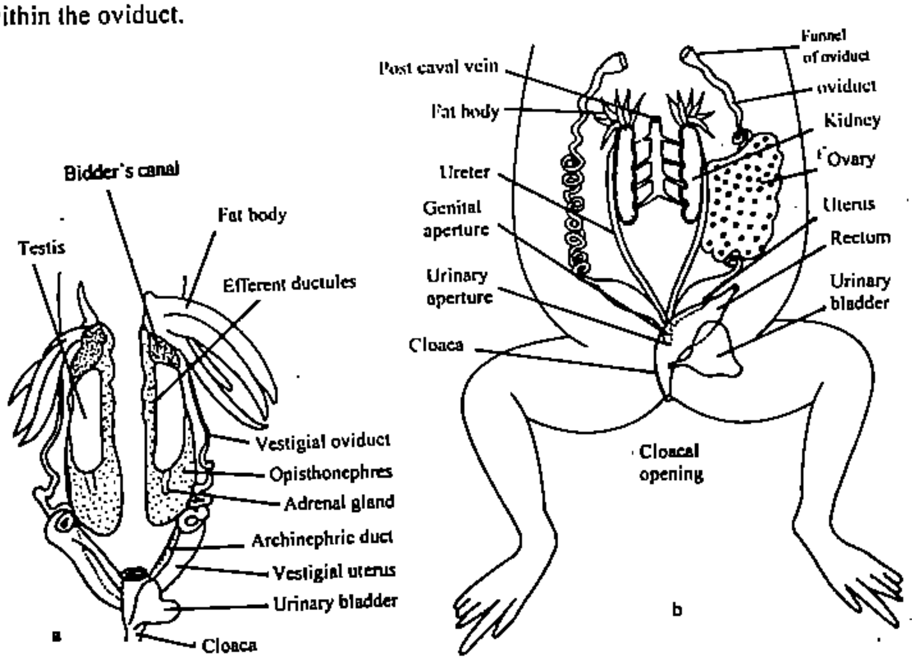


Fig. 9.29: Reproductive system of amphibians (a) male urinogenital organs of toad *Bufo americanus*, showing bidder's canal (b) female urinogenital system of toad *Bufo*, with right ovary removed.

Reptiles: In reptiles the mesonephric tubules are taken over entirely by the testes for sperm transport (Fig. 9.30 a and b). Urine is then carried across by a new duct, the ureter. The oviducts in the females, similar to that of amphibia and most fishes are also not involved with kidney or more appropriately excretory function. The intromittent organs, the hemipenis and penis of the reptiles indicate a clear adaptation towards terrestrial mode of life and hence internal fertilisation that has been phylogenetically continued into mammalian descendants of reptiles. In some species the oviducts of female may retain living sperm for a long period of time after copulation, upto four years in the case of some turtles.

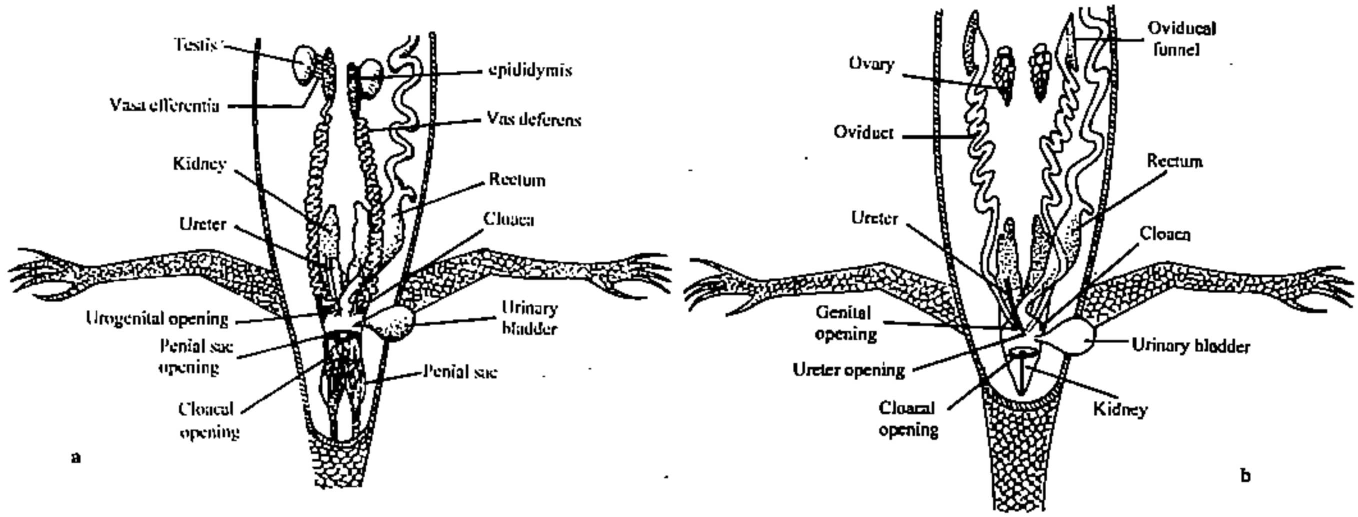


Fig. 9.30: Reproductive systems of reptiles (a) urinogenital system of the male lizard *Calotes* (b) female urinogenital system of lizard, *Calotes*.

Birds: Birds typically have reptilian reproductive organs except that in females only the left gonad develops in to an ovary (Fig. 9.27 c). The right gonad develops upto a certain stage, after which it regresses and remains undifferentiated. A penis occurs only in primitive birds.

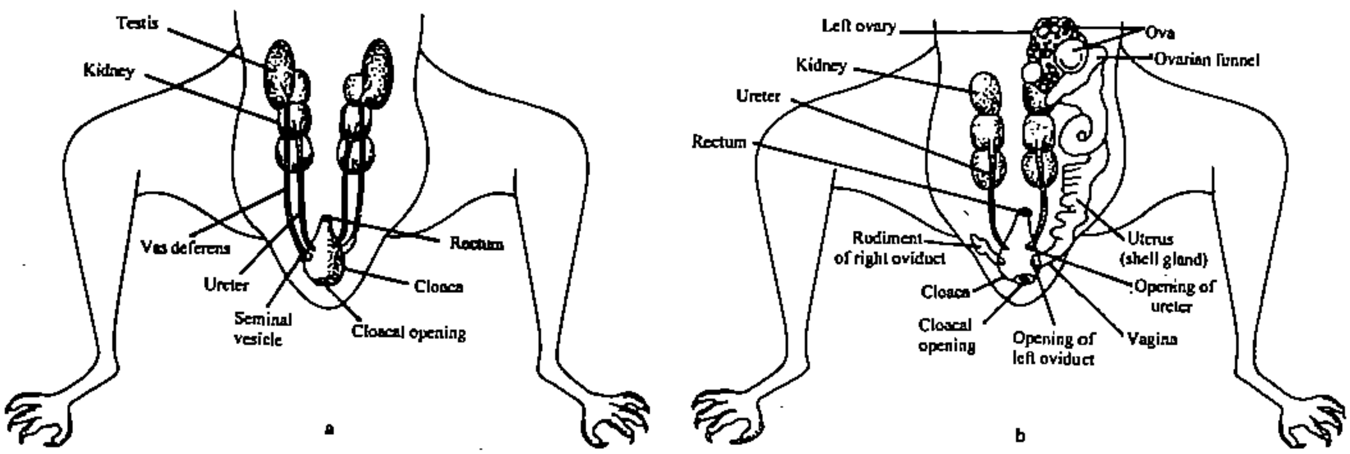


Fig. 9.31: Reproductive system of Aves (a) male urinogenital system of pigeon, *Columba* (b) female urinogenital system of *Columba*.

The oviduct at its posterior end has pockets called **sperm nests** that store sperm. As the egg leaves the ovary, it enters the infundibulum where it is fertilised. The fertilised egg is forced along the oviduct in which a spiral band of material called chalazae is added at each end, of the egg, as are also added thick and thin layers of albumen, shell membranes and the shell, around the egg.

Mammals

Primitive mammals like the monotremes(egg laying mammals) generally have a reptilian reproductive apparatus except for the fact that the penis is tubular instead of being grooved and the mammary glands are present. Monotreme have a distinct cloaca. The ureter in monotremes similar to reptiles and birds lies between the Wolffian or Mullerian ducts instead of lying lateral to the reproductive duct as in eutherian mammals. The oviducts of monotremes are relatively unspecialised as compared to most mammals. They are unfused and open individually into the urinogenital sinus. The oviducts are specialised to the extent that they produce a shell similar to that of reptilian eggs and also secrete **uterine milk** called **embryotrophe** which is absorbed by the embryo and used for nutrition.

The details of the reproductive system of the rest (Fig. 9.32 a and b) of the mammal groups have been given in various sections of this unit, however a figure of the reproductive system of a typical mammal is given below.

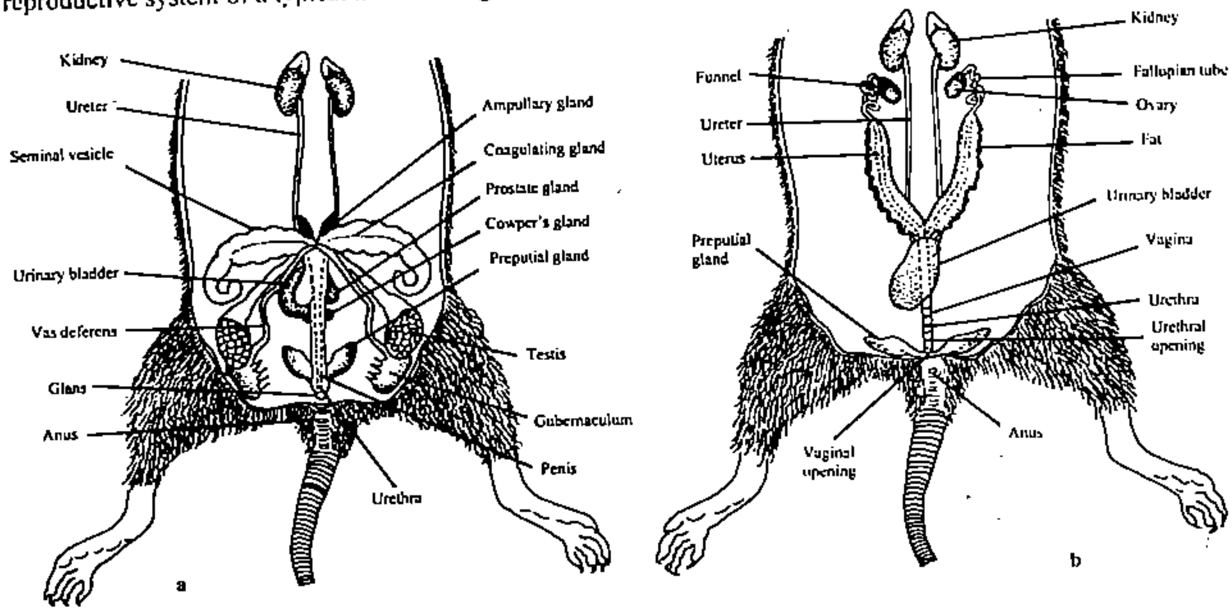


Fig. 9.32: Reproductive system of mammal (a) male urinogential system of male rat, *Rattus* (b) female urinogenital system of female rat *Rattus*.

SAQ 7

Fill in the blanks and compare your answers with those given at the end of this unit.

i) The four types of mammalian uteri are ...., ..., ... and ....

ii) The muscle layer of the uterus is called ....

iii) The sequence of organs of mammalian female genital system are: two ovaries ——> .... ——> .... ——> .... ——> genital opening.

iv) Caecilians among amphibians have .... fertilisation.

v) The oviducts of females of some viviparous species of amphibian produce nutrient secretions called .... for the young.

vi) In female birds only the .... gonad develops into the ovary.

vii) The oviducts of monotreme secrete uterine milk called ....

9.13 SUMMARY

- Both the urinary and reproductive organs arise embryologically from the same or adjacent tissue and maintain close anatomical and sometimes functional association, throughout the organise life.
- Several types of kidneys are found within the chordate groups.
- The organs of excretion of the protochordates *Branchistoma* (Cephalochordata) and *Herdmania* (Urochordata) show no relationship to any part of the vertebrate kidney or other known fluid regulatory structure.
- The excretory organs of the vertebrates consist of paired kidneys and their associated ducts.
- The various types of kidneys that are found in the vertebrates have been derived from a primitive structure termed as archinephros or holonephros.
- The archinephros (holonephros) consisted of paired archinephric ducts which extended the length of the coelom and were joined by segmentally in arranged tubules, one pair to each segment. The free end of each tubule opened into the coelom by means of a ciliated, funnel shaped nephrostome. Each tubule was intimately associated with a small knot of inter arterial capillaries known as glomerulus. The larval stages of the hagfish and calcilians exhibit an archinephric condition.

- Kidneys of living vertebrates have developed from this primitive plan of the archinephros type of kidney. The various types of vertebrate kidneys may be regarded as successive stages that have evolved in a craniocaudal direction from the original archinephros. They may be clearly observed during the embryonic development of the amniote vertebrate where there is a succession of three developmental stages of kidney – pronephros, mesonephros and metanephros. Some but not all these stages are also seen in other vertebrate groups.
- In adult anamniotes – cyclostomes, fishes and amphibians, the anterior part of the primitive archinephros usually becomes modified or degenerates. In the embryo it appears as a transitory structure called the pronephros. In a few lower vertebrates the pronephros persists in the adult stage and is called the head kidney. A head kidney is found in the adult hagfish and in certain teleosts. The part of the anamniote kidney that remains and forms the adult kidney and is called the opisthonephros. This retains the archinephric duct but differs from the pronephros in that several kidney tubules may be present in each segment and the tubules lose their peritoneal connections. In the opisthonephric kidney there is a general tendency for concentration of kidney tubules towards the posterior end. The anterior end loses its importance as an excretory organ and in males is the appropriate by the reproductive system, with the result that the archinephric duct becomes known as ductus deferens.
- In amniotes, of the three types of kidneys – pronephros, mesonephros and metanephros which appear in craniocaudal direction during embryonic development, only the metanephros persists to form the adult kidney. The archinephric duct in amniotes is termed as Wolffian duct.
- In male amniotes, the Wollfian duct gives rise to the epididymis, ductus deferens and certain other parts of the reproductive system.
- The urinary system of most vertebrates includes two kidneys and two ureters. A urinary bladder and urethra occur in all mammals and some vertebrates.
- Ducts from the kidney lead to cloaca in most forms. In teleost fishes they open directly to the outside.
- In mammals ducts of the kidney enter the urinary bladder (except in monotremes). Urinary bladder, may be present as ventral out pocketings of the wall of the cloaca. In mammals the bladder opens to the outside through a urethra which in males of all forms except for monotermes is also used by the reproductive system.
- Each mammalian kidney as well as that of most vertebrates is composed of a renal capsule, enclosing a cortex and an internal medulla. Numerous individual tubules called uriniferous tubules are the basic excretory unit of the kidney which produce urine. Each uriniferous tubules consists of i) nephron an excretory unit ii) collecting tubule.
- Each nephron consists of a cup shaped Bowman's or renal capsule, proximal convulated tubule (PCT), loop of Henle and distal convoluted tubule (DCT). Blood vessels associated with the nephron are an afferent arteriole, glomerular capillaries, an efferent arteriole, and peritubular capillaries.
- Kidneys are the principal organs of excretion and osmoregulation in vertebrates.
- The various functions of the urinary system are (i) excretion of metabolic waste products (ii) regulation of fluid, electrolyte balance and blood pressure (iii) secretion of hormone erythropoetin which is associated with production of blood cells in case of loss of blood or hypoxia.
- The kidneys of vertebrates are confronted with two kinds of problems since they occupy diverse habitats like those in which water (i) may not be available for example in terrestrial environment or marine environment or (ii) may be in abundance for instance in fresh water environment. Thus the kidneys and tubules of vertebrates are adapted according to the environment they inhabit.
- The urinogenital systems of various groups also differ to some extent.

GENITAL SYSTEM

- The reproductive system of chordates consist of primary sex organs, the gonads which produce gametes.
- The primary sex organs or gonads are testes in male and ovaries in female. The testes produce the spermatozoa and the ovaries the ova.

- The vertebrate reproductive system consist of primary and accessory sex organs. The accessory sex organs are ducts and glands which provide passage for transport of gametes (eggs or spermatozoa to the outside of the body). The archinephric duct in anamniotes or the Wolffian duct in amniotes becomes the reproductive duct or ductus deferens in the male. In females the Mullerian duct forms the oviduct. Ducts are absent in amphioxus and cyclostomes.
- In males, spermatozoa are formed within seminiferous ampullae or tubules in the testes.
- Each ductus deferens establishes connections with the testes usually by means of epididymis and persistent kidney tubules called efferent ductules. In anamniotes the epididymis and ductus deferens consists of parts of the archinephric duct which may serve in some cases as an excretory duct as well as for passage of the spermatozoa. In amniotes however the epididymis and ductus deferens are formed from the persistent Wolffian duct, which is entirely dissociated from the ureter of the adult metanephric kidney.
- The testes in vertebrates are located in the abdominal cavity, except in a number of mammals. In most mammals they are either temporarily or permanently located in a scrotum outside the body proper.
- In male vertebrates especially mammals accessory glands are associated with primary sex organs. These secrete seminal fluid in which spermatozoa are suspended and which are essential for the viability of the spermatozoa and for transport through the reproductive tract both male and female.
- Fertilisation in vertebrates may be external or internal. Most vertebrates with internal fertilisation have copulatory organs which are used in transferring spermatozoa from male to female. In fishes these usually consist of modified fins. In snakes and lizards paired hemipenis are present; but in turtles, crocodilians, certain birds and all mammals, a single penis is used for this purpose. The urethra coming from the urinary bladder passes through the penis in all mammals except in monotremes. It thus serves for passage of both urinary and seminal fluids.
- Eggs develop within ovaries and when fully developed they break out of the ovaries into the coelom. Each oviduct generally opens into the coelom by a funnel-shaped ostium. The oviducts of teleosts are derived in a different manner and may not be homologous with those of other vertebrates.
- In forms below mammals the paired oviducts are separate and usually open independently into a cloaca. In most higher mammals a cloaca is absent in the adult and each oviduct differentiates into three regions (i) fallopian tube (ii) uterus (iii) vagina. Various degrees of fusion of the paired uterus occur in mammals, resulting in different types of uteri.
- The external genitalia of females called vulva is feebly developed in comparison to males. Maximum development of female genitalia is in the primates.
- Accessory glands are associated with the female reproductive and secrete mucous.
- The parallel development of male and female reproductive system is very striking. The various structures in one sex have obvious homologous with those of the opposite sex.

9.14 TERMINAL QUESTIONS

1. Why are the urinary and reproductive systems usually studied under a common urinogenital system?

....

....

....

....

....

....

....

....

....

2. Draw a well labelled diagram of the uriniferous tubule of mammal.

3. Label the given diagram of human kidney.

4. Write short notes on (a) kidney blood circulation (b) types of mammalian uteri.

(a)..

....

....

....

....

....

....

....

(b)..

....

....

....

....

....

5. What are intromittent organs? Describe the reptilian intromittent organ.

....

....

....

6. List the functions of the excretory systems.

7. Describe the amniote testis.

....

....

....

....

....

....

....

9.15 ANSWERS

Self-assessment Questions

1. i) glomerulus; ii) hilum or hilus; iii) renal; iv) mesodermal

2. i) a) nephron; b) glomerulus; c) loop of Henle d) duct of Belleni
   ii) renal corpuscle/glomerulus and Bowman's capsule, proximal convoluted tubule, descending limb, Henle's loop, ascending limb, distal convoluted tubule, collecting tubule.
   iii) a, b, c
   iv)

	A	B
a)	capillaries of efferent arterioles	vas a rectae
b)	renal interstitium	prostaglandin
c)	macula densa	juxta glomerular apparatus
d)	erythropoietin	red blood cells

3. a – i; b – i; c – I

4. i) testis ovary; ii) secondary; iii) Wolffian/Mesonephric; iv) ovaries; v) cloaca; vi) mesorchium; vii) intromitten.

5. i) mesoderm; ii) primary; iii) oviparous; iv) viviparous; v) female

6. i) In cyclostomes sperms develop in seminiferous ampullae of testis.
   ii) Leydig cells secrete the hormone testosterone.
   iii) The male genital ducts are called ductus deferens or vas defens.
   iv) The accessory sex glands, prostrate glands and bulboutheral glands are found in male vertebrates.
   v) The intromittent organ in lizard is called hemipenes.

7. i) Duplex, bipartite, bicornuate, simplex;
   ii) Myometrium;
   iii) Two oviducts (fallopian tubes) ⟶ uterus ⟶ vagina;
   iv) internal;
   v) uterine milk;
   vi) left;
   vii) embryotrophe

Terminal Questions

1. Through the urinary and reproductive system have nothing in common functionally; they are usually studied under a common urinogenital system because both develop from the some segmental blocks of trunk mesoderm or adjacent tissues and share many of the ducts.

2. Draw figure on basis of Fig. 9.6 of this unit.
3. Label figure on basis of Fig. 9.9.
4. Refer a) subsection 9.5.2; b) subsection 9.11.2 – uterus.
5. Refer subsection 9.10.4. Intromittent organs of amniotes.
6. Refer Fig. 9.14 (b).
7. Refer section 9.10 testis and seminiferous tubules.

UNIT 10 NERVOUS SYSTEM AND SENSE ORGANS

Structure

10.1 INTRODUCTION

Each of us would have at some point in our life observed animals, how they move, catch prey or feed and respond to external and internal stimuli. All these activities take place because individual cells in the animal's body respond to certain stimuli and their responses are integrated in a meaningful co-ordinated manner. This co-ordination occurs in two forms, electrical through the nervous system and in chemical form through the endocrine system.In this unit you will learn about the organisation of the vertebrate nervous system while the other integrating system will be dealt with in Unit 12.

You have studied in LSE-05, and LSE-09 how specialised cells of the metazoan body the neurons, get organised into a nervous system and that these neurons operate on the same principles through out the animal kingdom. You would recall that the function of the nervous system is to receive stimuli or sensory information and to send impulses from one part of the body to another. In this manner it regulates an animal's activities by integrating incoming sensory information with stored information, the result of past experience and then translating past and present information into action through effectors. Nervous tissue is also the seat of all conscious experience.

In this unit you will learn briefly about the structure of a vertebrate nerve cell which is the functional and structural unit of the nervous system. We will discuss the organisation of the vertebrate nervous system and the brain in relation to function in different vertebrate groups. To be able to respond to the external and internal stimuli, animals possess sensory receptors which may be wide spread in the body or may be in the form of specialised organs the sense organs. These translate environmental energies into electrical impulses that are transmitted to the nervous system. We describe the three basic types of sense organs, the optic, auditory and olfactory organs.

Vertebrates differ in their ability to perceive stimuli, hence some vertebrate groups have specialised sense organs that have originated to suit their special mode of life. They too would be discussed briefly to emphasise how these organs help the animal to respond to its external environment.

Objectives

After studying this unit you should be able to:

- describe the central, peripheral and autonomic nervous system of vertebrates,
- give a comparative account of brain in vertebrates,
- correlate the evolution of brain structures with their function in vertebrates,
- illustrate the structure of eye, internal ear and olfactory organs in vertebrates,
- describe specialised sensory organs.

10.2 NERVOUS TISSUE IN VERTEBRATES

You have learnt in Block - 3 of the Developmental Biology Course (LSE-06) that all nervous tissue is ectodermal in origin. In vertebrates during embryonic development the flattened layer of ectoderm along the mid dorsal side of gastrula becomes thickened and is known as neural or medullary plate which gives rise to the neural tube and neural crest. The neural tube is the forerunner of the brain and spinal cord, and some of the neural crest cells migrate away from the neural tube to give rise to the bodies of neurons that lie outside the brain and spinal cord.

You would recall from earlier courses LSE-05 and LSE-09 the structure of a typical neuron which consists of a cell body and several processes arising from it - the dendrites, usually numerous and highly branched and the single long process the axon with branches- the terminal arboration at its end (Fig. 10.1).Collateral branches may be given off from the axon but often these are lacking. The axon terminal may make close contact (synapse) with the dendrites of another neuron and neurotransmitters are released at the axon terminals that conduct the information in the form of impulses across the synapse to the other neuron. This is normally unidirectional. A single neuron may have contact with thousands of other neurons that transmit information along their axons and receive information over dendrites.

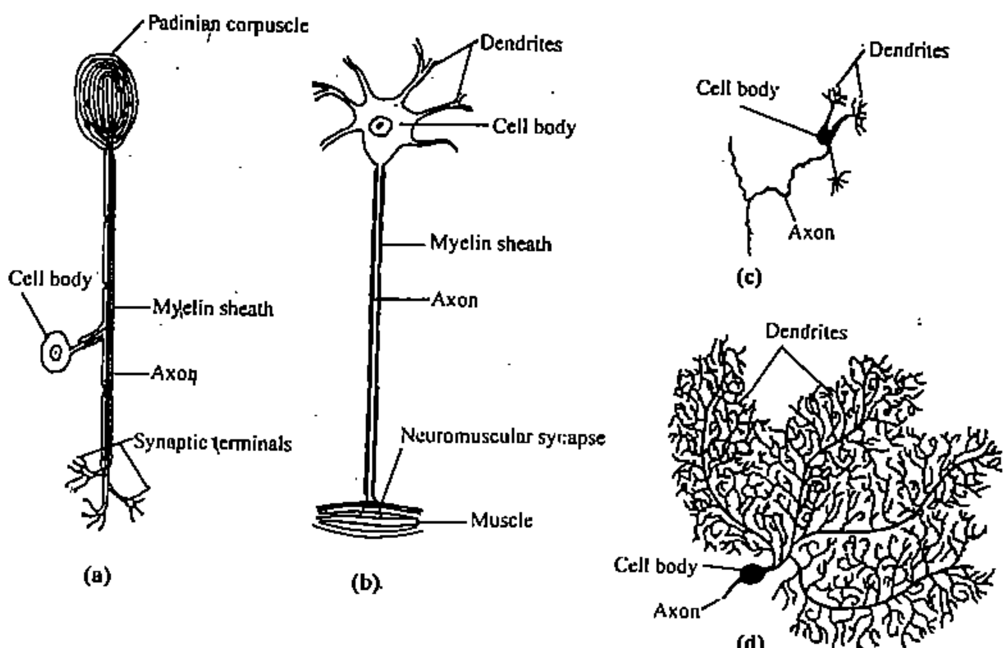


Fig. 10.1 : Typical neurons in vertebrates. a) Somatic sensory . b) Somatic motor. c) Granule cell (cerebellar cortex). d) Purkinje cell (cerebellar cortex).

Though the basic components of the nervous system is the neuron, another kind of tissue the **neuroglia** (nerve glue) are interspersed among the nervous elements and provide support and some degree of protection. These do not conduct signals nor emit neurotransmitters.

The two principal types of neuroglia are

1) **macroglia** of ectodermal origin.

2) microglia of mesodermal origin.

One kind of macroglia are the **oligodendrite** cells. These extend processes that wrap around axons. This wrapping or sheath is composed of **myelin** a substance rich in fats and proteins. Myelin sheaths are present generally in axons of only vertebrates. Axons of neurons outside the brain and spinal cord are also coated by ribbon like cells. These are **Schwann** cells and are similar to oligodendrites in that they also produce myelin that serves as insulating material which in the manner of coating on an electric wire, prevents loss of energy of the nerve impulse during its passage along the axon. Presence of myelin sheath also helps in fast conduction of nerve impulse as the fibres with thick covering of myelin conduct at the greatest speed. This myelin sheath is interrupted at regular intervals by circular constrictions forming the **nodes of Ranvier**. Amongst the vertebrates, myelin sheaths are absent in cyclostomes.

Another kind of microglial cells are the **astrocytes** which are the largest and the most abundant. They make contact with other nervous tissue and maintain normal nervous tissue physiology. They also play a role in brain development repair and healing and also maintaining the blood-brain barrier.

A collection of nerve cell bodies is known as a **ganglion**. Groups of nerve cell bodies and their dendrites and the proximal unmyelinated portion of the axons have a greyish appearance, they form the grey matter. The brain and spinal cord are chiefly composed of grey matter. On the other hand, white matter is composed of bundles of myelinated fibres. Such bundles are known as **nerve tracts** in the brain and spinal cord and **nerve** in the rest of the body. White and grey matter are sometimes intermingled. Such an arrangement is known as **reticular formation**.

The vertebrate nervous system has two main division.

1) **The central nervous system** (CNS) which consists of the brain and spinal cord.
2) **Peripheral nervous system** (PNS) consisting of the cranial nerves arising from the brain and the nerves and ganglia arising from the spinal cord. Part of the peripheral nervous system is composed of autonomic nerves which are distributed to those parts of the body that are under involuntary control.

   Let us now consider the central nervous system. But before you move onto the next section try the SAQ given below.

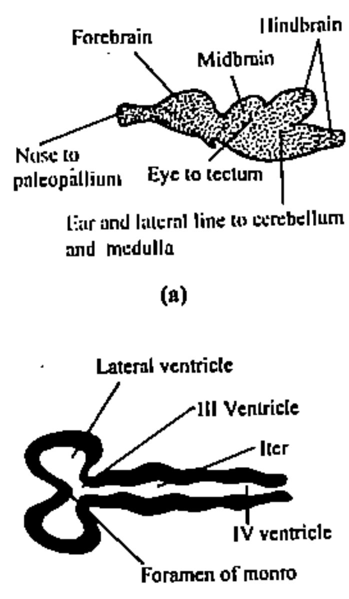


Fig. 10.2 : a) Diagrammatic view of the major subdivisions of the primitive vertebrate brain and their connections to the sense organs. b) Ventricles of the brain.

SAQ 1

Correct the following statements suitably:

a) Spinal cord and brain are formed of white matter.
b) Myelin sheaths are secreted by astrocytes.
c) Myelin sheaths are found only in the axons of the brain.
d) Bundles of axon in the brain form the reticular formation.

10.3 CENTRAL NERVOUS SYSTEM

The central nervous system is composed of the brain, which lies within the cranial cavity of the skull and the spinal cord lying within the neural canal formed by the neural arches of the vertebrae. With the differentiation of the neural tube of the embryo into the brain and spinal cord its original cavity becomes modified to form the fluid filled **ventricles** that are connected spaces located within the centre of the brain and the narrow central canal of the spinal cord.

The anterior end of the neural canal can be recognised into three embryonic regions, **prosencephalon, mesencephalon** and **rhombencephalon**. These form the **forebrain, midbrain** and **hindbrain** in the adult (Fig. 10.2).

10.3.1 Cavities of the Brain and Spinal Cord

The anterior end of the prosencephalon gives rise to the **telencephalon** that ultimately forms the two cerebral hemispheres in the higher forms; with the development of the cerebral hemispheres the cavities extending into them become lateral ventricles or ventricle I and II (see Fig. 10.2 b.). The remainder of the prosencephalon forms the **diencephalon** and its cavity is known as the **third ventricle**. Ventricles I, II communicate with ventricle III by means of interventricular foramen or **foramen of Monro**. In higher vertebrates the IIIrd ventricle communicates with mesencephalon by **cerebral aqueduct** a narrow canal and posteriorly the cerebral aqueduct leads into the **fourth ventricle** in the rhombencephalon. The portion of the fourth ventricle within medulla oblongata is referred to as **myelocoele** which is continuous with the canal of the spinal cord. The cavities of the brain and spinal cord are filled with lymph like **cerebrospinal fluid.**

10.3.2 The Spinal Cord

The portion of the neural tube which forms the spinal cord undergoes considerably less modification than that forming the brain. It generally assumes the shape of a more or less cylindrical, but slightly flattened tube. It widens at the anterior end, where it is continuous with the medulla oblongata. The posterior end usually tapers down to a fine thread the **filum terminale.**

In cyclostomes and fishes the spinal cord is fairly uniform in diameter but in most tetrapods two prominent swellings or enlargements are seen where the nerves going to the limbs arise. In the anterior part the cervical enlargement is the region where the large nerves supplying the forelimbs arise and the lumbar enlargement, near the posterior end of the cord where the nerves supplying the hindlimbs originate. In limbless forms such as snakes neither enlargement is seen.

Grey and white matter of the cord

In cross section, the spinal cord is seen to be composed of grey and white matter. The grey matter is almost completely surrounded by the white matter. The grey matter in amniotes is arranged in the shape of the letter 'H' (Fig. 10.3). The portions corresponding to the upper bars of the 'H' extend dorsally and are known as **dorsal columns** and the lower bars, the **ventral columns.** The connecting bar in which the central canal lies forms the **dorsal and ventral grey commissures,** above and below respectively (Fig. 10.3 a).

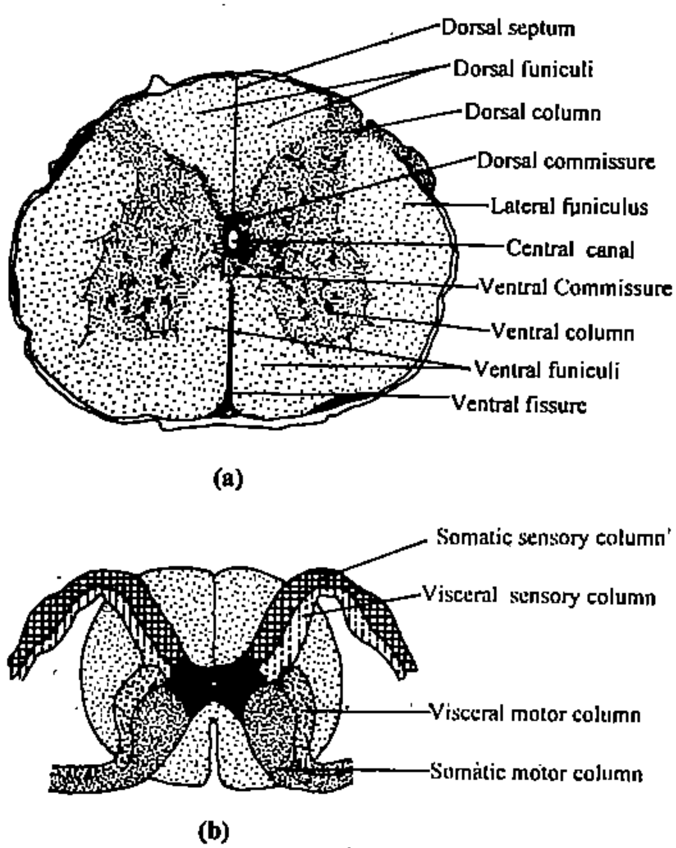


Fig. 10.3 : a) A cross section of spinal cord of cat, b) Relative positions of the four columns of grey matte in each side of spinal cord.

The cell bodies in the dorsal columns are, for the most part, those of association neurons. Their dendrites form synapses with the axons of sensory or afferent nerve fibres which enter the spinal cord via the dorsal roots of spinal nerves.

All functions in the body can be termed as either somatic or visceral. Somatic functions are those carried out by the skin and its derivatives, voluntary muscles and skeletal structures. Visceral functions are performed by other organ system of the body i.e. digestive, respiratory etc.

The axons of the association neurons form synapses with the dendrites of motor or efferent neurons, the cell bodies of which are located in the ventral columns. The somatic sensory fibres carry impulses from somatic tissue to central nervous system. They form synapses with cells in the upper portion of dorsal columns, while visceral sensory fibres form synapses with cells in lower portion of the dorsal column (Fig. 10.3 b). The cell bodies of somatic motor neurons and fibres are located in the lower portions of the ventral column (Fig. 10.3 b), whereas, the cell bodies of visceral motor neurons and fibres have their origin in the upper and lateral portions of the ventral columns.

The white matter of the cord is arranged in longitudinal columns called **funiculi** which lie outside the grey matter (Fig. 10.3 a). The funiculi are divided into fibre tracts, composed of medullated fibres, carrying impulses up and down the cord and to and from the brain. Lateral funiculi lie between dorsal and ventral columns, the dorsal funiculus lies between the dorsal septum and dorsal column and a ventral funiculus is located between the ventral fissure and ventral column of grey matter. The two ventral funiculi are connected through the ventral commissure. The dorsal funiculi carry the sensory nerve impulses up the cord and to the brain, while those in the ventral funiculi are primarily motor, carrying impulses down the cord and from the brain. The lateral funiculi carry both sensory and motor fibres.

Lower vertebrates do not have such an elaborate arrangement of columns and funiculi. In amphioxus there is no clear cut distinction between white and grey matter as medullated fibres have not appeared. In cyclostomes there is yet no sharp delineation between grey and white matter in the spinal cord.

SAQ 2

a) Match the following :

Telencephalon	Myelocoel
Diencephalon	Fourth ventricle
Rhombencephalon	Lateral ventricles
Medulla oblongata	Third ventricle

b) Fill in the blanks with appropriate words from the text.

i) The dorsal column of the spinal cord has cell bodies of .... neurons.
ii) Sensory nerve fibres enter the spinal cord via the .... roots.
iii) Ventral columns of the spinal cord contain the cell bodies of .... neurons.
iv) .... carry messages upto the brain while ....carry messages down the cord from the brain.

10.3.3 The Brain

The chordate brain is basically an enlargement of the anterior end of the neural tube. In primitive condition the cell bodies of the neurons comprising the central nervous system are aggregated around the central canal of the neural tube. Although this arrangement persists in the spinal cord, in the brain region, migration of cells to the peripheral areas occurs.

In amphioxus the brain is seen in its simplest form, as a cerebral vesicle. As the vertebrates evolved their brain grew larger and more complex, and the various parts of the brain developed to suit the specialised demands of their particular environment. For example, cavefish, that live in permanently dark subterranean environments have reduced eyes. Correspondingly, the part of the brain which normally receives visual input is reduced as well. In salmon, on the other hand the same portion is enlarged as visual information constitutes a large part of the sensory input to the brain.

The three primary divisions of the brain prosencephalon (forebrain), mesencephalon (midbrain) and rhombencephalon (hindbrain) are often referred to as the brain stem (Fig. 10.2a). Each of these divisions may have evolved in association with the major senses. Forebrain or prosencephalon is related to the sense of smell; midbrain or mesencephalon to sight; and the sense of pressure changes, equilibrium can be related to the hindbrain or rhombencephalon. Cerebral hemispheres, roof of midbrain and cerebellum appeared later as outgrowths of the brain stem and nerve cells migrated into them so that grey matter appears on the periphery in these parts.

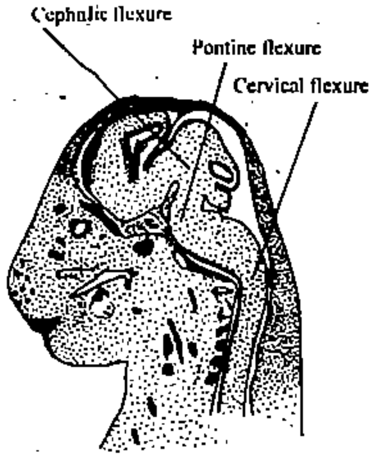


Fig. 10.4 : Flexures of the brain as seen in sagittal section of 18 day old rat embryo.

Flexures

Primitively, the vertebrate brain was merely a modestly developed anterior region of the neural tube. Only in the amphioxus do we find that the brain and spinal cord are in a straight line. With evolution, we find that certain flexures or bending of the brain occurs during embryonic development. The anterior end folds downwards giving rise to a **cephalic flexure** (CF) (Fig. 10.4).

Since the brain lengthens more rapidly than other head structures, the bending is influenced by space limitations. In all vertebrates a cephalic flexure occurs in the region of the mesencephalon in such a manner that the derivatives of the forebrain are bent downward at right angles to the rest. The second flexure is **cervical** which occurs near the junction of medulla oblongata and spinal cord. The third **pontine flexure** is found in the region of the metencephalon and is opposite in direction to the other two.

Meninges

Both brain and the spinal cord are surrounded by membranes. These membranes protect and give support to the central nervous system and their complexity increases as the vertebrates evolve.

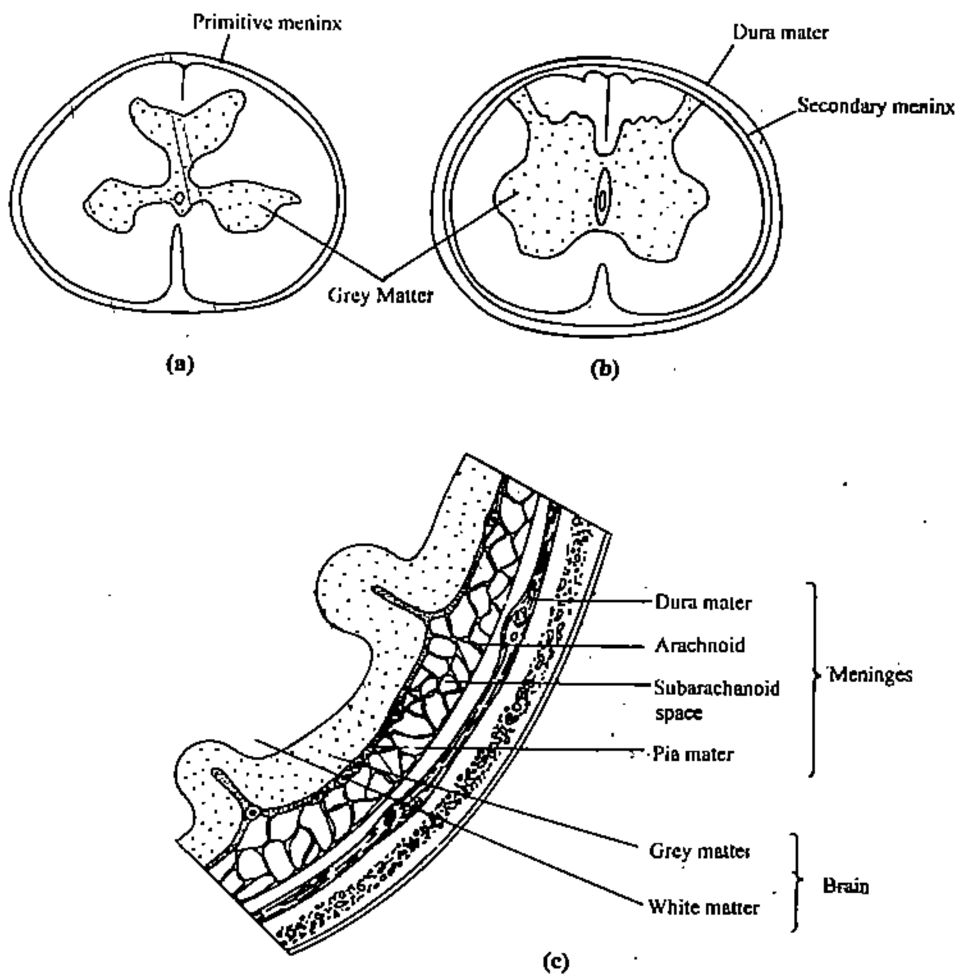


Fig.10.5 : Meninges. a) Meninges of fish consist of only a single thin layer of primitive meninx. b) In all tetrapods except mammals the meninges is double layered. c) Cross section of a triple layered meninges in mammals.

Cartilage and bone are covered with a tough vascular membrane, perichondirum, that lines the cavities in which the brain and spinal cord lie. In cyclostomes and fishes (Fig. 10.5a) a single membrane, meninx primitiva forms a close union with brain and spinal cord. With the adoption of terrestrial life the meninges doubled. In amphibians, reptiles and birds (Fig. 10.5b), instead of a single meninx, an inner pia-arachnoid layer and outer dura mater is observed. The cavity between these two layers is filled with cerebrospinal fluid that protects the brain and spinal cord from shocks during terrestrial locomotion. In mammals (Fig. 10.5 c) the tough dura mater persists and pia-arachnoid membrane differentiates into two layers, an inner pia mater and an outer arachnoid membrane. The pia mater contains blood vessels that supply the underlying nervous tissue. A subarachnoid space filled with cerebrospinal fluid makes its appearance between the two. In the brain region the cranial dura mater fuses with the endorachis and the epidural space and thus disappears. The cerebrospinal fluid, present in the ventricles of the brain, circulates slowly through the various cavities and spaces between the membranes.

The cerebrospinal fluid is derived from blood and returns to it while circulating over the nervous tissue and in the ventricle of the brain. It is however, devoid of all red blood cells as well as other large formed elements. When a person is injured and trauma to the CNS is suspected, the cerebrospinal fluid sample is taken. If it contains red blood cells then the brain or spinal cord may be damaged.

Grey and white matter of the brain

The grey matter of the brain like the spinal cord consists of nerve cell bodies with their dendrites and proximal portions of their axons. They are usually together in the form of nuclei. The white matter consists of tracts of myelinated fibres connecting various parts of the brain and of ascending and descending fibres carrying impulses to and from the spinal cord.

Let us now consider the structure of the vertebrate brain as it has evolved from the primitive chordates to the advanced mammals. It would be better if you would read this description while referring to Figure 10.6 closely.

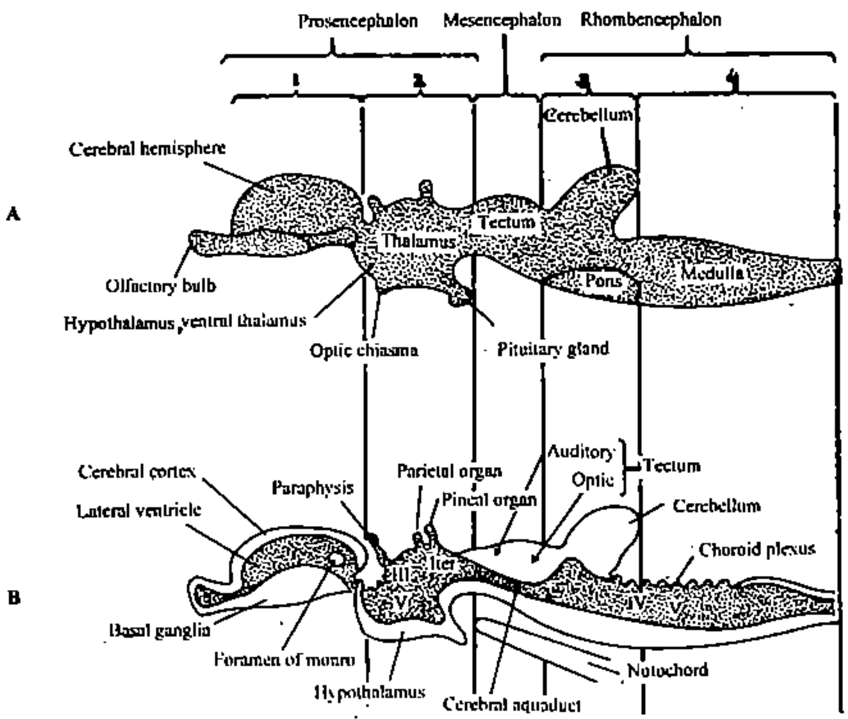


Fig. 10.6: Structure of generalised brain in vertebrates. A) Prosencephalon consists of (1) telencephalon and (2) diencephalons. Rhombencephalon consists of (3) metencephalon and (4) myelencephalon, (B) lateral view of generalised brain showing ventricles.

Hindbrain consists of the **myelencephalon** and **metencephalon** (Fig. 10.6 A).

Myelencephalon is the posterior most portion of the hindbrain and merges with the spinal cord. It forms the **medulla oblongata**. It is also referred to as the oldest part of the brain as it is well developed in all vertebrates even though other portions may be rudimentary. The general structure of medulla is like the spinal cord except that the central canal enlarges (as the 4th ventricle) and a thin highly vascular roof known as posterior choroid plexus forms dorsal to the central canal. The choroid plexi of the brain produce the cerebrospinal fluid and control its composition.

The medulla contains important nerve centres or nuclei which control vital physiological functions that are involuntary like heartbeat, respiration and metabolism. It also houses the primary nuclei of cranial nerves. Damage to the medulla can be life threatening. The dorsal anterior portion of the medulla contains-nuclei associated with the nerves from lateral line system and inner ear. In terrestrial vertebrates these nuclei are associated with equilibrium and auditory functions of the ear. The medulla also serves as a route for descending and ascending pathways that run from and to the higher brain centres.

Metencephalon is the anterior part of the hindbrain, the dorsal part of which becomes elevated and thickened to form the **cerebellum.** The cerebellum is highly developed in animals that are active and whose balance and precise motor movements are well developed whether in water, air or on land.

The function of the cerebellum is to monitor and modify motor outputs but it does not initiate them. It operates at an involuntary level and maintains equilibrium. Information regarding touch, vision, hearing, proprioreception (related to limb position, joint angle, state of muscle contraction) and motor input from higher centres of the brain are processed in the cerebellum. For an organism to fly, jump swim in a three dimensional world in space in relation to gravity, the cerebellum is involved in maintaining its positional equilibrium. Another function of cerebellum is refinement of motor action, removal of cerebellum will still allow the organism to move but the movement would be uncoordinated. The size of the cerebellum is proportional to its role. In fishes and amphibians (salamanders) the cerebellum is small and simple, as their locomotion is simple and mainly co-ordinated by the spinal reflexes. In advanced tetrapods such as mammals and birds there are so many cells in the cortex that it is folded. The increase in cells also increases the number of fibres and these fibres form bulging masses. The ventral side of metencephalon of mammals and some birds is composed of a prominent mass of transverse nerve fibres known as **pons.** Motor fibres from cerebral cortex pass via the pons to the cerebellum.

Midbrain (Figs. 10.6A and B) or **mesencephalon** is marked off from the hindbrain very early in development by a conspicuous constriction, the isthmus. The floor and walls of the mesencephalon are thick and composed of fibre tracts, cerebral peduncles connecting forebrain and hindbrain. The roof consists of a thick layer of grey matter, the **optic tectum.** The central canal of the midbrain is of a relatively small diameter forming a canal the cerebral aqueduct between the hindbrain and midbrain. In lower vertebrates two optic lobes arise from the roof. The optic lobes in lower vertebrates serve as centres for the visual sense. In higher forms however the optic lobes are practically solid and the roof is known as **tectum.**

In fishes and amphibians the midbrain is often the most prominent region of the brain as all visual information is received here directly from the eyes.The anterior region of tectum in snakes and mammals is specialised into superior colliculi which serves to integrate visual inputs and posterior region is known as inferior colliculi, which integrates auditory inputs. Thus, visual information in all vertebrates reaches the forebrain via the tectum. In mammals however, due to development of cerebral hemispheres the superior colliculi are less important as visual centres.

Forebrain consists of the **diencephalon** and the **telencephalon.** Diencephalon is the initial portion of the forebrain and regulates many bodily functions. It contains the expanded neural canal or third ventricle (Figs. 10.6 A and B) with a thin dorsal roof, the **epithalamus**, the walls form the **thalamus** and the floor forms the **hypothalamus.** Each is thickened by the presence of a proliferation of neurons. The epithalamus is made up of a **parietal body** or **parapineal** body and **pineal gland** in lower vertebrates. The parietal body is absent from most higher vertebrates, only the pineal body or gland is present in all. The pineal body affects skin pigmentation in lower vertebrates and probably affects photoperiod. In higher vertebrates it is important in controlling biological rhythms. The thalamus contains a number of cell clusters that are important in co-ordinating sensory impulses from all parts of the body, except olfactory impulses that go directly to the cerebral cortex. The thalamus is actually a relay centre for all sensory information going to the cerebral cortex. The anterior part of the roof of the diencephalon forms the anterior choroid plexus.

The hypothalamus is the most ventral portion of diencephalon. This includes the **posterior pituitary** (neurohypophysis). Hypothalamic nuclei are involved in maintaining the body's internal homeostasis. They regulate appetite, sexual activity, body temperature, water balance and alertness and some aspects of emotional behaviour. Hypothalamus stimulates the pituitary gland to regulate many homeostatic functions.

In neurophysiology a nucleus is a small cluster or aggregate of nerve cell bodies within the central nervou system.

Telencephalon or **cerebrum** is the terminal portion of the forebrain. It shows the greatest difference in degree of development among vertebrates. In primitive vertebrates the forebrain is mainly concerned with integrating sensory inputs from nasal olfactory sensors which are important in complex aspects of behaviour.

From both sides of telencephalon arise the **cerebral hemispheres** that are associated with paired **olfactory bulbs**. The neural canal extends into the lateral ventricles of the cerebral hemispheres. (In amphioxus the neural canal does not branch as there are no cerebral hemispheres nor olfactory bulbs). The cerebral hemispheres enlarge to an increasing degree as the vertebrate scale is ascended and in the highest forms the cerebral hemispheres cover over the greatest part of the remainder of the brain.

The seat of consciousness lies in the cerebral hemispheres. The nerve centres controlling the activities which characterise the highly developed psychic life of man, such as intelligence, thought and sensation are located in this region.

At the anterior end of each hemisphere is an outgrowth called the olfactory lobe (Fig. 10.6 B). The olfactory lobe may come in contact with the nasal apparatus. In the lowest living vertebrates, the hemispheres are divided into an anterior and posterior olfactory lobe, concerned mainly with receiving olfactory impulses that are relayed to the diencephalon. In all vertebrates the floor of each hemisphere differentiates into a thickened **corpus striatum**. The grey regions of corpus striatum are often referred to as basal nuclei. The remainder of the hemisphere consists of a pallium which form a roof over the lateral ventricles. It is the pallium that has become so highly developed and modified in the evolution of the higher groups of vertebrates. In fishes the pallium is thin-walled and the grey matter is present only on its inner walls adjacent to the ventricle and the telencephelon serves mainly as an olfactory centre. As the vertebrate scale is ascended, there is an increasing tendency for nerve cells from the inner grey layer to migrate out into peripheral area. The first real change is seen in reptiles. The cerebral hemispheres enlarge in size and extend backwards to cover partially the diencephalon and increased grey matter migrates to the periphery. A new area the **neopallium** appears in the reptiles and this is what forms the large cerebral hemispheres in mammals. In crocodile for the first time nerve cells migrate to the outer surface in the neopallium and form the true cerebral cortex.

In mammals the neopallium enlarges enormously and the grey cell bodies form a layer of grey matter which even in humans is only a few centimetres thick. In all vertebrates below mammals, the cerebral hemispheres though large, are smooth. In many mammals the surface becomes convoluted or folded. The ridges are called **gyri** and depressions **sulci**. These convolutions increase the surface area and total amount of grey matter. Larger mammals have more convolutions though these are not necessarily connected to intelligence!

Decussation

Commissures serve to connect similar regions in the left and right sides of the central nervous system, and make bilateral integration possible. There are also fibre tracts in the brain which in their course, cross over, or decussate to the opposite side. Injury to one side of the brain often results in paralysis of muscles of the opposite side.

SAQ 3

a) Match the following correctly.

Metencephalon	Medulla oblongata
Mesencephalon	Cerebellum
Diencephalon	Optic tectum
Telencephalon	Epithalamus, hypothalamus thalamus
Myllencephalon.	Cerebrum

b) Fill in the blanks:

i) In fishes the ....covers the brain and spinal cord.

ii) Reptiles and birds have a double membrane made up of .... and .... to protect the brain.

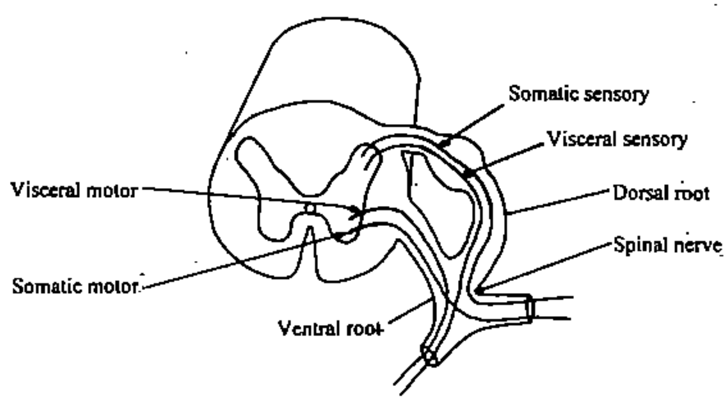
iii) In mammals the layers of the meninges are called .... and ....

10.4 PERIPHERAL NERVOUS SYSTEM

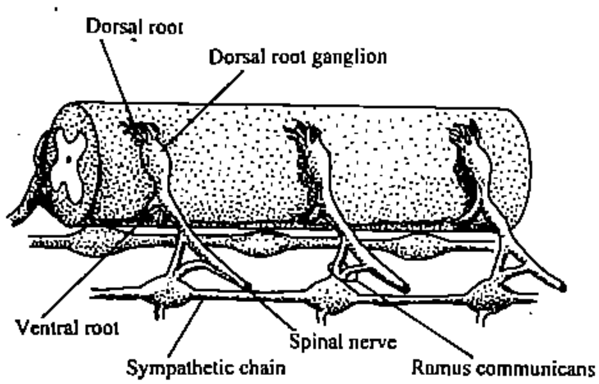
The nerves and ganglia which form connections with the central nervous system and which are distributed to all parts of the body, comprise the peripheral nervous system or PNS. The autonomic portion of the peripheral nervous system is composed of those nerve fibres distributed to structures under involuntary control. Connection with the central nervous system is mediated via spinal and cranial nerves.

10.4.1 Spinal Nerves

Each spinal nerve connects to the spinal cord by means of two roots, dorsal and ventral. Dorsal roots originate from neural crests. A band of neural-crest cells is present on either side of the spinal cord and extends in a longitudinal direction in the embryo.



(a)



(b)

Fig. 10.7 : Spinal cord and spinal nerve anatomy.
- a) Sensory and motor routes in the spinal nerve.
- b) Dorsal and ventral roots connect the spinal nerve to the spinal cord. Spinal nerve joins the autonomic chain ganglion through a communicating ramus.

At metameric intervals in each band enlargements occur and the parts of the band between enlargements gradually disappear. In these thickenings, each neuroblast sends out two processes: 1) an axon which grows towards the spinal cord and enters in the region of the dorsal columns and 2) a dendrite, which grows peripherally to the skin, voluntary muscles, skeleton, or some visceral structures. These thickenings form the dorsal root ganglion (Fig. 10.7). The ventral roots arise from neurons in the grey matter of the ventral column of the spinal cord.

The sensory nerve impulses travel towards the spinal cord via the dorsal roots and are spoken of as **afferent fibres**. The sensory fibres are said to be either somatic or visceral. Somatic sensory fibres are those coming from the skin and its derivatives, voluntary muscles and skeletal structures. They form synapses with cells in the somatic sensory column of grey matter. Visceral sensory fibres from visceral structures terminate in the visceral sensory column of the grey matter of the cord (see Fig. 10.3 b again).

Cell bodies of the neurons making up the ventral roots lie in the grey matter of ventral columns of the spinal cord. In motor fibres, impulses are conveyed away from the spinal cord, hence they are referred to as **efferent fibres**. Somatic motor fibres arise in the somatic motor column of grey matter in the spinal cord and are distributed to somatic structures . Visceral motor fibres pass to autonomic ganglia, where they form synapses with motor autonomic neurons (Fig. 10.7 b).

The dorsal roots are strictly sensory in the amniotes. In amphioxus and lamprey dorsal roots are composed of both sensory and motor fibres. In fishes and amphibians visceral efferent fibres pass through both dorsal and ventral roots.

Near the area where dorsal and ventral roots unite to form spinal nerves, three rami are usually given off. These include 1) a dorsal ramus supplying skin and muscles of dorsal part of the body, 2) a ventral ramus distributed to the ventral and lateral regions, and 3) a visceral ramus that forms connections with one of the chain ganglia of the peripheral autonomic nervous system (Fig.10.7 b). Both dorsal and ventral rami are composed of somatic sensory and somatic motor fibres.

A typical visceral ramus consists of a white ramus and a grey ramus. The white ramus carries medullated visceral sensory and medullated preganglionic motor fibres. The grey visceral ramus carries only non-medullated postganglionic autonomic motor fibres. The fibres of grey ramus join the spinal nerve and travel out either via dorsal or ventral rami where they supply structures under involuntary control such as blood vessels, muscles and glands of the skin.

10.4.2 Cranial Nerves

The peripheral nerves which form connections with the brain are called cranial nerves. There are 10 pairs of cranial nerves in anamniotes and 12 in amniotes. All but the first four are joined to the medulla oblongata. Some are entirely sensory, composed of afferent fibres alone; others are purely motor. Still others are mixed nerves, consisting of both motor and sensory fibres. The nature and distribution of different cranial nerves is given Table 10.1.

Early human anatomists assigned them numbers in an anterior posterior sequence. This system has now proved to be artificial and superficial but continues because of convenience and familiarly. Later in 1894 a new cranial nerve was discovered which was numbered 0 to preserve the terminology of 1-10, or 1-12.

Table 10.1: Cranial nerves, their nature and distribution.

Number	Name of the Cranial nerve	Nature of the cranial nerve	Distribution of the cranial nerve to various organs
0	Terminal	Somatic Sensory	From olfactory mucous membrane to Jacobson's organ (Best developed in elasmobranch fishes).
I	Olfactory	Special somatic Sensory	From Olfactory epithelium, olfactory lobes, Jacobson's organ.
II	Optic	Special somatic Sensory	From retina to optic bulb in brain optic tectum. (actually a fibre tract of brain rather than nerve)
III	Occulomotor	Somatic Motor	To four of the six eye muscles.
IV	Trochlear	Somatic Motor	To superior oblique eye muscle.
V	Trigeminal	Mixed	From Skin, dorsal side of head and snout, conjunctiva, cornea, iris, ciliary body, lachrymal gland, nose and forehead skin, eyelid.

	Maxillary	Somatic Sensory	From upper jaw, upper lip, lower eyelid, teeth of upper jaw.
	Mandibular	Mixed	From lower lip, teeth of lower jaw, skin of temporal region, external ear, lower part of the face to muscles used in chewing.
VI	Abducens	Somatic Motor	To eye muscle, nictitating membrane.
VII	Facial	Mixed	To muscles of face, scalp, external ear, lacrimal gland, mucous membrane of nose
VIII	Auditory	Special somatic Sensory	From inner ear.
IX	Glossopharyngeal	Mixed	From posterior region of tongue and taste buds.
X	Vagus	Mixed	To lower jaw and throat, larynx and salivary glands.
XI	Spinal accessory	Visceral Motor	To pharynx, larynx, (Considered as posterior branch of vagus)
XII	Hypoglossal	Somatic Motor	Muscles of tongue and muscles below the tongue in the lower jaw

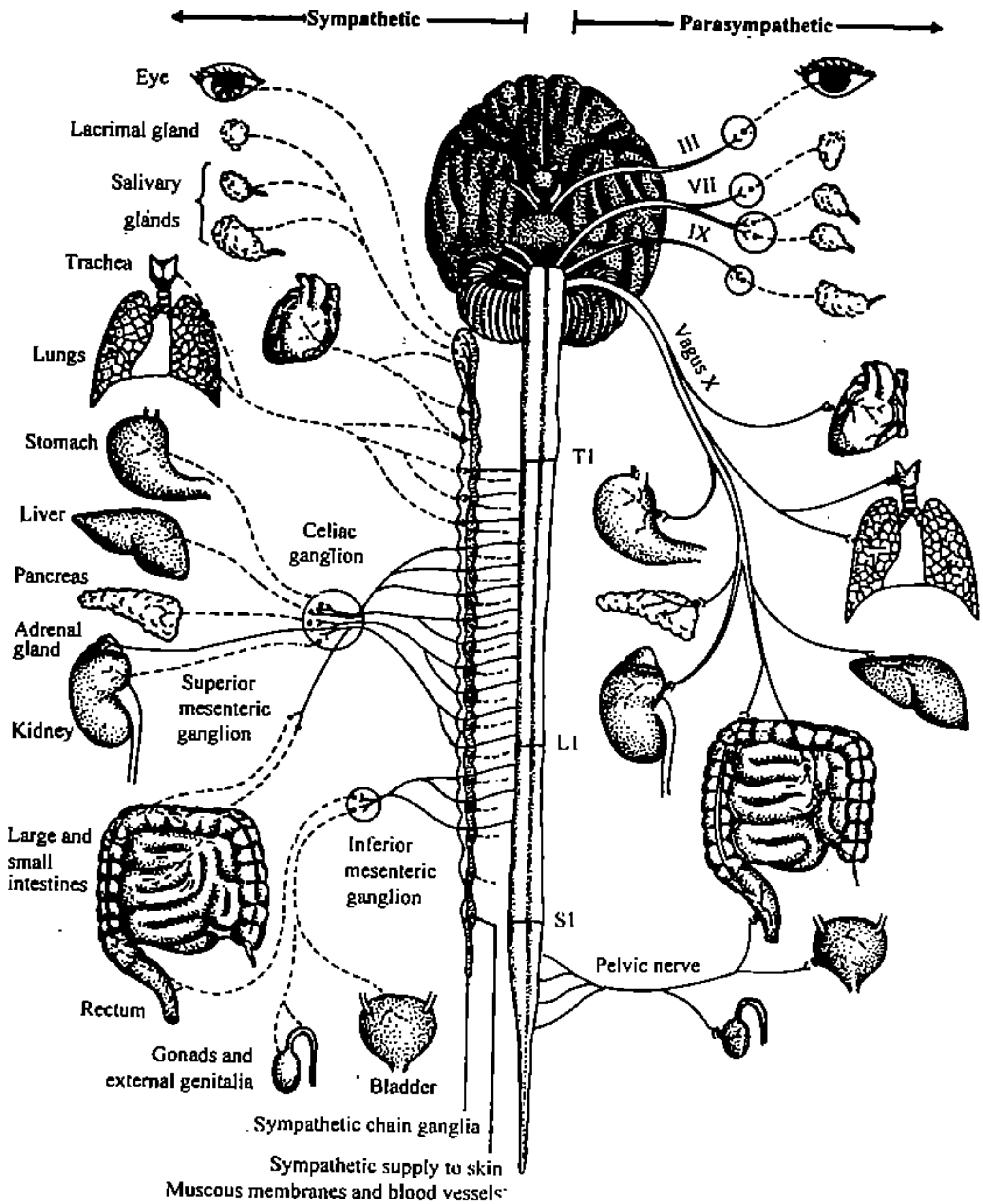


Fig.10.8 : Autonomic nervous system in humans. *Left* sympathetic division postganglionic fibres shown in dotted lines. *Right* parasympathetic division.

10.4.3 Autonomic Nerves

The autonomic portion of the peripheral nervous system is composed of both sensory and motor fibres. Autonomic sensory fibres monitor the internal environment of the organism, that is, blood pressure, oxygen and carbon dioxide tension, core and skin temperature and activity of the viscera, while the autonomic motor fibres send impulses to smooth muscles and glands in various parts of the body. Autonomic nervous system regulates the functions of structures which are under involuntary control. The proper functioning of this part of the nervous system is necessary for regulating such activities as rate of heartbeat, respiratory movements, composition of body fluids, constancy of temperature, secretion of various glands, peristalsis, and other vital processes and it is controlled by hypothalamic centres.

Even though autonomic system is not under voluntary control, conscious centres also can affect visceral activity controlled by the autonomic nervous system. For example through practice of meditation or through deliberated effort it is possible to affect the heart beat or release of sweat. The ancient yogis mastered the art.

The system is composed of preganglionic and postganglionic fibres and a number of ganglia which serve as relay centres (Fig. 10.7).

The cell bodies of the preganglionic neurons are located in the visceral motor column of grey matter in the central nervous system. Their medullated fibres pass to outlying ganglia. Postganglionic neurons have grey nonmedullated axons. The cell bodies of these neurons, lie in outlying ganglia which are often located at some distance from the central nervous system. It is here, that the preganglionic fibres form synapses with the dendrites of postganglionic neurons.

The autonomic portion of the peripheral nervous system is divided into two main parts, the sympathetic and parasympathetic system. The essential parts of both the systems are summarised in Figure 10.8.

Both these systems work antagonistically. The sympathetic system functions to strengthen the body reactions against adverse condition, it calls for expenditure of energy. The parasympathetic system is concerned with restoring and conserving energy. In mammals, almost every visceral organ has sympathetic and parasympathetic innervation except the adrenal gland, peripheral blood vessels and sweat glands; all of which receive only sympathetic innervation. Cessation of sympathetic stimulation allows these organs to return to resting state.

Post ganglionic axons of the sympathetic system except those going to uterus and sweat glands secrete norepinephrine or epinephrine (also known as noradrenaline or adrenaline). The postganglionic axons of the parasympathetic system release the neurotransmitter acetylcholine. Acetylcholine is also released between pre- and post ganglionic fibres in both these divisions of the autonomic system (Fig.10.9).

The sympathetic and parasympathetic functional components are clear in mammals, however, in other vertebrates their comparative anatomy is not well understood.

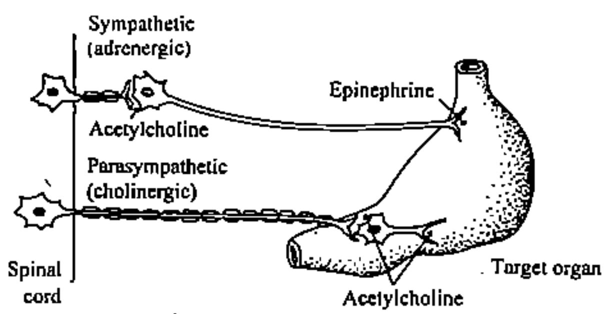


Fig. 10.9 : Neurotransmitters of the autonomic system. Epinephrine and acetylcholine are released at the post ganglionic nerve endings of the sympathetic and parasympathetic circuits respectively. This is the basis of their antagonistic functions.

Sympathetic nervous system

The visceral motor neurons that participate in sympathatic activity depart from the thoracic and lumbar regions of the spinal cord, hence it is also known as 'thoracolumbar outflow'.

On either side of the ventral part of the vertebral column lies a long sympathetic trunk, extending from foramen magnum to the coccyx. At fairly regular intervals, each sympathetic trunk bears enlargements known as chain ganglia (Fig.10.8). The chain ganglia are numbered according to the vertebrae opposite which they lie, but fusion may occur which obscures their segmental character. The white visceral rami of all thoracic spinal nerves and I, II & III lumbar nerves may terminate in the ganglion at the point where they enter or send fibres up or down the sympathetic trunk. The sympathetic preganglionic neurons have short axons and synapse in the chain ganglion or in a ganglion some distance away from the vertebral column. The postganglionic fibre is usually long. Other preganglionic fibres pass without synapses through ganglia of the coeliac plexus, located in the abdominal region in front of the lumbar vertebrae. The prevertebral ganglia of the coeliac plexus include the coeliac superior mesenteric and inferior mesenteric ganglia.

Preganglionic fibres pass directly to the medulla of the adrenal gland. This ectodermal, glandular structure, derived from neural-crest cells is composed of specialised, or modified, sympathetic ganglionic cells which are homologous with postganglionic sympathetic neurons and secrete adrenaline and noradrenaline too.

Because adrenaline and noradrenaline serve as chemical signals of the postganglionic nerve endings, it could cause confusion in the adrenals which secrete them as hormones. Therefore, postganglionic fibres are absent. Since preganglionic nerve endings secrete acetylecholine, direct innervation of the adrenal removes the possibility of any ambiguity.

Functions of sympathetic system

1. Constriction of cutaneous blood vessels, causing pallor.
2. Contraction of pili muscles, causing "goose flesh" and causing the hair to stand erect.
3. Secretion of sweat glands.
4. Dilation of pupil.
5. Reduction in amount of saliva secreted.
6. Acceleration of heartbeat.
7. Dilation of the bronchi.
8. Relaxation or inhibition of the smooth muscles of the digestive tract.
9. Relaxation of bladder musculature.
10. Contraction of the sphincter muscles of the bladder.
11. Increase in blood sugar, red corpuscles in the blood stream.
12. Rise in blood pressure.
13. Decrease in clotting time of blood.

The above reactions together are usually associated with pain, anger, fear and gear up the body to react suitably to these situation.

Parasympathetic nervous system

The term 'craniosacral' outflow is frequently used to designate the complex of preganglionic fibres of the parasympathetic nervous system as the parasympathetic fibres depart from the v,vi, ix, and x cranial and spinal nerves from the sacral region.The trigeminal, oculomotor, facial, glossopharyngeal and vagus nerves are composed at least in part, of preganglionic parasympathetic fibres (Fig.10.8). The ganglia in which they terminate are situated close to or in, organs supplied by this system. Hence the preganglionic fibres are rather long and the postganglionic fibres are very short.

The part of the parasympathetic system known as the sacral outflow is composed of efferent fibres which course through the white visceral rami of the II, III & IV sacral nerves, which together form the pelvic nerve. The pelvic nerve supplies the lower part of the large intestine, kidneys bladder and reproductive organs. Postganglionic fibres within these organs are relatively short.

Functions of the parasympathetic system:

1) Dilation of blood vessels (except the coronary vessels of the heart).
2) Constriction of the pupil.
3) Increase in salivary and gastric secretion.
4) Constriction of bronchi.

5) Contraction of walls of the digestive tracts.
6) Contraction of bladder musculature.
7) Relaxation of the sphincter muscles of the bladder.
8) Dilation of blood vessels of the external genital organs.

These reactions when taken together are associated with sensations of pleasure or comfort and conserve energy. The general scheme of arrangement of autonomic system is similar in all tetrapods except that it starts from the representation in a primitive form in lower vertebrates and increases in complexity as the evolutionary scale is ascended.

SAQ 4

a) i) Which of the cranial nerves are purely sensory in nature?
   ii) Which part of the peripheral nervous system controls visceral activity?
b) A nerve carrying information about the condition of internal viscera to the central nervous system is a .... nerve.
c) Which of the activities given below are controlled by sympathetic or parasympathetic part of the autonomic nervous system?
   i) dilation of pupil,
   ii) increase in heartbeat
   iii) constriction of bronchi,
   iv) contraction of bladder muscles,
   v) increase in blood sugar, and
   vi) decrease clotting time of blood.

10.5 BRAIN - A COMPARATIVE ACCOUNT

You learnt in earlier sections that all vertebrates share the major brain divisions, ten or more cranial nerves, spinal nerves and major spinal pathways to and from the brain. As we examine the chordates from amphioxus to mammals we find that the structure of brain undergoes various modifications along with the evolution of major head sense organs (eyes, ears, nose, taste and lateral line system). The brain acquired major functions that were not found in primitive forms.

As we compare the brains of various vertebrate classes (see Fig. 10.10) we find that the hindbrain has become specialised for processing sensations from touch, taste and balance from the near environment while the mid- and forebrain have become specialised for processing sensations from the eyes, and nose from the distant environment.

10.5.1 Jawless Fishes

The brains of lamprey (Fig. 10.10 a) and hagfish have a well developed hindbrain that suggests that its functions are the most important. The cerebellum is small and the forebrain is mostly concerned with olfaction. This suggests limited locomotor abilities but highly developed sensory abilities, which is what is required in their environment.

10.5.2 Jawed Vertebrates

The medulla is well developed in all jawed vertebrates showing its connections with the visceral network and as a screen through which all the information enters or leaves the brain.

The cerebellum is distinct in cartilaginous fishes (Fig. 10.10 b) with one or more transverse fissures. In teleosts the cerebellum is large in actively swimming fishes and relatively small in inactive fishes.

Amphibians often have small or rudimentary cerebellum (Fig. 10.10 d) reflecting simple locomotry abilities. In advanced tetrapods, the lateral part of the cerebellum expands to control the muscles of the appendages which are specialised for locomotion.

Cerebellum is seen in alligators amongst reptiles, and becomes more prominent in birds and mammals, again reflecting their complex locomotor abilities.

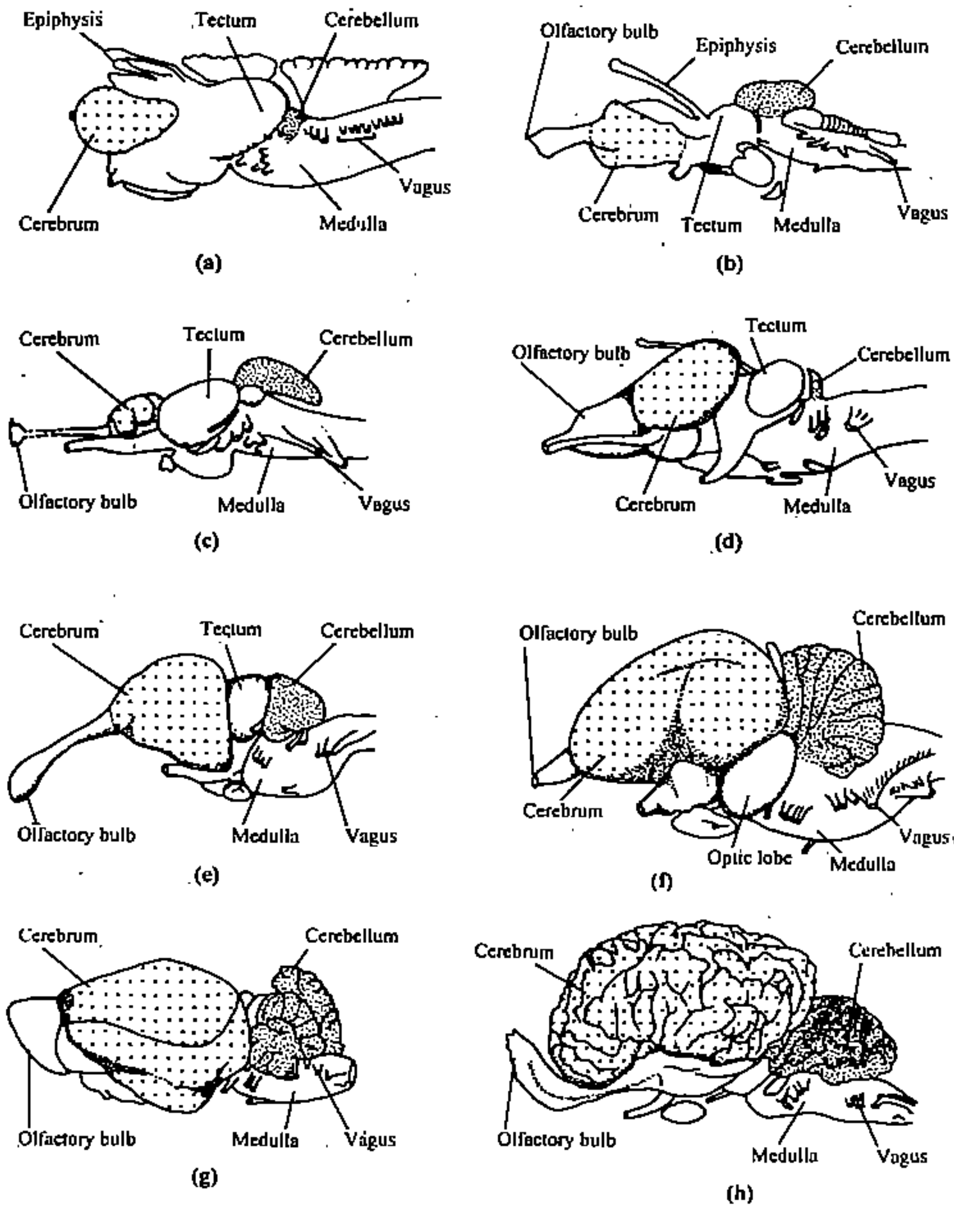


Fig. 10.10: Vertebrate brain (side view). a) Jawless fish. b) Cartilaginous fish. c) Bony fish. d) Amphibian. e) Reptile. f) Bird. g) Primitive mammal. h) Advanced mammal.

In mammals the sides of the cerebellum expand into separate hemispheres (Fig. 10.10 g). In primates, as in no other vertebrates the most lateral part is associated with finger coordination.

The midbrain optic tectum in particular is large in vertebrates that depend on their visual abilities but in mammals it is relatively small as visual functions are taken over by the cerebral hemispheres. In primitive vertebrates the midbrain is relatively important as a principal centre of integration and its sensory link to the cerebrum through thalamus is extremely well developed in amniotes especially in mammals.

The cerebrum is relatively small in all fishes. Olfactory bulbs and a thin walled pallium is present in cartilaginous and bony fishes. In fishes the cerebrum is mainly associated with olfaction. In amphibians the pallium is thicker than fishes.

The first change in the cerebral hemisphere is seen in reptiles with the migration of the inner nerve cells to the peripheral areas. The cerebral hemispheres enlarge greatly and grow backwards to cover partially the diencephalon. The olfactory lobes merge with the cerebral hemispheres. In crocodiles the first emergence of a true cerebral cortex or neopallium is seen.

In birds the olfactory lobes are rudimentary (Fig. 10.10 f). Neopallium, however, is absent in birds. The cerebral hemispheres are large because the corpus striatum of birds is unusually large.

In mammals, particularly in human beings the cerebral cortex is the most highly developed. The neopallium has taken over the greater part of the expanded and highly convoluted surface of the hemispheres and because of this expansion, the hemispheres tend to cover the other brain structures (Fig. 10.10 h). Beginning with marsupials, a broad white mass the corpus callosum appears in mammals between the two hemispheres. It consists of medullated fibres and connects the neopallial cortical sides of the two sides.

SAQ 5

Choose the correct word from the parenthesis

i) Olfactory lobes are well developed in (birds/mammals).
ii) Neopallium is first seen in (birds/reptiles).
iii) Cerebellum is most well developed in (reptiles/mammals).
iv) Optic tectum is not an important visual centre in (fishes/mammals).

10.6 SENSE ORGANS

In earlier sections you learnt about the organisation of the nervous system of vertebrates. The peripheral nervous network gathers information from the various 'sensory receptors' of signals that reach the organism and these in turn are relayed to the central nervous system. In higher centres of the brain these signals or impulses are interpreted as sensations. The receptor organs or 'Sense organs' themselves do not perceive any sensations but merely serve as means of access to the nervous system. The information gathered by sense organs provides the body with a continuous preview of a changing environment. The information may concern **stimulus quality** (.eg. yellow light, static pressure, sweat, taste, pain, etc.), **stimulus intensity** (e.g. brightness, how strong) **spatial patterns**(orientation, distribution). Sensory receptors may be exo receptors or external receptors that receive information from the external environment or intero receptors that receive information from internal organs.

Broadly the various sensory receptors in the animal body can be classified according to the kind of energy they are able to perceive i.e. mechanical, chemical, light or thermal. For additional information you can refer to Table 10.2 which lists the various kinds of receptors found in vertebrates.

Table 10.2 : Extero and intero receptors of vertebrates.

External senses	
Sight	Photoreceptors
Hearing	Phonoreceptors
Smell	Olfactoreceptors
Taste	Gustatoreceptors
Touch	Tangoreceptors
Pressure	Mecanoreceptors
Temperature	Thermoreceptors
Heat	Thermoreceptors
Cold	Caloreceptors
Pain	Frigidoreceptors
Currents of water	Algesireceptors
	Rheoreceptors
Internal senses	
Muscle Position	Proprioreceptors

In general most vertebrates have sensors for the five major senses of taste touch, sight smell and hearing. Some vertebrates have greatly refined one or more of these familiar five. Let us first examine the specific sense organs associated with sight, smell and hearing before we take up the special sensors.

10.6.1 The Eye

The sensing of light is an important ability of chordate. Their most important photoreceptors are eyes, highly specialised structures that originate, as outpocketing of the brain. The simplest and smallest vertebrate photo sensory organ is the **median eye** or **parietal eye** located near the middle of the top of the head (Fig. 10.11). Today only a few fishes, and lizards possess a median eye which forms from the diencephalon. The lizard median eye consists of several thousand sensory cells that transmit information to the brain. There is transparent lens overlying the sensory layer and light is concentrated by the lens on the sensory layer. The median eye is really a dosimeter of light exposure and does not produce any images as the lateral eyes do.

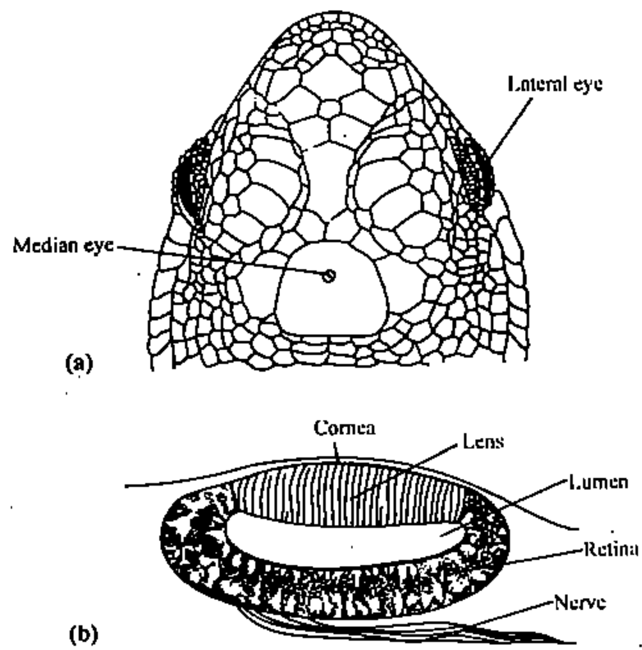


Fig. 10.11 : a) Median eye in a reptile, b) sagittal section of median eye of reptile.

We will discuss the human eye as an example of the vertebrate eye because eyes of all vertebrates are built on the same general pattern with variation according to their habitat.

You would recall the development of the vertebrate eye from unit 17, Block – 3 of the Development Biology course (LSE-06). The embryonic sources of the eye are the anterior brain or diencephalon for the retina and optic nerve ; ectoderm for lens and part of cornea; and nearby mesoderm for sclera, muscles and adjacent tissue. The first signs of the eye appear as lateral bulges of the diencephalon –the optic vesicles, with a small connection to the brain, the optic stalk. As the optic vesicle enlarges it contacts the ectoderm of the head and invaginates to form the two layered optic cup. The inner wall of the cup develops into the sensory retina, while the outer one forms the pigmented layer of the retina (choroid tapetum) The opening of the cup narrows to form the pupil. The ectoderm thickens, invaginates to form the closed lens of the eye. The distal rim of the optic cup forms the ciliary body and iris along with the pupil. They are innervated with autonomic postganglionic fibres. In addition to the ectodermal coat of the eye, a vascular choroid wall fused with the outer protective sclerotic coat is present. This entire structure is called the eye ball. In the front region the sclerotic layer becomes transparent forming the cornea to which the conjuntiva is attached. The cornea has a complex development that includes scleral connective tissue, ectoderm, and neural crest cells.

Cones are atleast two order of magnitude less sensitive than rods to light and fail to function at night or in low intensity light.

The eye functions like a camera and the retina is the screen on which the image is focused. This screen is multilayered and includes sensory and nonsensory cells. The photosensitive cells are of two types, the **rod cells** and **cone cells**.At the margin of the retina near the ciliary body and iris there are no rods or cones.The rods contain a photo sensitive pigment **rhodopsin** or **visual purple** which gets bleached into **lumi – rhodopsin** by low intensity light and initiates rod cell activity to produce a visual stimulus. In the cones another pigment **iodopsin** is present that is bleached only in high intensity light. Vertebrates that usually live in low light levels or are nocturnal have more rods than cones. Those that need to see more details have large retinas because resolution is controlled by the density of receptors. Cone cells are responsible for colour vision.

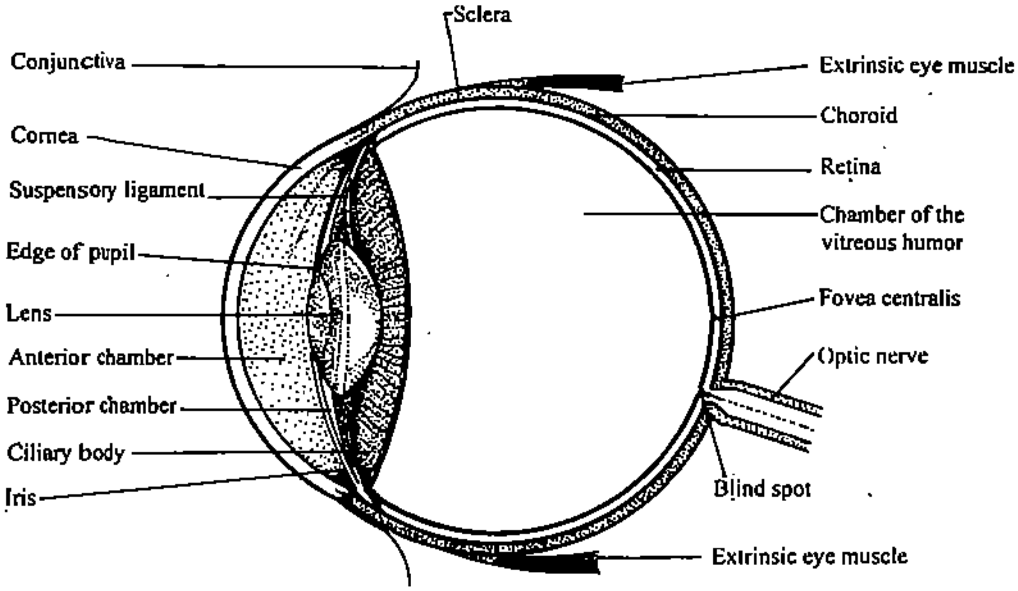


Fig. 10.12 : Structure of the human eye. The eyeball is almost spherical in shape and is built of three layers 1) The outer tough sclera that provides support and protection, 2) The middle chorold coat containing blood vessels and nourishment, 3) The light sensitive retina.

Several types of neurons in the retina convey information to the brain either directly or by interaction modify the input to the visual centres of the brain (see Fig.10.13). Light energy is converted to electrical signals and transmitted by the **bipolar cells** to the **ganglonic cells** which then transmit the signal to the brain. Other neurons like **amacrine** and **horizontal cells** interact with the transmission between photo receptors and bipolar cells or between bipolar and ganglonic cells. The axons of the ganglion cells come together along the inner surface of the retina and turn inwards in one place to form a nonsensory area the **blind spot** and continue to the brain as optic nerve. Fibres from left and right optic nerves cross at the optic chiasma and the nerve impulses travel from right to left field of vision of occipital cortex.

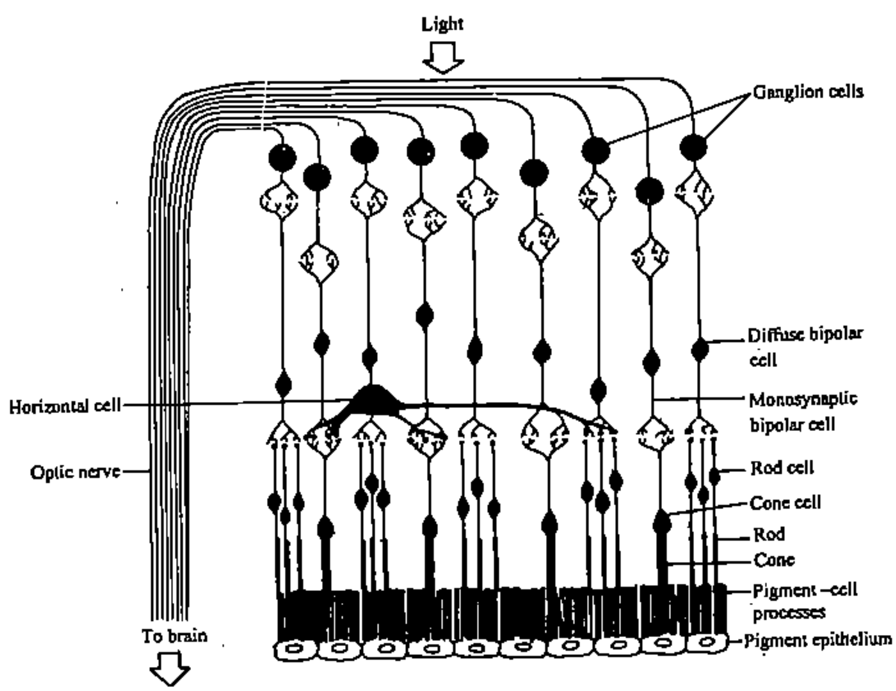


Fig. 10.13 : Photosensitive receptors and other neurosensory cells of the retina.

At the base of the retina is the pigmented choroid. It is either black or very shiny. Choroid pigment in day adapted animals is black and absorbs any stray light so that it does not get reflected to the sensory retina. Reflected light produces images that do not get correctly aligned to the primary image and thus reduce visual acuity. Nocturnal animals have a mirror like choroid known as **tapetum lucidum** that reflects back the light into the retina. Because little light is lost through absorption by choroid their eyes are sensitive to dim light but at the cost of visual acuity because reflected image does not coincide exactly with primary image.

Image formation in vertebrates is done by the cornea and crystalline lens. Cornea is almost flat in fishes but in terrestrial animals the cornea is curved and main image former and the crystalline lens is used for fine focusing. Many animals have a method to control the amount of light entering the eye. Like the aperture of the camera, their pupil which is an opening in the iris regulates the light intensity (Fig. 10.14). In most diurnal animal the pupil tends to be circular and relatively small. Nocturnal animals have round and relatively large pupils that permit maximum amount of light to enter the eye. Pupils of animals that are active both during day and night are able to expand greatly at night and become fine slits at day.

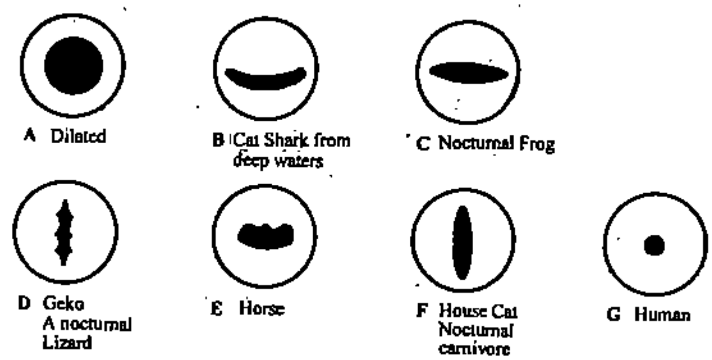


Fig. 10.14 : The pupils of most vertebrates are able to expand or contract to let more or less light enter the eye a) is dilated pupil in vertebrate to allow light. b-g) contracted pupils of vertebrates.

As said earlier, the eye is protected by the tough sclerotic coat which merges with the cornea in front. Between the cornea and the lens is the fluid aqueous humor and between the lens and the retina is the fluid vitreous humor that help to hold the lens in place along with the muscle and are exchanged with blood on a controlled basis to supply nutrition to the lens. The sclera may contain cartilage or bone rings that prevent damage to the eye. The cornea is covered by a thin membrane known as conjunctiva. The eyelids and nictitating membrane found in many vertebrates help to protect and moisten the surface of the eye. Modified sebaceous glands secrete an oily substance that spreads on the cornea and lacrimal glands contain a watery fluid that lubricates, washes and moistens the conjunctiva.

Comparative anatomy of vertebrate eye

Fundamentally the vertebrate eye has the same plan. In some forms, the eyes are primitive, while in others they are degenerated and functionless. There occur variations in methods of accommodation, degree of retinal development and the pupil shape. The structural features of eyes among various groups are described below.

1) Cyclostomes

In hagfishes the eyes lie beneath the skin, minute, degenerated and functionless. The cornea, sclera and the choroid are not differentiated. On the other hand, lamprey eye though primitive, is nevertheless a well-developed structure. The eyeball is flattened, sclera and the cornea are not fused to skin. There is a lack of suspensory ligament, and ciliary apparatus, the pupil is of fixed size and the eyelids are absent. Rods outnumber cones.

2) Fishes

In elasmobranchs, the eyes, are large. In holocephalians the eyes are largest in relation to body size among all the groups of fishes. A characteristic optic pedicel is present. The sclera is cartilaginous and there is lack of intrinsic muscles in the ciliary body. In elasmobranchs the surface of choroid coat contains light-reflecting crystals of **guanin**. Cones are absent in elasmobranchs. Colour vision seems to be wide spread in bony fishes.

Ciliary muscles and functional iris are absent. Deep-sea fishes have relatively enormous eyes. Recognition of enemies, prey, members of the same species and opposite sex is thus possible. In adult flatfishes, both eyes are on the same side of the head. The eyes of certain teleosts are adapted for vision in both air and water.

3) **Amphibians**

In terrestrial amphibians movable eyelids, moistened with glandular secretions make their appearance for the first time. Closure of the eye is accomplished by retracting the entire eye within the orbit by means of retractor bulbi muscle. The protrusion of eye is brought about by means of levator bulbi muscle. The eyes in anurans are best developed amongst all the amphibians. No tapetum lucidum is present though the eyes appear to shine. It is doubtful if amphibians have colour vision.Ciliary bodies are present. In caudate amphibians the eyes are small. The lids are absent in permanently aquatic forms. The caudate lens is exceptionally large and the ciliary body is less developed. The cave-dwelling salamanders show degenerated eyes.

4) **Reptiles**

Eyes in reptiles show further adaptation to terrestrial life. Except for snakes and a few others, eyelids have become more movable. A true nictitating membrane and Harderian gland is present lacrimal glands are well developed except in snakes, chameleon and *Sphenodon*. A relative increase in number of cones is apparent. In most reptiles in the retina, a central area for acute vision is present. Colour vision is believed to exist in turtles and lizards but is of doubtful occurrence in crocodiles and snakes. In snakes, a fixed transparent skin is formed over the eyes as the eyelids are fused, A very important difference in the reptilian eye is the special ciliary apparatus, which alters the shape of the lens and cornea.

5) **Birds**

The birds have uniocular vision except in birds of prey such as owls and to a lesser degree, hawks and eagles which have binocular vision. They have uniform eye structure. The eyeball is very large and is correlated with aerial mode of life. The eyeball is partly concave and a highly developed nictitating membrane is present which offers protection during flight. The ciliary bodies are well developed. The cones predominate in birds of diurnal habit, while the rods predominate in nocturnal forms. Colour vision is wide spread. Pecten a special feature of birds is a serrated, fan shaped structure which extend into the vitreal cavity is well developed which might aid in perception of movement and may act as a supplemental nutritive device for retina.

6) **Mammals**

The human eye structure is more or less typical of that seen in mammals. Variations are seen among mammals that are aquatic, terrestrial and those that lead an aerial life. Tapetum lucidum is present in nocturnal forms. Round pupil is most common but variations do occur. The retina mostly contains rods and cones. Though capacity of colour vision is mostly limited to higher primates. The optic nerve deccusation leads to binocular vision giving a third-dimensional effect.

10.6.2 The Ear

The vertebrate ear is a specialised receptor for detecting sound waves in the environment. It usually functions in a dual capacity, serving at least in higher forms, both as an organ of hearing and of equilibration. What we see as the ear in mammals is actually only the external ear. The actual function of hearing and equilibrium are performed by the internal ear which has a similar structure in all vertebrates and is enclosed in a bony skull protected from the external environment. During evolution the vertebrate internal ear originated primarily as an organ for balance, the labyrinth also known as the **vestibular apparatus**. We will explain the structures responsible for equilibrium first.

Vestibular apparatus

In all jawed vertebrates the labyrinth has a similar structure. It consists of two chamber - like enlargements, an upper **utriculus** (little bottle) and a lower **sacculus** (little sac). These chambers are connected by a constriction the **sacculoutricular duct**. A narrow endolymphatic duct joins either the sacculus or sacculoutricular duct. Three narrow tubes, the **semicircular ducts**, connect at both ends with utriculus (Fig. 10.15) and lie at right angles to each other. One of these lies in the horizontal plane while the other two are vertical, one directed forward and the other backwards. In cyclostomes the hagfish has only one semicircular canal which bears an ampulla at each end. In lamprey there are two semicircular canals. From fishes onwards all vertebrates have three semicircular canals and a slight projection of the ventral wall of the sacculus may be present. It is referred to as the **lagena**. The lagena is the forerunner of the auditory portion of the ear.

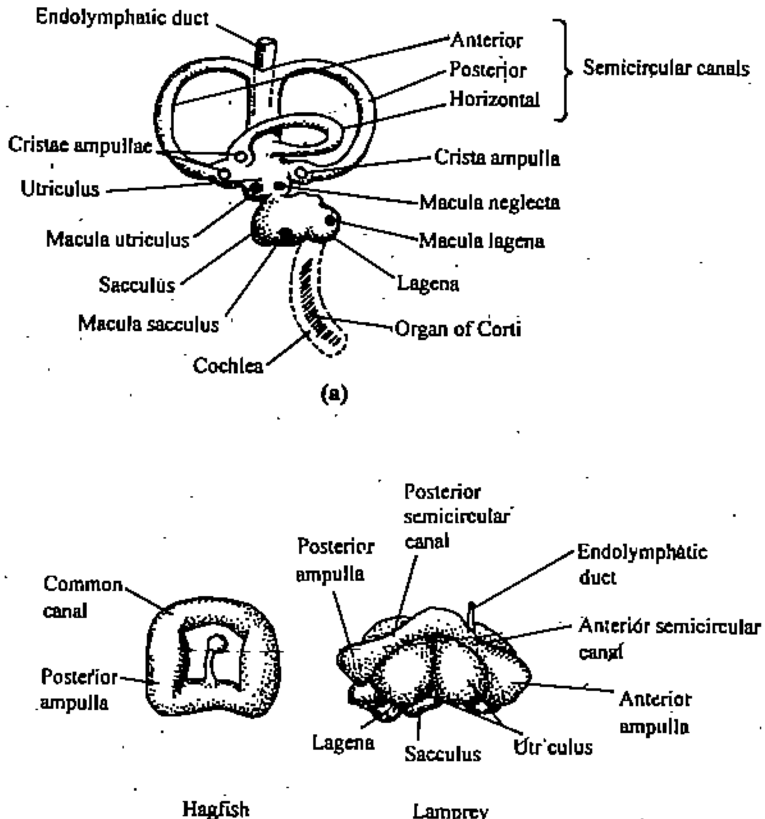


Fig. 10.15: a) Generalised vestibular apparatus of vertebrates showing the three semicircular canals and major compartments, the utriculus, sacculus and lagena. b) Inner ear of hagfish and lamprey.

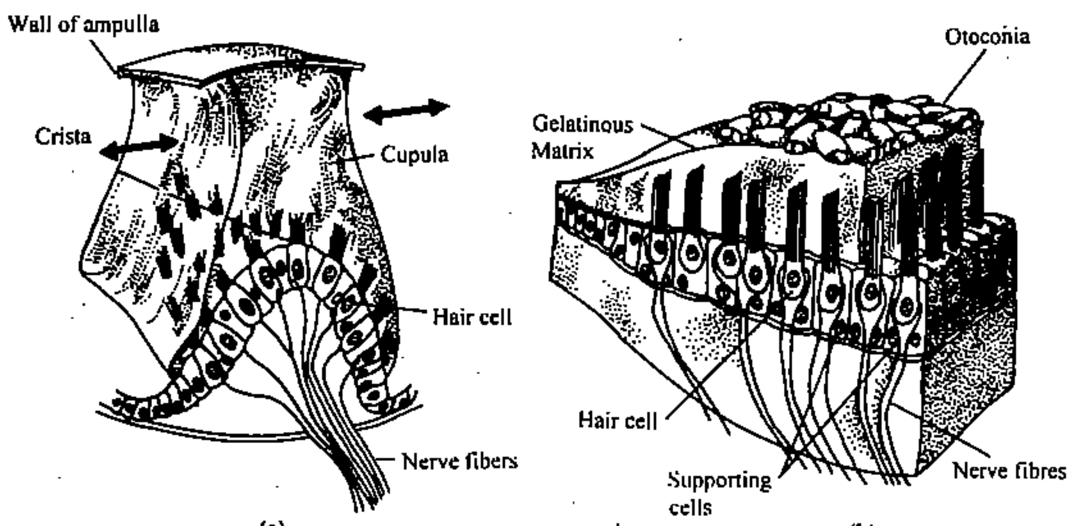


Fig. 10.16: Sensory receptors in the internal ear. a) One crista resides at the base of each semicircular canal in the ampulla. b) Macula containing otoconia reside in the three compartments of the inner ear.

The membranous labyrinth is filled with **endolymph** a fluid that is more viscous than water. Almost completely surrounding the labyrinth is the perilymphatic space filled with a fluid perilymph, with is actually the cerebrospinal fluid. Surrounding the perilymphatic space is cartilage or bone depending on the species. In higher forms, a bony labyrinth, situated in the temporal bone, encloses the membranous labyrinth. The semicircular canals are those portions of the bony labyrinth, which surround the semicircular ducts. The actual receptors for the sense of equilibrium consist of patches of sensory cell of **cristae** and **maculae** The former are located in the ampullae of the semicircular ducts and are made up of supporting cells and hair cells (see Box 10.1). The maculae lie in the walls of the utriculus, and the sacculus. The macula too is made up of a gelatinous cupula and hair cells except that embedded in its membrane is a high density mass of calcium carbonate crystals known as **otoconia** (Fig.10.16).

The semicircular canals are designed to respond to rotational acceleration and are relatively insensitive to linear acceleration. When the head is rotated the fluid in the canal tends not to move at first because of inertia. Since the cupula is attached, the free end is moved in a direction opposite to the movement of heads, stimulating the sensory hair cells thus setting up impulses transmitted to the brain by branches of the auditory nerve. While rotational movements affect the cristae in the ampullae of the semicircular ducts, the utriculus and sacculus are static balance organs that give information about the position of the head or body with respect to gravity. As the head is moved the stony mass moves over the hair cells sending nerve impulses to the brain.

Box 10.1:

Detecting water currents, maintaining balance and hearing sound seem to be very different sensory functions. However, all three are based on mechanoreceptors, sensory cells that respond to changes in pressure or mechanical force. The basic mechano receptor is the hair cell which has nothing to do with hair but is a cell which has a tiny hairlike process on its apical surface. Hair cells are transducers that change mechanical stimuli into electric signals and these cells originate from surface ectoderm. Each hair cell is embraced by a sensory fiber of neurons sensitive to ionic changes in the hair cell. Through synapses or similar contact points electrical excitation is passed on from hair cell to their embracing neuron which sends the signal on to the central nervous system.

A neuromast organ is a small collection of hair cells, supporting cells and sensory nerve fibers and the projecting hair bundles are usually embedded in a gelatinous cap called cupula. The neuromast organ or its modification is the fundamental component of all three types of mechanoreceptive systems, the lateral line systems, vestibular apparatus that senses equilibrium and auditory system that responds to sound.

Hearing

Hearing in vertebrates probably appeared as a mechanism to alert animals to nearby activity that could be dangerous. Later it also became important in the search for food, mate and in communication. In most vertebrates, part of the inner ear became modified to receive sound waves and certain hair cells in the inner ear became specialised to detect sound. You have learnt that the sacculus is fishes gives rise to a tiny pocket the lagena that, during evolution of vertebrates developed into the hearing apparatus of the tetrapods. This lagena elongates and in birds and mammals becomes coiled to form the **cochlea**. Within the lagena or the cochlea lies the sensory receptor for sound, the **organ of Corti** that is a specialised strip of neuromasts connected to the nervous system via the auditory nerve.

The ear is made up of three compartments: external, middle and internal ear (Fig. 10.19 a) shows the typical mammalian ear, which is made up of all three compartments.

The external ear is absent in fishes and amphibians. It appears for the first time in reptiles in some lizards and crocodiles and is made up of a short tube the **external auditory meatus** that opens to the exterior by an **external orifice**. In birds and mammals, the external auditory meatus is elongated. The part we consider as 'ear' is the **pinna** found only in the mammals. The pinna helps differentiate sounds from various directions and channels them into the external auditory meatus. Paired ears provide stereophonic hearing just as the paired eyes provide stereoscopic vision.

The middle ear is made up of a diaphragm the **tympanum** or tympanic membrane and appears first in ancient amphibians. In amphibians and a few reptiles the tympanum is flush with the body surface but in most reptiles, birds and mammals it is present at the inner end of the external auditory meatus. The jawless fishes and cartilaginous fishes lack a middle ear and cannot detect sound from distant sources. In some bony fishes sound is transmitted through extensions of the swim bladder in direct contact with the inner ear. This gas or swim bladder contracts and expands at frequencies corresponding to incoming sound waves. Special bony processes the **Weberian ossicles** provide a direct link between the swimbladder and inner ear (Fig. 10.17) increasing the ability to perceive higher frequency sounds.

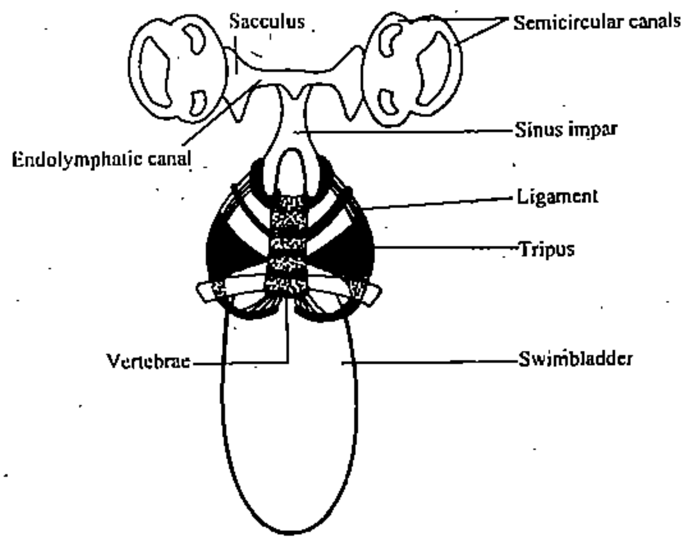


Fig.10.17: The fish inner ear or Weberian apparatus.

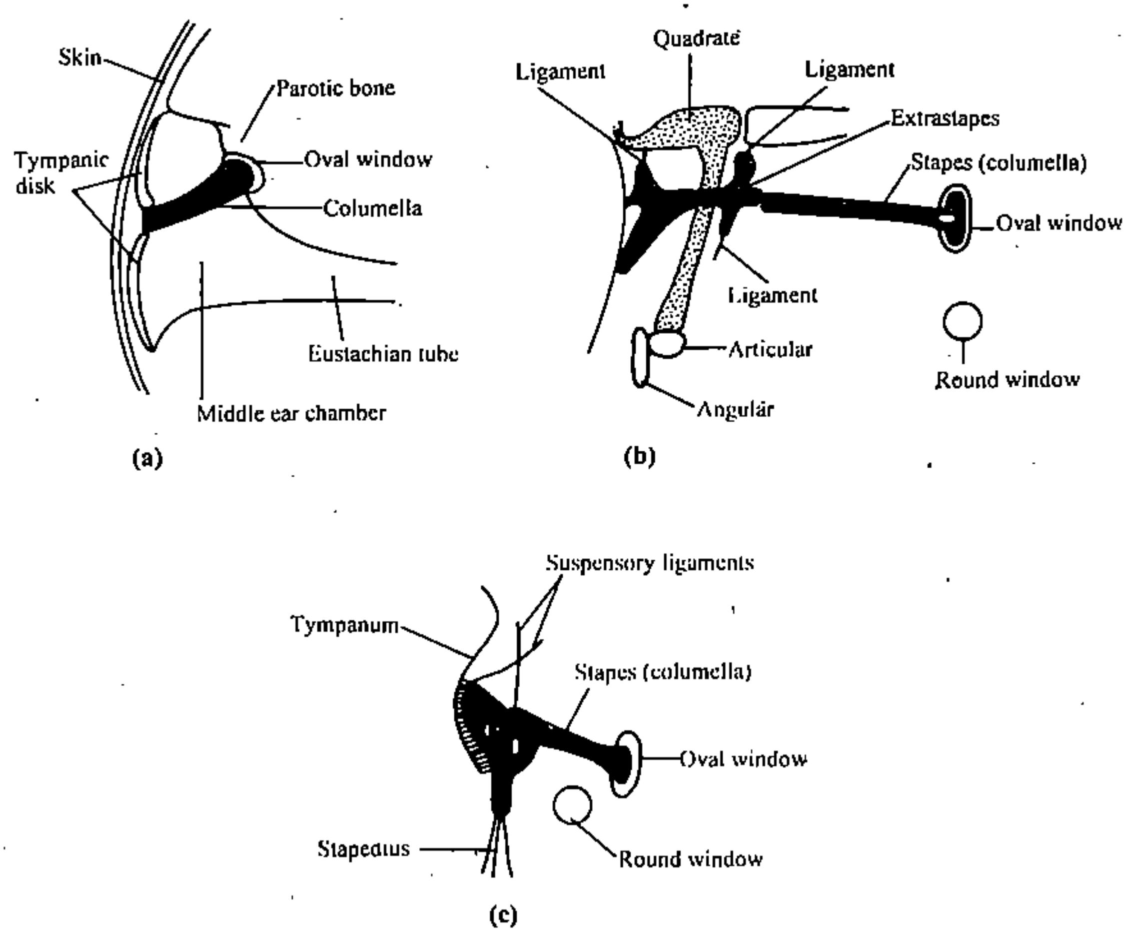


Fig. 10.18: Middle ear of tetrapods. (a) frog. (b) lizard. (c) bird.

As the tetrapods evolved on land the first gill pouch enlarges to form the middle ear cavity which is connected to the pharynx by a tube the Eustachian tube which serves to equalise the air pressure in the middle ear cavity with the outside the ear. Sound waves that vibrate the eardrum are transmitted to the inner ear by a bone or ear ossicle known as

columella which first appears in amphibians (Fig. 10.18). Columella is a derivative of the hyomandibular of fishes. In some amphibians, reptiles and birds the collumella is tipped with a cartilaginous structure the **extracolumella** which rests on the undersurface of the typmpanic membrane.

In mammals there are three bones in the middle ear: the **stapes** (stirrup) which is the reduced columella of reptiles, the **incus** (anvil) and **malleus** (hammer) which are derived from the quadrate and articular bones respectively. These three bones form a chain that bridges the gap between the tympanum and the inner ear (Fig. 10.19b).The middle ear is capable of transforming pressure waves from the distance environment into mechanical motion.

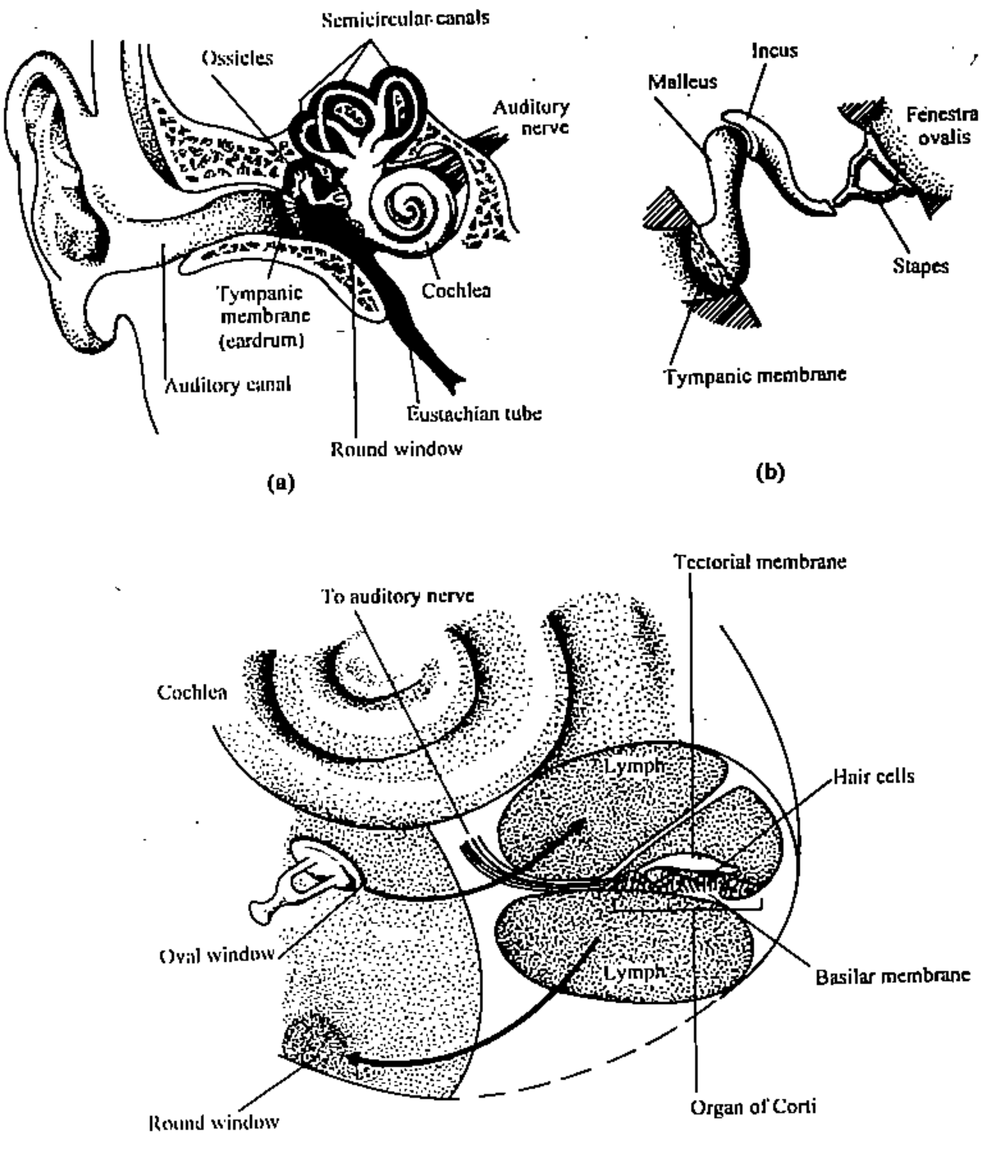


Fig.10.19: Ear of mammal. a) external, middle and internal ear. b)The three middle ear ossicles. c) Internal ear. Note that the lagena has lengthened and coiled to form the cochlea.

You already know that the inner ear includes the vestibular apparatus and surrounding perilymphatic space. The auditory apparatus in the inner ear consists of the lagena in amphibians and reptiles. This lagena extends to form the tubular lagena in birds. In mammals the lagena forms the coiled cochlea. The organ of Corti is present along a central channel suspended within the lagena. Two parallel perilymphatic channels run on either side of the central channel. The cochlea of mammals is coiled making two and a half turns in humans and is made up of three tubular canals running parallel with one another. These canals become progressively smaller from the base to the tip (Fig. 10.19c). The three canals are, **vestibular** canal, the base of which is closed by the oval window or **fenestra ovalis**. The end of the stapes expands into a plate which occupies the oval window. The other canal is the **tympanic canal** that is in communication with the vestibular canal at the tip of the cochlea and at its base is the round window or **fenestra rotunda**. A flexible membrane covers this window. Between these two canals is the middle canal or **cochlear duct**, which contains the actual sensory apparatus the **organ of Corti**. Within the organ of Corti are fine rows of hair cells that run lengthways from the base to the tip of cochlea. There are atleast 24,000 of these hair cells in the human ear. Each cell is connected with neurons of the auditory nerve. The hair cell rest on the **basilar membrane** which separates the tympanic canal from the cochlear duct. The organ of Corti vibrates with the basilar membrane in response to sound waves. In some vertebrates the hair cells of the organ of Corti are embedded in a firm plate the **tectorial membrane**.

When a sound wave strikes the ear, the energy is transmitted through the bones of the middle ear to the oval window, which oscillates back and forth driving the fluid of the vestibular and tympanic canals. The fluid oscillations also cause the basilar membrane with its hair cells to vibrate simultaneously causing impulses to be generated that are carried by the auditory nerve to the brain where they are interpreted by the hearing centres. The loudness depends on the number of hair cells stimulated and the quality of tone is produced by the pattern of hair cells stimulated.

10.5.3 Olfactory Organs

In neurophysiology a nucleus is a small cluster or aggregate of nerve cell bodies within the central nervous system.

The sense of smell or olfaction involves chemoreceptors usually located in the nasal passages. There are three components involved in olfaction. The olfactory epithelium, which is specialised epithelium within the nasal cavity. It contains **basal cells**, supporting cells known as **sustentacular cells** and the **olfactory sensory cells** which are the actual chemoreceptors (Fig. 10.20). Each sensory cell has a tuft of cilia at its apical end, embedded in mucous secreted by the sustentacular cells and they communicate directly with the olfactory bulb by their axons that pass through the bony cribriform plates.

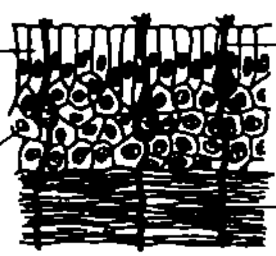


Fig. 10.20 : Cellular organisation of olfactory epithelium. The sensory cells are actual nerve cells that penetrate the epithelium with modified dendrites.

In most fishes the olfactory sensory receptors are embedded in paired blind-ended pits known as nasal sacs. Water carrying chemical flows in and out of these sacs as the fish swims. In tetrapods, a small external opening or **naris** provides access to each nasal passage and the back of the nasal passage opens into the mouth through the **internal naris**. In amphibians, some reptiles and mammals a separate and distinct region of the olfactory epithelium forms the vomeronasal epithelium of the **vomeronasal organ or Jacobson's organ** (See Fig. 10.21).

The vomeronasal organ is absent in most turtles, crocodiles, birds, some bats, primates and aquatic mammals. Vomeronasal organ is an accessory olfactory system and its sensory cells project into the lumen by means of microvilli. The neural circuiting also is separate and runs parallel to the olfactory neural system.

The sense of smell is well developed in fishes but is a secondary sense in bats, birds and primates. One way flow of water in aquatic vertebrates ensures a continuous flow of new water to wash away the chemicals that have been detected by the olfactory epithelium. In tetrapods air replaces water and air that flows through the nostrils must pass the olfactory epithelium on its way to the lungs. The sniffing of terrestrial vertebrates increases the turnover of air in the nasal chamber and thus the animal can sample the environmental odors.

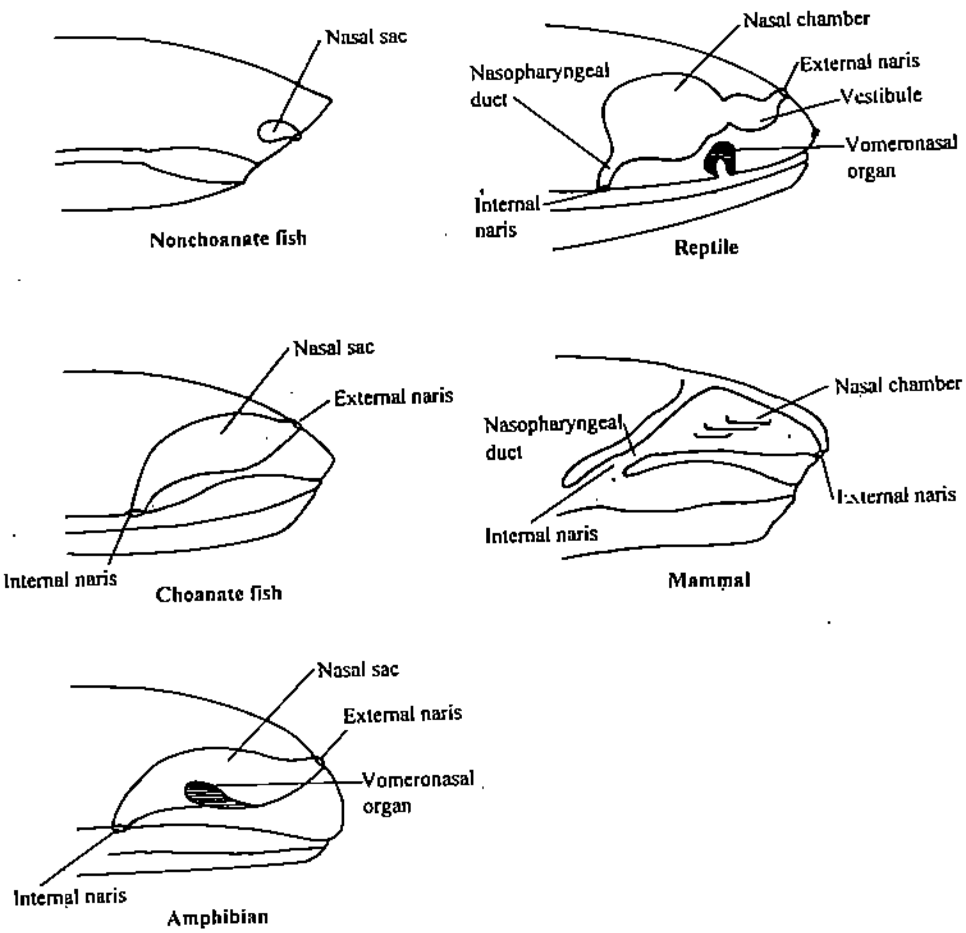


Fig. 10.21: Olfactory organs and vomeronasal organ in vertebrates. Note that the vomeronasal organ is absent in fishes.

SAQ 6

a) What is the function of rods and cones?
b) The space between the membraneous and bony labyrinth is filled up by ....
c) Which part of the ear is responsible for the sense of balance.
d) Name the three bones in the middle ear in mammals.
e) Lagena is present in mammals in the form of ....
f) What is the function of the parietal eye?
g) What are the sensory cells in the ear responsible for hearing called?
h) What are the gravity sensors in the inner ear called?

In the next section we will discuss some specialised sense organs found only in particular groups of vertebrates.

10.7 SPECIALISED SENSORY ORGANS

Some sensory structures are considered to be so unique, or so complex that they are called special sensors, for example electroreceptors, lateral line system, pit organ thermorecepters of snakes and system for ecolocation. We will first discuss the lateral line system in fishes.

10.7.1 Lateral Line System in Fishes

Reception of deep vibrations in water and of stimuli caused by currents or movements of water, including minor currents produced by the animal itself, are among the functions ascribed to the lateral-line organs. The lateral line system is present within the skins of most cyclostomes, other fishes and aquatic amphibian, but is unknown in terrestrial vertebrates The sensory receptors of the lateral line system are the neuromasts(refer to Box 10.1).

The role of neuromasts of fishes has remained controversial. However, it is supposed to have a secondary auditory function, temperature reception and a chemical sense. Disturbances of many kinds in the surroundings of a fish can activate the neuromasts, but water moving on the body surface provides most active stimulation. The sensory hair can detect two types of water currents i.e. water moving from head to tail and from tail to head. Neuromasts send a steady spontaneous train of bioelectric potentials along their nerves and the rhythm of the pulse changes during stimulation. The sensory cells are pear-shaped and have hair-like processes at their free ends (Fig. 10.22 c). The neuromasts are supplied with VIIth and Xth cranial nerves. The canals contacting the neuromasts are in the form of open grooves in primitive shark, while in Holocephali, they are fully exposed. Majority of elasmobranchs and teleosts contain closed tubes filled with mucous. They open to the exterior at intervals by means of tubules (Fig. 10.22 a). Lateral line system is sensitive to surface waves and concentric ripples, allowing fishes to detect prey in the water. Removing the lateral line organs or blocking them causes disorientation in fishes and loss of ability for schooling behaviour.

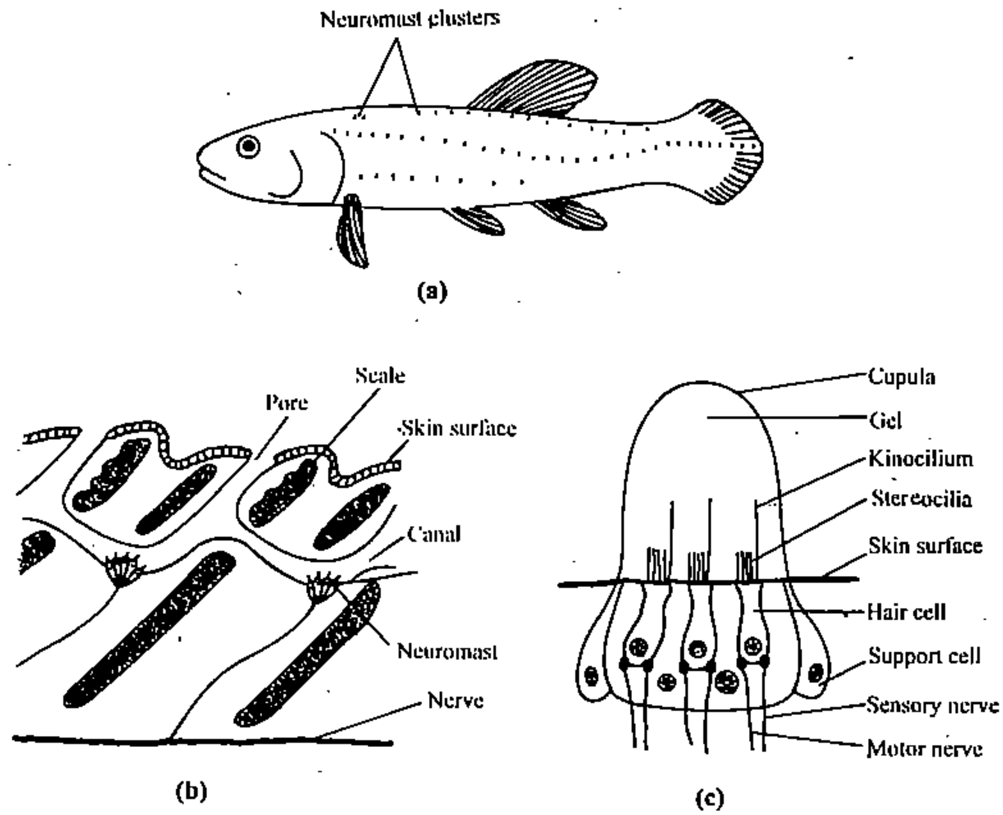


Fig. 10.22: a) Lateral line organs in fish, b) canal organ neuromast. Each opens to the exterior by a pori, c) superficial neuromast.

Electroreception in Fishes

Besides functioning as an organ for detection of water currents, there is a considerable agreement that a part of neuromast system responds to weak electric potential. This information helps the fish to orient itself, to avoid enemies and to participate in schooling. Most fishes produce enough electric potential when their muscles contract to make their presence detectable. Others produce a more powerful electric field by specially modified muscles or tissues-the electric organs and can monitor disturbances in their field caused by objects that enter it. Fishes that have electric organs may use them to signal other individuals or to defend themselves. Electroreceptors are not effective in terrestrial animals, as electric currents are not conducted so easily in air as in water.

10.7.2 Pit Organs in Snakes

The pit receptors of reptiles bear a striking morphological resemblance to the external neuromasts of fishes. Hence it has been hypothesised that the pit organs are evolutionary derivatives of neuromasts. However, their innervation by spinal or Vth cranial nerve is not consistent with this hypothesis.

Two families of snakes, Viperidae and Boidae have specialised heat sensors or receptors on the body surface in the form of pits. Pits open to the surface between epidermal scales. These pits contain free nerve endings that are excited by infrared radiation and the information is transmitted to the optic tectum of the midbrain. Apical pits are scattered on the body surface, mostly on the trunk, and provide sites for the input of tactile stimuli. In boa constrictors and pythons of family Boidae the free nerve endings lie between epidermal scales along the lips these are known as labial pits. In sub-family Crotalinae to which the snake, pit viper belongs, specialised pit receptor is found on the head. The pits are located on the posterior region of loreal scale, which is located between the external nares and the eye, and are termed as loreal pits or facial pits. These pits are directed forward and may be several millimetres wide and equally deep (Fig.10.23 a and b, see also Fig. 3.31, Unit 3, Block 1). These differ from the labial pits of pythons. Sensory nerve endings are suspended in a thin pit membrane halfway between the bottom of the pit and not lying at the bottom as in pythons.

The pit or cavity is divided into an inner and outer chamber. A duct between the inner chamber and the skin of the snake may prevent differential changes in pressure arising between the two chambers. The separating membrane is innervated by trigeminal nerve, which is responsible for the input from the head sensor to brain in snakes. Experimentally it was recorded that the frequency of nerve impulses increases as the receptor object warms up. Fluctuation occurs during the cooling of the object that is registered by the pit.

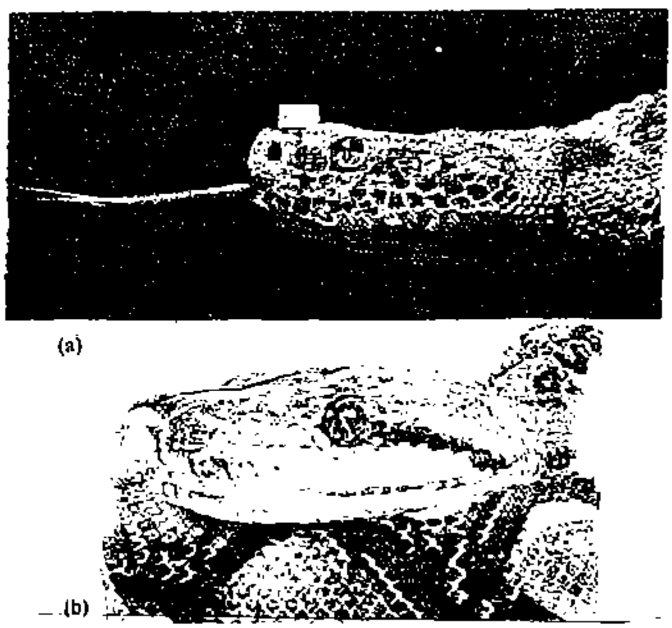


Fig. 10.23: Thermoreceptive pit organs in snakes. a) Facial pits in viper, b) Labial pits in python.

Since birds and mammals are warm bloodied, they emit infrared radiation and experiments show that temperature changes of 0.003°C can be detected by the pit organs. It was observed that a consistent change in the pattern of electroencephalogram occurs after a stimulus has been received by the peripheral nervous system called as evoked potential. It was also shown that the mitochondria enlarge after exposure of the receptor to an infrared stimulus, while when exposed to cold body, the mitochondria are condensed.

10.7.3 Echolocation in Bats

Amongst mammals bats and cetaceans have made hearing as a distance sense for navigation. It was found that insectivorous bats produce sound waves of high frequency. The human ear cannot perceive these sounds. The bats perceive objects by emitting sound waves that are reflected by the objects and are then detected by the bat's ears. Bats can thus locate and avoid obstacles in total darkness by means of echolocation.

The vespertilionid bats produce very short sound impulses each lasting only approximately one to two milliseconds. These ultrasonic bursts are produced in the larynx and emitted through the slightly opened mouth. The animals detect the difference between the emission of a sound and its return as an echo. The time differential in the arrival of the echo into the different ears gives information about the direction of the reflecting object.

The horseshoe bats (Rhinolophidae and Hipposideridae) have peculiar cutaneous growths on their noses (Fig.10.24) and emit ultrasonic sounds of consistently high frequency. They can produce sound with the mouth closed or while catching and eating insects. The horseshoe-shaped flaps around the nostrils are used as a sound cone, almost as a megaphone, during the emission of ultrasonic sounds; and the curvature of these flaps can be changed by muscle contraction. Thus, the animals are in a position to change the width of the sound cone in accordance with the different distances of the sound reflecting object by sweeping the sound beam back and forth to scan their surroundings .

The cave dwelling members of the genus *Rousettus* orient themselves with the help of large eyes when sufficient light is available. In total darkness, they can produce ultrasonic cries and use them for, echo sounds. These sounds are not made in the larynx, but by a clicking of the tongue.

The most surprising of all the specialised bats are the species that feed on fish. These bats have a well-developed system of frequency-modulated sonar, but sound loses much of its energy in passing from air into water and from water to air.

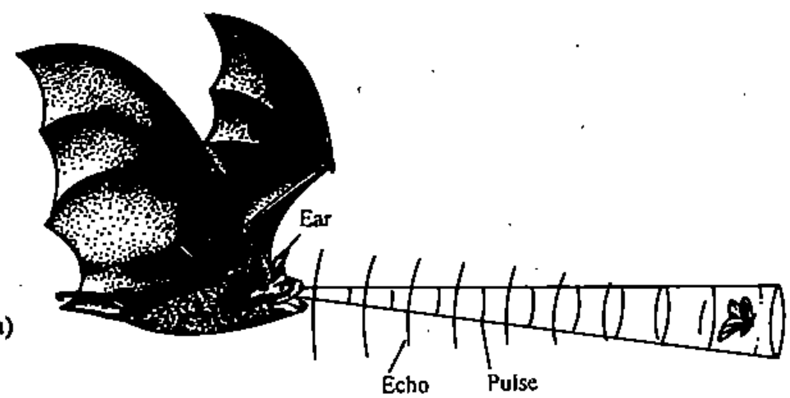


Fig. 10.24 : a) Echolocation of an insect by little brown bat. *Myotis lucifugus*. b) Modification of nose to broad cast the FM pulses.

SAQ 7

Fill in the blank spaces with appropriate words:

i) Lateral line organs consist of sensory papillae called .... which are composed of .... surrounded by supporting cells.
ii) Pit organs of snakes are .... receptors.

iii) .... is a method used by bats to orient themselves in space by detecting the differences between the .... of the sound and its return as an ....

iv) The cave dwelling bat produces ultrasonic cries by ....

10.8 SUMMARY

After studying this unit you have learnt that:

- Almost all the nervous system is derived from the neural tube and neural crests which appear very early in embryonic development.
- Nerve fibres are of two types : medullated or nonmedullated. Medullated fibres are white in appearance; nonmedullated fibres are grey. Bundles of nerve fibres are called nerves, whereas aggregations of nerve cell bodies are known as ganglia.
- The nervous system is divided into three main parts a) the central nervous system composed of brain and spinal cord; b) the peripheral nervous system, made up of cranial and spinal nerves and c) the autonomic system, consisting of portions of certain cranial and spinal nerves, as well as outlying ganglia connected with those structures of the body under involuntary control.
- In lower forms, brain and spinal cord are disposed in a straight line. In higher forms, flexures or bends occur which make possible the accommodation of a larger mass of nervous tissue within relatively narrow confines of the cranium.
- The greatest changes occur in the development of the telencephalon which is a part of the forebrain. The anterior portion of the forebrain is primarily concerned with the olfactory sense. The floor of the diencephalon, called the hypothalamus, contains centres which integrate the activities of the autonomic nervous system with those of other nervous tissues. The anterior part of the roof of the diencephalon remains epithelial but forms the anterior choroid plexus, while posterior portion may give rise to parietal and pineal outgrowths. An invagination from the floor, the infundibulum forms the posterior lobe of the pituitary gland.
- The dorsal part of mesencephalon forms paired optic lobes. The anterior part of the haidbrain called the metencephalon, gives rise to the cerebellum which coordinates the neuromuscular mechanism of the body. The myelencephalon or medulla oblongata is the posterior part of the hindbrain. The roof remains epithelial and forms a posterior choroid plexus.
- Brain and spinal cord are surrounded and protected by membranes called meninges. The spinal nerves are paired. Most spinal nerves give off three branches of rami.
- The cranial nerves, arising from the brain, number 10 in anamniotes and 12 in amniotes. Some cranial nerves are purely sensory (I, II and VIII, and other are purely motor (III, IV, VI, XI, XII). The remainder (V, VII, IX, X) are mixed (sensory and motor).
- The autonomic nervous system is made up of sympathetic and parasympathetic components. Each consists of preganglionic and postganglionic system. Preganglionic sympathetic system is often called the thoracolumbar outflow, while the parasympathetic system is referred to as the craniosacral outflow.
- Receptor organs are structures capable of responding to definite stimuli by setting up impulses which are in turn transmitted by nerve fibres to the centre nervous system. Receptor organs are classified as external and internal sense organs.
- The vertebrate eye has no true homologue among other phyla and appears for the first time in cyclostomes.
- In the vertebrate eye, light must pass through various cellular layers of the retina before it can stimulate the sensory receptors, or rod and cone cells. Six broad, strap-shaped muscles move the eye. Other accessory structures associated with the eyes of different vertebrates in each case serve to adapt the animal better to its own particular environmental needs.
- The vertebrate ear, at least in higher forms, functions in a dual capacity as an organ of equilibration and hearing. The sensory portion of the ear is called the inner ear or membranous labyrinth. The portion concerned with equilibrium consists of utriculus, sacculus, endolymphatic duct and three semicircular canals. The portion concerned with hearing is lagena. In mammals and birds it is the coiled choclea.

- The receptors for the sense of smell are confined to the olfactory epithelium of fishes, and olfactory epithelium of the nasal canal of tetrapods. In higher forms outgrowths from the walls of the nasal passages in the form of folds and scrolls (tubinates or conchae) increase the surface of the respiratory and olfactory regions.
- Neuromast organs are fluid-filled pits consisting of sensory and supporting cells and sensory terminals. They may open to exterior or occur located enclosed in canals. They are present only in fish and aquatic amphibians. Electroreception and mechanoreception are the attributed functions. Neuromast organs are innervated by cranial nerves VII, IX and X.
- Snakes exhibit pit receptors of uncertain homology. Apical pits occur at the apex of body scales. Pit organs occur on the head of vipers and boas. Apical pits are probably mechanoreceptors, while pit organs are thermoreceptors.
- Echolocation is observed in bats. They make use of reflected sound waves in orientation. This method is highly developed in microchiropteran bats that emit high frequency and short wavelength sounds.

10.9 TERMINAL QUESTIONS

1. What are the primary divisions of the nervous system? Add a note on their subdivisions.

   ....

   ....

   ....

   ....

   ....

2. Name the flexures and their position, that are present in vertebrate central nervous system.

   ....

   ....

   ....

   ....

3. Mention the cranial nerves of special senses and the nerves that innervate the eye muscles.

   ....

   ....

   ....

   ....

4. What are the components of the dorsal and ventral column in the spinal cord?

   ....

   ....

   ....

   ....

5. Which part of the brain is well developed in all vertebrates and why?

   ....

   ....

   ....

   ....

6. With which parts of the brain are the essential senses of small sight and hearing associated?

....

....

....

....

7. What are neuromasts? Give three functions of neuromasts.

....

....

....

....

8. What are pit organs in reptiles? How do vipers and boas locate the prey?

....

....

....

....

9. What do you understand about the phenomenon of echolocation?

....

....

....

....

10. What is electro-reception in fishes? Comment on its functional significance?

....

....

....

....

10.10 ANSWERS

Self-assessment Questions

1. a) Brain is formed mostly of grey matter except the medullated tracts while spinal cord is formed of both grey and white matter.
   b) Myelin sheaths are secreted by Schwann cells and oligodendrites.
   c) Myelin sheaths are found both in brain and spinal cord.
   d) White and grey matter intermingled in the brain forms the reticular formation.
2. a) Telencephalon matches lateral ventricles
   Diencephalon matches third ventricle
   Rhombencephalon matches fourth ventricle
   Medulla oblongata matches myelocoel
   b) i) sensory
   ii) dorsal roots
   iii) motor neurons
   iv) dorsal funiculi
   v) ventral funiculi
3. a) Metencephalon - cerebellum
   mesencephalon - optic tectum
   diencephalon - epithalamus, hypothalamus
   Telencephalon - thalamus, cerebrum
   myelencephalon - medulla oblongata

b) i) menix primitiva
   ii) dura mater and pia arachnoid
   iii) dura mater, pia mater, arachnoid
4. a) i) O, (Terminal); I, (Olfactory); II (optic); VIII (auditory)
   b) autonomic motor
   c) Dilation of pupils – sympathetic
   increase in heartbeat -- sympathetic
   constriction of bronchi – parasympathetic
   contraction of bladder muscles – parasympathetic
   increase in blood sugar – sympathetic
   decrease in clotting time – sympathetic
5. i) mammals
   ii) reptiles
   iii) mammals
   iv) mammals
6. a) Rods are exceptionally sensitive to light receptors while cones are also photoreceptors less sensitive than rods. Cones are responsible for visual acuity and colour vision.
   b) perilymph
   c) inner ear or the vestibular apparatus
   d) Incus, stapes, malleus
   e) Cochlea
   f) It is a dosimeter for light and does not form images.
   g) Organ of Corti.
   h) Sacculus and utriculus.
7. i) Neuromasts, hair cells
   ii) Infrared rays
   iii) Echolocation, emission, echo
   iv) clicking of tongue.

Terminal Questions

1. The primary subdivisions of the nervous system are:
   i) central nervous system and the
   ii) peripheral nervous system.

   The subdivisions of the central nervous system are composed of brain and the spinal cord and the peripheral nervous system consists of spinal nerves, cranial nerves and autonomic nerves.
2. Three types of flexures are present in vertebrates:
   i) a cephalic flexure between forebrain and midbrain,
   ii) a cervical flexure near the junction of medulla oblongata and spinal cord.
   iii) A pontine flexure in the region of metencephalon.
3. Terminal nerve, olfactory nerve and the optic nerves are termed as the nerves of special sense.
   Occulomotor, trochlear and abducense nerves innervate the eye muscles.
4. In the spinal cord, the dorsal column is composed of upper somatic sensory and lower visceral sensory regions. The ventral column in turn, is composed of upper visceral motor and lower somatic motor regions.
5. Myelencephalon or medulla is the oldest part of the brain and well developed in all vertebrates as it controls the vital functions of the body, including the involuntary functions and equilibrium.
6. Smell is connected to the forebrain; sight to midbrain and hearing is connected to hindbrain.
7. Neuromasts are the sensory papillae surrounded by supporting cells, present on the surface of the skin. The three functions of neuromasts are: (1) short distance auditory function, (2) temperature reception and (3) chemical sense.
8. Pit organs in reptiles are the thermoreceptors that respond to radiant heat. Vipers and Boas can detect even very mild fluctuation in temperature and warm-blooded animals at a distance of several feet, and thus locate the prey.
9. Echolocation is the phenomenon in which the animal can orient itself, avoid obstacles and also detect the prey with the help of reflected sound.
10. Electroreception is a special sensory system in fishes, through which the animal produces electrical potential and is able to detect, and paralyse the prey. It also helps them in schooling and breeding behaviour.

UNIT 11 SKELETAL SYSTEM

Structure

11.1 INTRODUCTION

You have studied soft-bodied animals. They can bend and twist their bodies as they like it. They can wriggle through burrows and crevices to avoid obstacles. At the beginning of evolution of life this ability appeared to be an advantage. But it is not always so. It puts a restriction on size because large soft bodies are difficult to manage. A large body needs support to prevent it from collapsing. The supporting structure needs to be hard. Only then it can provide a definite shape and also help protect the soft vital parts of the body. It would also be helpful in locomotion. Locomotion as you know is brought about by the movement of the body due to contractions and expansions of muscles, the contractile tissue. Muscles need to be attached to hard surfaces to assist in contractions. All these needs were fulfilled by the development of a chitinous hard structure as in arthropods or formation of a calcareous shell as in molluscs or a connective tissue product consisting of bone or cartilage as in vertebrates. This supporting structure of shell or chitin or of cartilage or bone is called skeleton.

Generally there are two types of skeleton in animals; (a) the **exoskeleton** found on the outside of the body and (b) the **endoskeleton** found inside the body of the animal. A typical exoskeleton is found in animals belonging to the phylum Arthropoda. It is chitinous in nature and is secreted by the epidermis. It serves the function of protecting the body, providing support to the body and a hard surface for the attachment of muscles. The remarkable success of these animals among the invertebrates is mostly due to this chitinous exoskeleton. There are shortcomings in this type of skeleton. A loose exoskeletal jacket-like structure cannot be efficient. It should be a close fit. Even the close fit puts restrictions on the growth of the animal. Moreover, the arthropodan exoskeleton is a dead tissue. The arthropodans have overcome this disadvantage by trying to discard the old exoskeleton as the animal grows and developing a new larger exoskeleton to suit the larger body. This process is called moulting. These animals moult a number of times during their life time. For example, the post-hatching stages of cockroach, the nymph and the caterpillar of the butterfly moult about five times before growing into a sexually mature adult animal. The calcareous shell of the molluscans is secreted by the mantle as an external epidermal structure. The molluscan shell grows with the growth of the animal. Vertebrates are also provided with exoskeletal structures like scales, feathers and hairs which are also epidermal in origin. They serve the function of providing protection against enemies and harsh environmental conditions. The internal skeleton of vertebrates is called the endoskeleton. It is a living tissue of mesodermal origin and grows with the growth of the animal. It helps to hold the soft parts of the animal together. It serves as a mechanical framework for the animal body giving it a distinct shape and rigidity. It also provides a hard surface for the attachment of muscles and protects the vital internal organs of the body. The vertebrate endoskeleton is a connective tissue.

Objectives

After reading this unit, you should be able to:

- explain the advantages of endoskeleton,
- discuss the differences between the cartilage and the bone,
- describe a typical skeleton of a vertebrate,
- discuss the differences between skeleton of a frog and of a rabbit,
- explain the modifications in the skeleton of limbs for running in horse, for flying in bat, swimming in whale and for walking in man.

11.2 CARTILAGE AND BONE

The vertebrate endoskeleton is composed of two different types of components derived from the supportive connective tissue, the **cartilage** and the **bone**. Cartilage is a relatively soft elastic tissue, whereas bone is a more ossified hard rigid tissue. Both the cartilage and the bone consist of living cells surrounded by a non-living ground substance called matrix.

Matrix consists of a protein called **chondrin** secreted by the cells themselves. Matrix is composed mainly of mineral salts mostly of calcium combined with phosphates and carbonates.

Phylogenetically bone appeared earlier than cartilage though embryologically cartilage appears earlier than bone during development. Cartilage which appears first during development in vertebrates is later replaced by bone. But the complete skeleton of elasmobranch fishes and cyclostomes is made of cartilage only. However, the skeleton of a majority of vertebrates is bony. The matrix of cartilage contains elastic or tough white fibres. The protein found in cartilage is **chondrin** and the cartilage cells are called **chondrioblasts**, (Fig. 11.1). But the matrix of the bones contains a protein called **collagen** and inorganic matter mostly **calcium phosphate**. Compact bone is composed of a calcified bone matrix arranged in concentric rings.

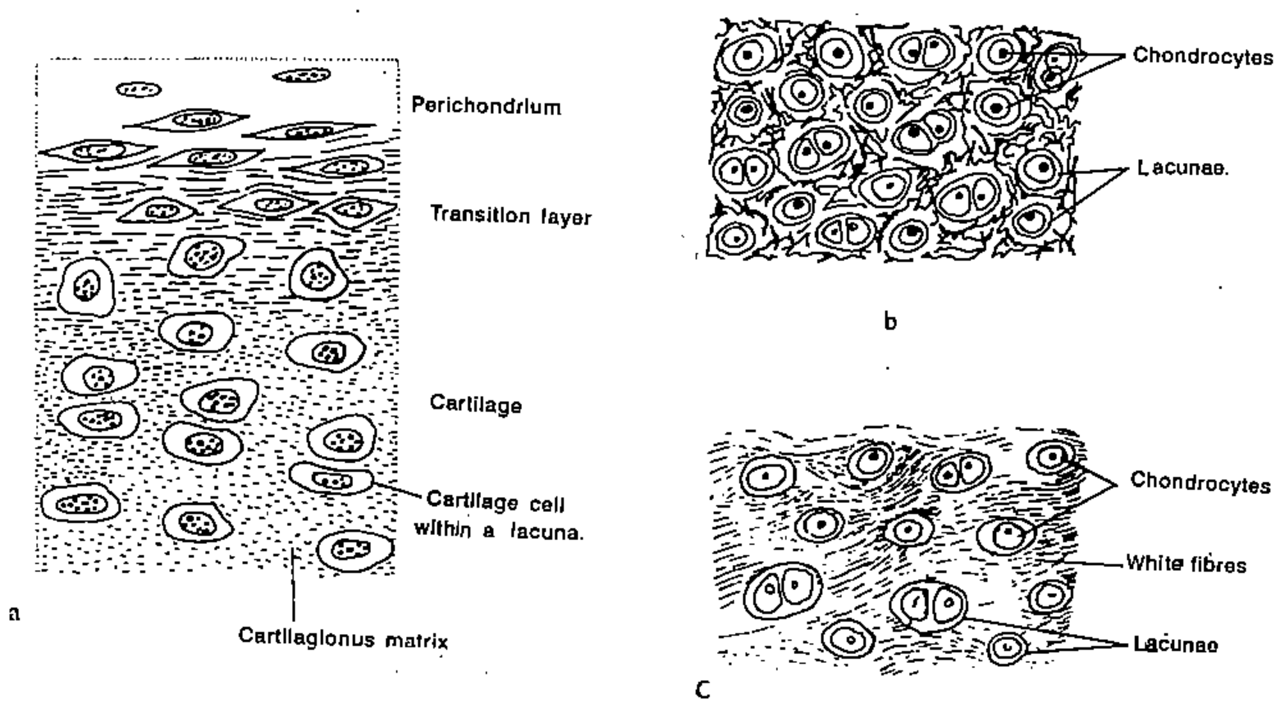


Fig. 11.1 : (a) Section through a piece of hyaline cartilage adjacent to the connective tissue perichondrium. Cartilage of this type would be found in joints and the rings of the trachea; (b) Elastic cartilage; (c) Fibro cartilage.

The rings contain cavities (lacunae) filled with bone cells (osteocytes) which are interconnected by many minute passages (**canaliculi**). These serve to distribute nutrients throughout the bone. This entire organisation of lacunae and canaliculi is arranged into an elongated cylinder called an **osteon** also called **haversian system** (Fig. 11.2). The bone secreting cells are called **osteoblasts**.

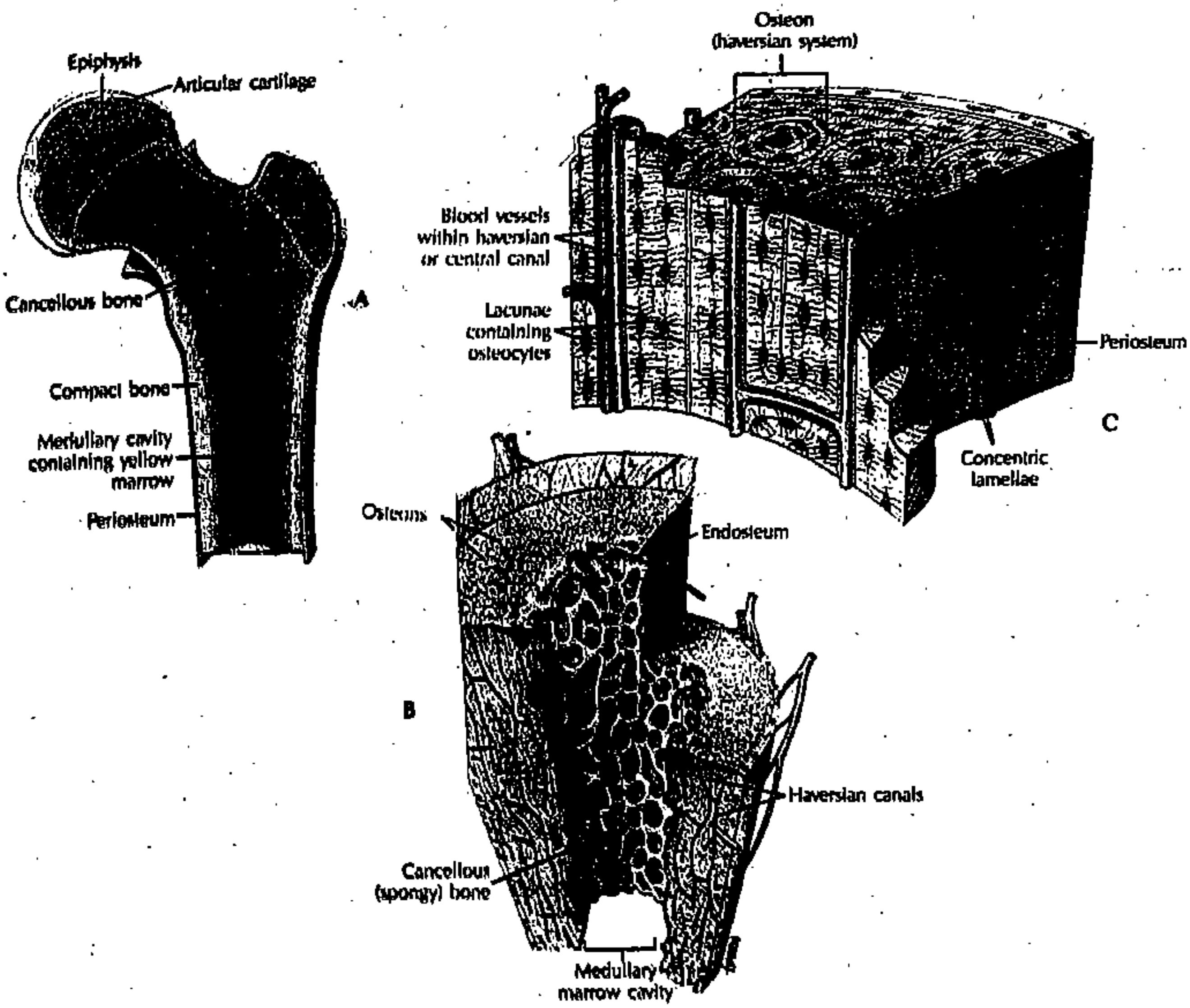


Fig. 11.2 : Bone structure. (A) Adult long bone. (B) Enlarged section showing how bone cells and the dense calcified matrix are arranged into units called osteons. (C) Fine structure of compact bone.

There are two types of bones based on the manner of their formation during development. Bones of the first type may be formed by ossification of the pre-existing cartilage. They are called **cartilage bones**. They are also called **replacing bones** because they replace the pre-existing cartilages. In the second type bones may be formed afresh at places where membranes form the covering. They are called **membrane bones**. They are also called **investing bones** because they form as an investment over membranes.

11.3 CLASSIFICATION OF SKELETON

The endoskeleton of vertebrates is divided into two main parts based on their position in the body.

a) **The Axial Skeleton:** This is found arranged along the anteroposterior axis of the body. It consists of the skull the head skeleton and the vertebral column. The sternum, the breast bone is also included in this type.
b) **The Appendicular Skeleton:** It is found on the sides of the body as appendages of the axial skeleton. It includes the skeleton of the limbs and the limb girdles.

11.3.1 Axial Skeleton

The skeletal elements of axial skeleton are represented by skull and vertebral column. They surround and protect the structures of the central nervous system, the brain and the spinal cord. The skull is enlarged and specialised to enclose the brain and the sense organs found in the head. The vertebral column forms the longitudinal skeletal axis of the body behind the head. It encloses the spinal cord and blood vessels of the trunk and the tail.

The Skull

The skull forms the skeletal framework of the head of craniate vertebrates. It is also called cephalic skeleton or head skeleton. In fact, vertebrates are divided into two sub-divisions based on the presence or absence of head skeleton. Those without head skeleton are called **Acraniata** and those with head skeleton as **Craniata.** Urochordates and cephalochordates belong to Acraniata and the rest of the vertebrates are grouped under **Craniata.**

Skull consists of different parts enclosing brain, cranial nerves and other sense organs found in the head. The part enclosing the brain is called the **cranium.** The parts of the skull enclosing the sense organs are called respective sensory capsules. Thus there are **auditory capsules,** olfactory capsules and a bony cup-like structure the orbit containing eye balls.

The cranium or the brain box is oriented anteroposteriorly. It constitutes the main axis of the head. The olfactory capsules are present on the anterior end and the auditory capsules are present on the posterolateral sides of the cranium. The head skeleton provides passage for blood vessels serving various parts of the head.

The gill slits present on the pharyngeal wall are supported by a skeletal structure called **visceral skeleton.** This is seen in living fishes today. During evolution of vertebrates visceral skeleton has lost its importance because of the gills being replaced by lungs due to terrestrialisation. However, the structure which constituted visceral skeleton has been retained and incorporated in the formation of jaws, providing skeletal elements to the middle ear which have assumed the function of transmitting sound waves to the internal ear and forming the skeletal support for the floor of the buccal cavity.

The skull of cyclostomes does not contain jaws and they are thus included under the group **Agnatha** (meaning without jaws). The rest of the vertebrates have jaws and are included in the group **Gnathostomata** (meaning mouth bound by jaws).

In vertebrates, early stages of development brain and sensory capsules are surrounded by tough membranous skull called the **membranocranium.** Later the membranes are strengthened by the development of cartilage. This cartilaginous skull is called the **chondrocranium.** The brain-case or chondrocranium of cartilage or its replacement bone, forms the anterior end of the axial skeletal system. Chondrocranium is modified in relation to the brain and specialised sense organs of the head. In most vertebrates, the brain case is fused with dermal and visceral skeletal materials to form a definitive and complex skull. Chondrocranium appears as a stage in the development of head skeleton of all vertebrates. It is later replaced by a bony skull by ossification or replacement of cartilages by bones and/or formation of bones afresh at places covered by membranes.

Development of the Skull

The structure of the skull can be best understood by studying its formation during development. The formation of the skull is initiated by the appearance of a pair of cartilaginous plates called **parachordals.** The parachordals are formed on either side of the anterior end of the notochord. Another pair of curved cartilaginous rods called **trabeculae** are formed infront of the parachordals. These two pairs of cartilages lie below the brain. Further, cartilaginous investments appear around the three sensory organs thus establishing the sensory capsules. The olfactory capsules are formed around the organs of smell situated infront of the brain, optic capsules around the eye balls anterolaterally and the auditory capsules around the organs of hearing posterolateral to the brain. The olfactory and the auditory capsules soon establish connections with the skull proper. The optic capsules remain free and provide mobility to the eye balls. In the course of development the trabeculae and the parachordals unite to form a single basal plate lying below the brain. It forms the floor of the cranium. Vertical outgrowths develop from the basal plate to enclose the brain and contribute to the formation of the cranium i.e. brain box. The hind end of the cranium forms the occipital region. The occipital region encloses a large opening called the **foramen magnum** through which the brain is continuous with the spinal cord. There are two bulb-like bulgings on either side of the foramen magnum. They are called condyles and since they are in the occipital region they are called **occipital condyles.** These condyles fit into suitable concavities on the anterior end of the first vertebra thus helping in articulation of the skull with the vertebral column. There are two occipital condyles in the skulls of amphibians and mammals. They are thus called **bicondylar.** In reptiles and birds there is only one condyle and they are thus called **monocondylar.** The optic capsules are present in the form of two depressions at the anterolateral sides of the cranium. The eye balls fit into the depressions and they are called orbits. The region between the orbits is called the **interorbital region.** There is usually a **rostrum** extending infront of the olfactory capsules. The rostrum represents the extensions of the cranium. Generally there are one or more openings in the roof of the cranium, called **fontanellae** and they are usually covered by membranes. The cranium contains certain apertures called **foramina** for the passage of cranial nerves.

The different sensory capsules of the skull in different groups of vertebrates show different degree of ossification (change into bone). They are simple and contain fewer bones in primitive vertebrates. In the skull of frog there is only one bone in the auditory capsule, the **prootic** and in mammals there are as many as six bones. In frogs the orbit is not ossified and is covered by membranes.

In addition to the cranium and the sensory capsules the skull contains other structures which are derived from the visceral skeleton. The visceral skeleton originally formed a part of the pharyngeal region supporting the gill slits. The visceral skeleton consists of a series of cartilaginous rods forming dermal support of the pharyngeal wall between gill slits in fishes. The skeletal elements are segmented and occur in the lateral wall of the pharynx constituting visceral arches. The number of **visceral arches** corresponds to the number of gill slits which is assumed to be seven in the hypothetical vertebrate ancestor. In cyclostomes there are innumerable number of gill slits and the visceral skeleton forms a structure called **branchial basket.** The anterior most or the first visceral arch is called the **mandibular arch.** It lies just behind the oral aperture (the mouth). The second arch is called the **hyoid arch.** Subsequent arches are called branchial arches. The skeleton of the **branchial arches** supports gill slits in the aquatic vertebrates. Each visceral arch consists of a series of cartilaginous rods encircling the pharynx forming paired half loops on the side wall. The left and the right bars of the corresponding arches are united on the floor of the pharynx by an unpaired midventral cartilage. During the evolution of vertebrates there was a backward shift of the mouth thus establishing contact with the first gill slit. The skeletal support of the first gill slit became the supporting structure of the mouth giving rise to jaws. Each mandibular arch consists of a dorsal **palatoquadrate** and a ventral **meckel's cartilage.** The two palatoquadrates grow along the anterior or the upper margin of the mouth, unite with one another in the midline to form the upper jaw. Similarly the meckel's cartilages extend along the lower or posterior margin of the mouth, unite in the midline anteriorly to form the lower jaw. The quadrate portion of the palatoquadrate helps suspending the jaws to the skull. This is called **suspensorium** (Fig. 11.3). In the earlier stages of evolution of gnathostomes jaws were attached to the skull by means of ligaments. This condition is called autodiastylic type of suspensorium. In the next stage of evolution the palatoquadrate forming the upper jaw was attached to the skull anteriorly and posteriorly attached to it by means of ligaments. This condition is found in dogfishes. But in most elasmobranchs the hyoid arch enters to help the jaws to be attached to the skull. In shark and other fossil fishes jaws are suspended to the skull by both ligaments and the hyomandibular, a cartilage derived from the hyoid arch. This condition is called **hyostylic suspensorium.** The condition where the palatoquadrates are directly articulated with the skull is called **amphistylic suspensorium.** In tetrapods the upper jaw is directly fused with the skull and this condition is called **autostylic suspensorium.** The elements of the hyoid arch thus released from participating in providing the suspensorium are incorporated into the middle ear as **ear ossicles.** The branchial arches allow dilation and contraction of the pharynx. This allowed swallowing and expulsion of water during respiration. These elements of branchial arches are lost in tetrapods with the loss of branchial respiration and being replaced by pulmonary respiration. Thus the mechanism of operation of jaws got modified and in turn modified the skeleton of the head depending on the mode of articulation of the jaws and the manner of attachment of muscles or the type of teeth. Bones and cartilages represent functional responses to the mechanical lever action or due to resistance to compression strain. It is a continuously responding tissue. It can be laid down or reabsorbed or reformed to suit altered needs.

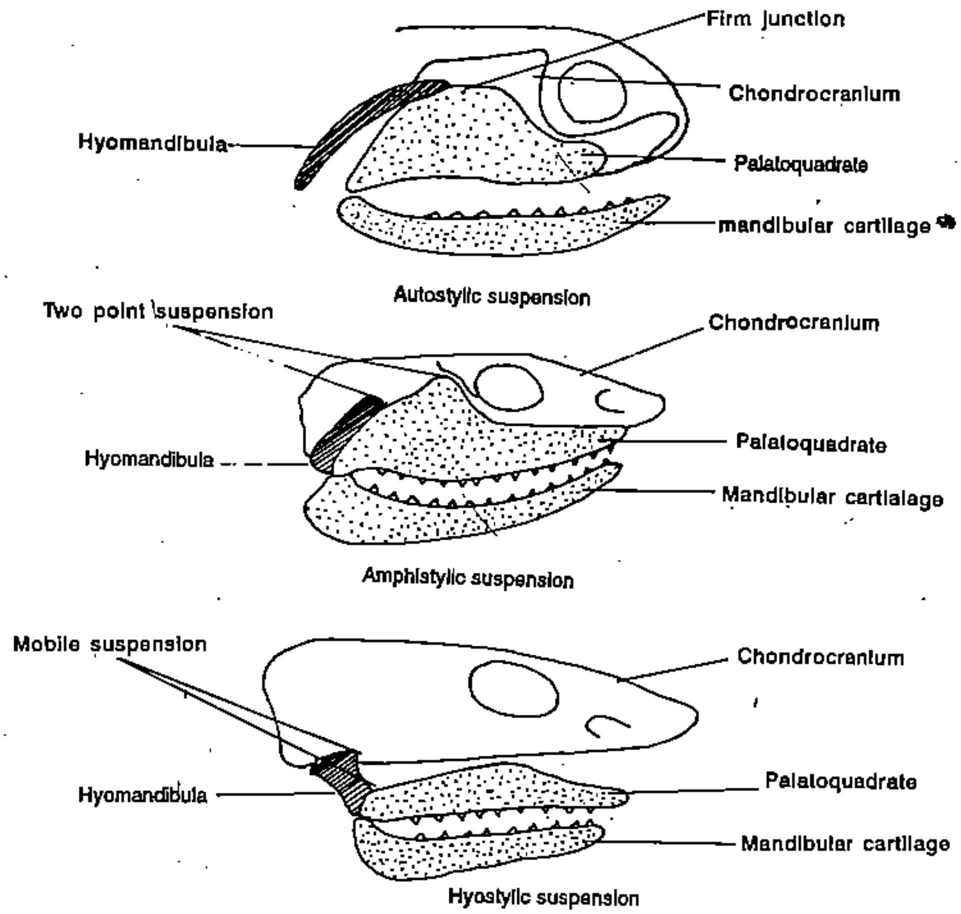


Fig. 11.3 : Jaw suspensorium. A, Autostylic Jaw Suspension (presumed primitive condition). B, Amphistylic Jaw Suspension (primitive cartilaginous and bony fishes). C, Hyostylic Jaw Suspension (most modern cartilaginous and bony fishes).

The Vertebral Column

Presence of a stiff rigid rod-like notochord extending from the head to the tip of the tail is characteristic of vertebrates. During development the mid-dorsal part of the archenteron of the neurula is cut off to form the notochord. In craniate chordates notochord extends into the head region only upto behind the pituitary body. In acraniate chordates it extends upto the anterior end of the head. In vertebrates the notochord appears only during the embryonic stage. Later in course of development the notochord gets replaced by a segmented column in the adult. The vertebral column is a chain of segmented structures called **vertebrae** (vertebra - singular). The vertebral column extends from behind the skull anteriorly to the tip of the tail posteriorly. It forms the longitudinal axis of the animal. It provides both stability and mobility to the animal. Vertebrae have specific structure which allows them to be joined to each other firmly and also allow some amount of movement. Articulation of vertebrae is achieved by developing bulges (convexities) and depression (concavities). The bulging of one end of one vertebra fits into the depression on the other vertebra. In addition there are additional structures to strengthen articulation and keep the extent of mobility in check. This helps to prevent dissociation and dislocation. The series of vertebrae form tube-like structure dorsally to enclose and protect the spinal cord.

Similarly, the vertebrae of the tail region of some animals form a ventral tube to enclose blood vessels.

A typical vertebra consists of the following parts:

a. A central body in line with the notochord of early developmental stage, the **centrum**. The centrum bears depressions and bulges on its anterior and posterior ends for articulation with each other.
b. A dorsal arch-like structure enclosing the spinal cord, called the **neural arch** (Fig. 11.4). Neural arches of all vertebrae together form the tube enclosing the neural canal which encloses the spinal cord. Neural arches are formed by vertical neural plates arising from the dorsolateral sides of the centrum. The two neural plates of either side meet above the spinal cord. There is usually a backwardly directed neural spine dorsally above the neural arch.
c. There are a pair of lateral processes extending outwards from the centra into the muscles. They are known as transverse processes.
d. There is usually a **haemal arch** ventrally in the tail region of higher vertebrates. They are formed by a pair of plates (**haemapophyses**). The haemal arch contains the haemal canal which encloses the blood vessels. There may also be a ventrally projected **haemal spine**.
e. The centrum bears a couple of plate-like projections both in front and behind. They are called **zygapophyses** and **metapophyses** (Fig. 11.4). They help in firm articulation of vertebrae and check the limit of movement between the vertebrae.
f. In higher vertebrates there are a pair of lateral processes on each side arising from the base of the neural arch. They are known as **diapophyses**. Usually there is another pair of processes arising from the centrum known as **parapophyses**.

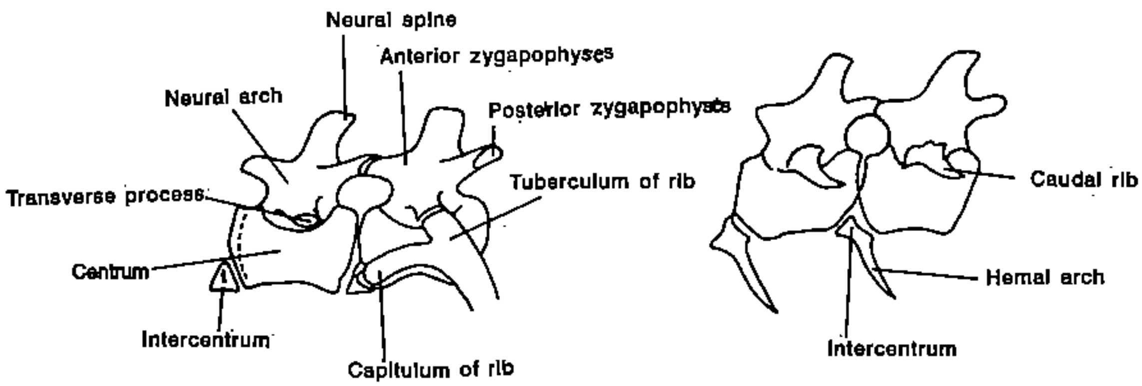


Fig. 11.4 : Left, two trunk vertebrae of an early generalised reptile (anterior end to the left). Right, two caudal vertebrae.

Types of Vertebrae

The bifurcated heads of the ribs are attached to these processes on each side. The vertebrae are classified into different categories on the basis of the structure of the centrum:

i) **Procoelous:** The centrum of the vertebra bears concavity in front (anterior) and a convexity behind (posterior). The convexity of the vertebra in front fits into the concavity of the vertebra behind, (Fig. 11.5 a).
ii) **Opisthocoelous:** It is the opposite of procoelous structure with a convexity in front and a concavity behind, (Fig. 11.5 b).
iii) **Amphicoelous:** The vertebral centra have concavities both infront and behind. They appear dumble shaped in the lateral view, (Fig. 11.5 c).
iv) **Heterocoelous:** The centrum of this vertebra appears concave when seen from side to side and convex from above downwards and opisthocoelous in sagittal view. They are also described as saddle shaped. These vertebrae articulate with each other by synovial capsules. These vertebrae are characteristic of birds, (Fig. 11.5 d).

v) **Acoelous or Amphiplatyan:** The centra are usually flat without any bulgings or depressions. These vertebrae are found in mammals, (Fig.11.5e).

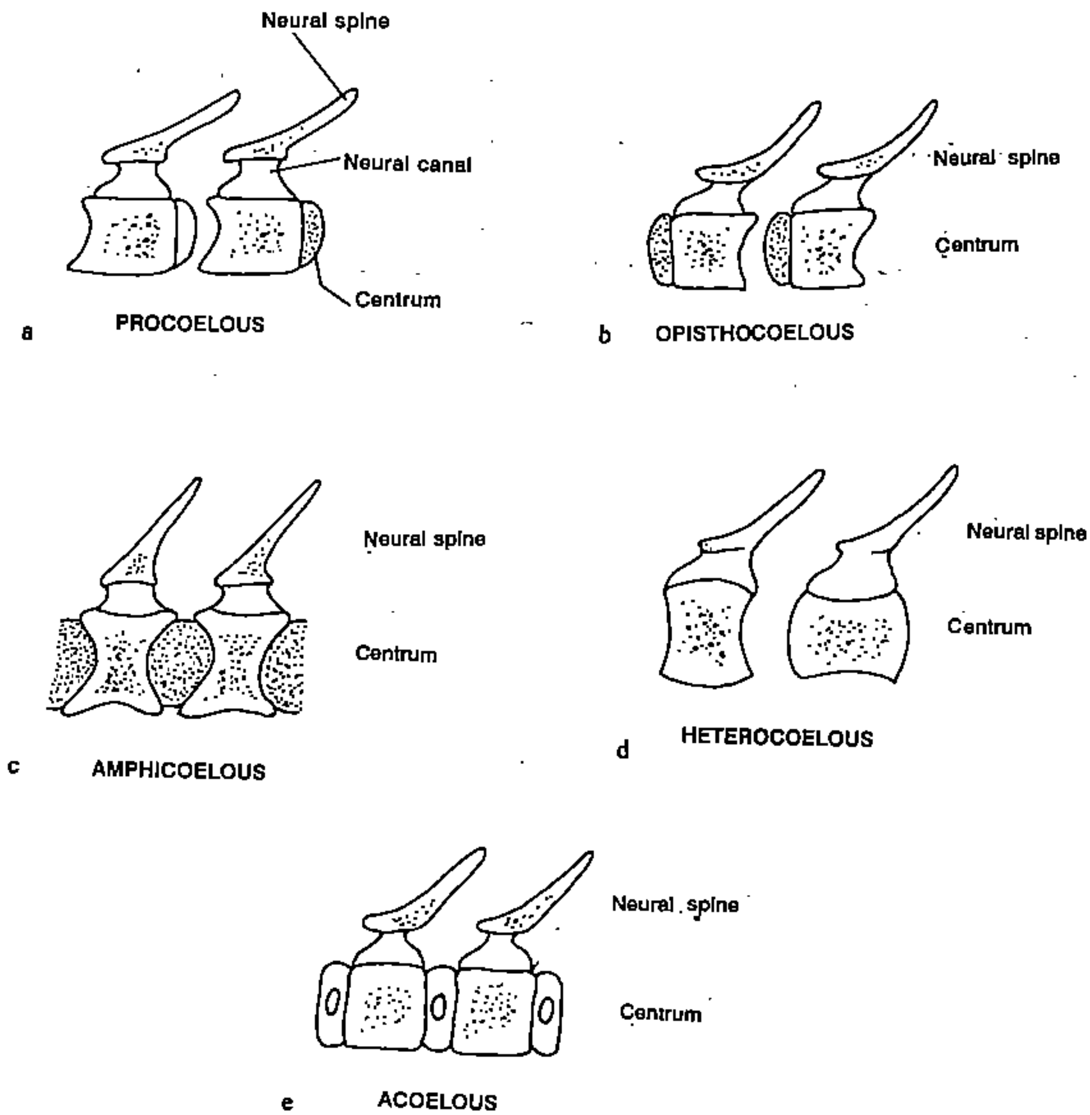


Fig. 11.5 : Different types of centra (a) Procoelous; (b) Ophisthocoelous, (c) Amphicoelous; (d) Heterocoelous; (e) Acoelous.

During development in all vertebrates the vertebral column is preceded by the development of a notochord. The notochord appears as a solid rod along the median dorsal wall of the archenteron lying immediately below the nerve cord. The notochord is made up of vacuolated cells covered by a two layered elastic sheath. The outer and the inner layers are called **elastica externa** and **elastica interna** respectively. The lateral coelomic pouches which are pinched off from the dorso-lateral sides of the archenteron give rise to myotomes. These myotomes are arranged metamerically on either side of the notochord. The inner layer of these myotomes or somites buds off mesenchymal cells which surround the notochord to form the **skeletogenous layer**. The skeletogenous layer contains cartilage forming cells known as **chondroblasts**. Paired outgrowths are formed from the skeletogenous layer. These outgrowths form a tube-like structure above the notochord. This tube encloses the nerve cord. A similar tube is formed from the outgrowths on the ventral side to form the **haemal canal** enclosing the blood vessels.

Further, the chondroblasts give rise to block-like structures called **sclerotomes** (Fig 11.6). These sclerotomes arrange themselves on the lateral sides of the skeletogenous layer medial to each myotome on either side. Each sclerotome divides to form an anterior **cranial half** and a posterior **caudal half.** During development of vertebra the caudal half of one sclerotome unites with the cranial half of the sclerotome behind so that the caudal half of the sclerotome becomes the anterior half and the cranial half of the sclerotome becomes the posterior half of the vertebra (Fig. 11.7). Thus the vertebral segment alternates with the myotomal segments. In this way each myotome is attached to two vertebrae and each vertebra is attached to two myotomes. This provides firm attachment and allows bending movements of the vertebral column.

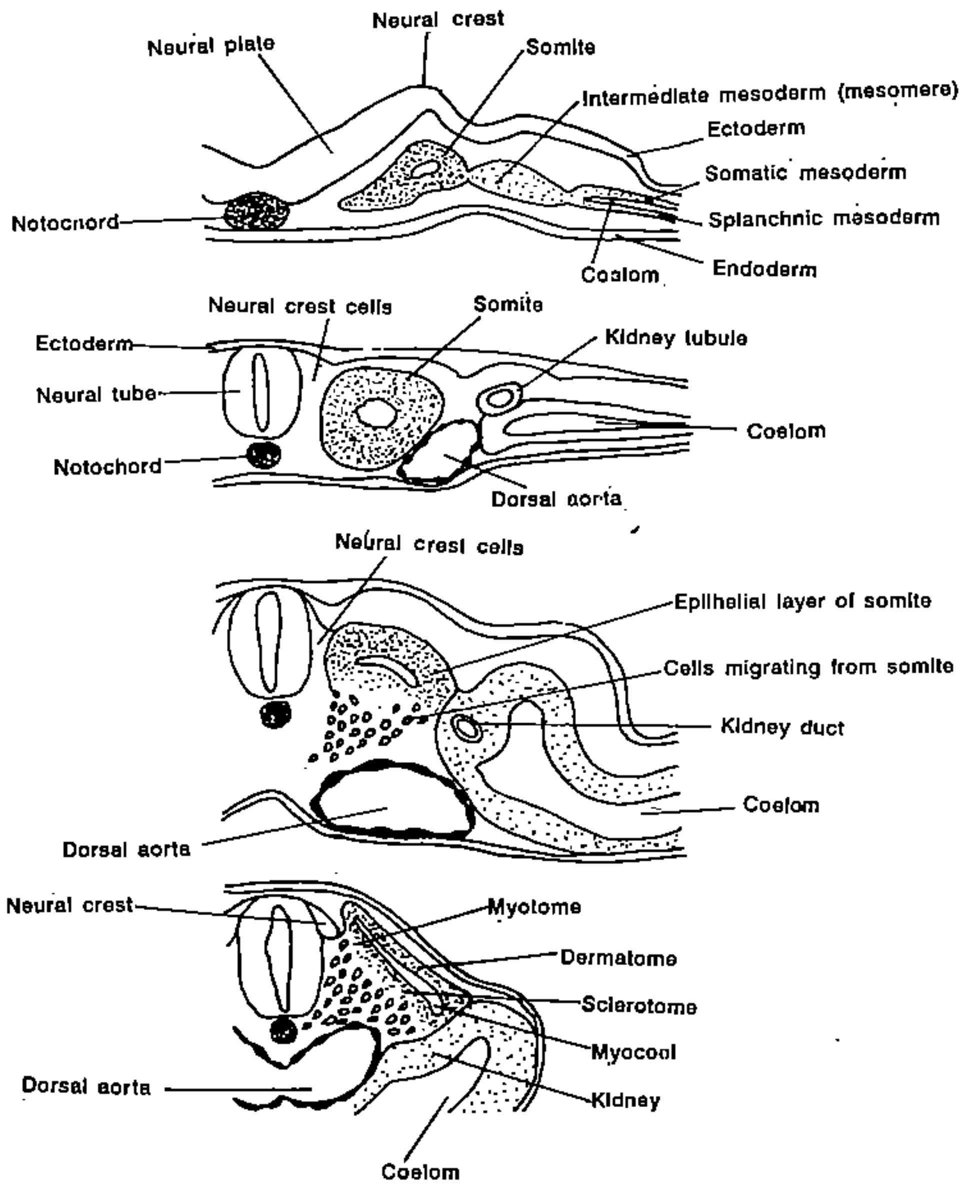
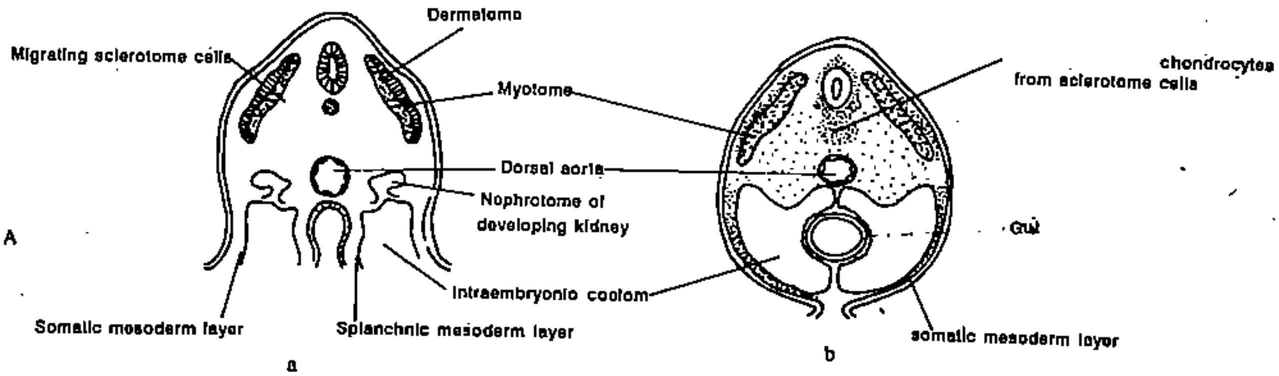


Fig. 11.6 : Differentiation of somites in the bird, early (top) to late (bottom). Three regions of a somite are recognised and named according to their ultimate fates; (1) the ventral and part of the medial wall (sclerotome), which form skeletal tissue,(2) the dorsal and part of the medial wall (myotome) which form skeletal muscle; and (3) the lateral wall (dermatome) which forms much of the dermis of the skin. Under notochordal, and neural induction, the sclerotome begins to specialise first transforming into cells that migrate around the notochord and neural tube.

A



B

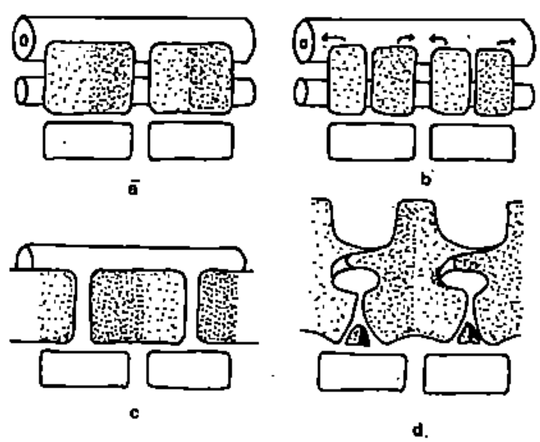


Fig. 11.7 : A. Diagram of a transverse section through the trunk of an early 4 - week (a) and late 4-week (b) human embryo. In (a) the sclerotome cells begin to migrate away from the myotome and dermatome. By the end of the fourth week (b), the sclerotome cells are condensing to form the vertebra, the dermatome is starting to form the dermis, and myotome cells are migrating ventrally down the walls of the embryo. B. Diagrams to illustrate the manner of utilisation of mesenchyme in the formation of amniote vertebrae. Anterior is to the left. (a) is a diagrammatic lateral view of the sclerotomes of two somites; nerve cord and notochord are shown behind them, and below is arbitrarily figured a portion of the musculature belonging to these somites. In (b) the sclerotomes have split into anterior and posterior halves, which move apart and in (c) have fused with the adjacent halves of neighbouring sclerotomes. These newly formed sclerotome masses are the materials from which successive vertebrae are derived, and in (d) is diagrammatically represented (by difference in stippling) the dual origin - from parts of two segments of an adult vertebra. As a result of this seemingly odd developmental process, the vertebrae (as seen by reference to the blocks of segmental origin) are intersegmental rather than segmental in position.

Sclerotomes also give rise to paired cartilaginous block-like structures called **arcualia**. It is these arcualia that give rise to neural and haemal arches of the vertebrae. Each sclerotome gives rise to two pairs of dorsal and two pairs of ventral arcualia. The anterior arcualia are called **interdorsal** and the posterior as basidorsal. Similarly the anteroventral arcualia are called **interventral** and posterior as **basiventral** respectively. The interdorsal and basidorsal are larger than interventral and basiventrals. The interdorsal and interventral form the anterior half of the vertebra and the basidorsal and the basiventral form the posterior half of the vertebra.

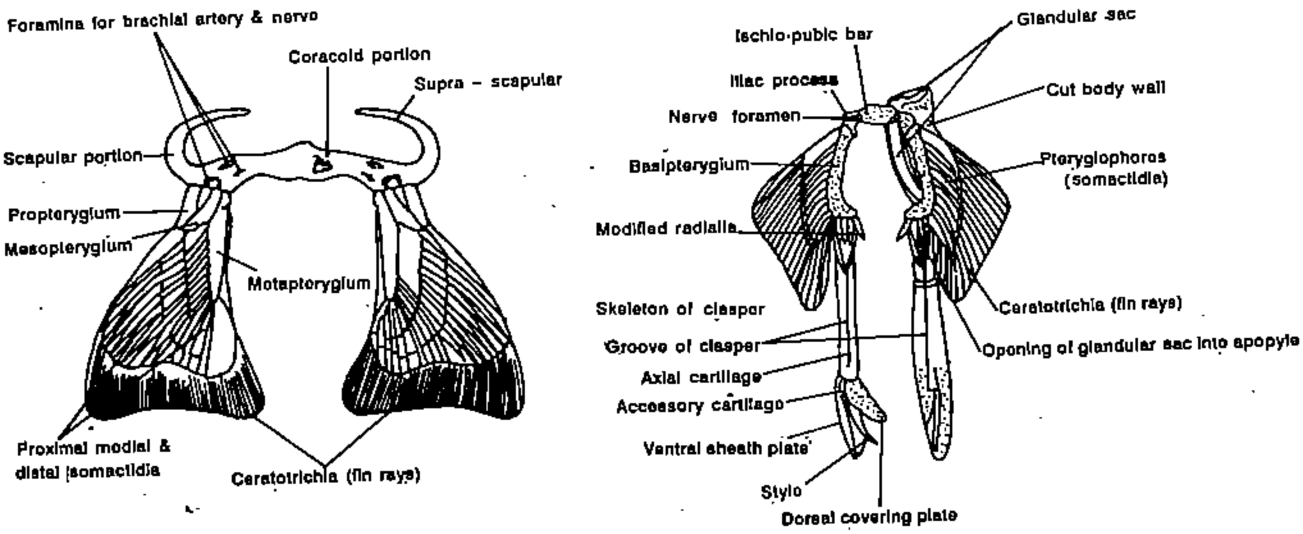


Fig. 11.8: *Scoliodon*, girdles (a) Pectoral girdle and fins, (b) Pelvic girdle and fins.

11.3.2 Appendicular Skeleton

Most vertebrates have two pairs of appendages, an anterior (pectoral) and a posterior (pelvic) pair. Fishes have paired fins (pterygia) as seen in figure 11.8 and tetrapods have jointed limbs (podia). The paired appendages of fishes appear as horizontal folds and the limbs of tetrapods appear as buds during development. The skeleton of paired appendages is supported by girdles. Girdles and skeleton of paired appendages constitute the **appendicular skeleton.** The girdles appear in the form of inverted arches in the body wall spread horizontally on the ventral side and extend upwards on either side above the attachment of the limbs. In their simplest form the pectoral girdle is divisible at the point of attachment of limbs as an upper **scapular** and a ventral **coracoid** region. Similarly the pelvic girdle can be divided into a dorsal **iliac** and a ventral **ischio-pubic** part. The points of articulation of the forelimb with the pectoral girdle and the hindlimb with the pelvic girdle are called **glenoid** and **acetabular** cavities respectively. The tetrapod limbs are typically pentadactyl being provided with five digits each. The tetrapod limbs have similar joints and similar number of skeletal elements. The general pattern of the parts and skeleton can be described as follows:

	Forelimb	**Hindlimb**
Point of attachment of the limbs to the girdle	Shoulder joint	Hip joint
Upper arm/thigh	Humerus	Femur
Point of attachment of upper arm and lower arm/ thigh and shank	Elbow joint	Knee joint
Lower arm/shank	Radius and Ulna	Tibia and Fibula
Wrist/Ankle	Carpals	Tarsals
Palm/Sole	Metacarpals	Metatarsals
Fingers/Toes	Phalanges	Phalanges

Ribs and Sternum

Sets of paired slender curved bones called ribs are found in the thoracic region of most vertebrates. They are attached to vertebrae at one end and to the sternum at (breast bone) the other end, (Fig. 11.9). Together with the vertebral column and the sternum the ribs

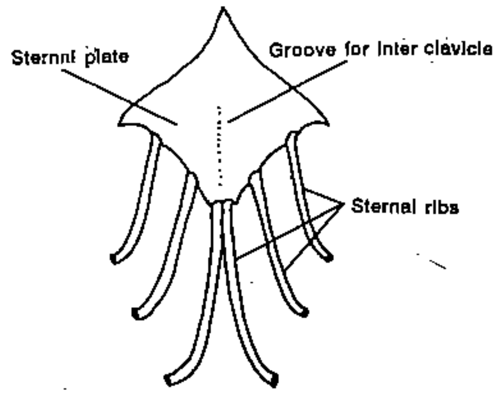


Fig. 11.9: Sternum.

form a skeletal cage enclosing and protecting the organs of the thorax. In the course of evolution ribs first appear in Gnathostomes. Two types of ribs are found; the **dorsal** or **intramuscular** and **ventral** or **haemal ribs**. The dorsal ribs grow as extensions of the vertebrae and extend into the horizontal septa. Dorsal ribs are found in elasmobranchs and amphibians. They are short and incompletely developed, whereas in amniotes they are well developed. They establish contact with vertebral column and sternum and surround the body. In primitive reptiles like *Sphenodon* dorsal ribs are attached to vertebral centrum through a head which touches both the centrum and the neural arch. In higher vertebrates, particularly the amniotes they are attached to the vertebral column. A typical rib has two heads for attachment with the vertebrae, the **capitullum** attached to the centrum and the **tuberculum** attached to the transverse processes of the vertebrae. The two heads of the ribs enclose a space between them known as **vertebrarterial canal** through which the vertebral artery passes. The ventral ribs seem to have arisen from the haemal arches. They also encircle body but lie inside the peritoneal cavity. Ventral ribs are found in most teleost fishes, ganoid fishes and Dipnoi. Both dorsal and ventral ribs are found in most teleost fishes. The ribs which are short and not attached to the sternum are called **false ribs**. False ribs are also found in crocodiles.

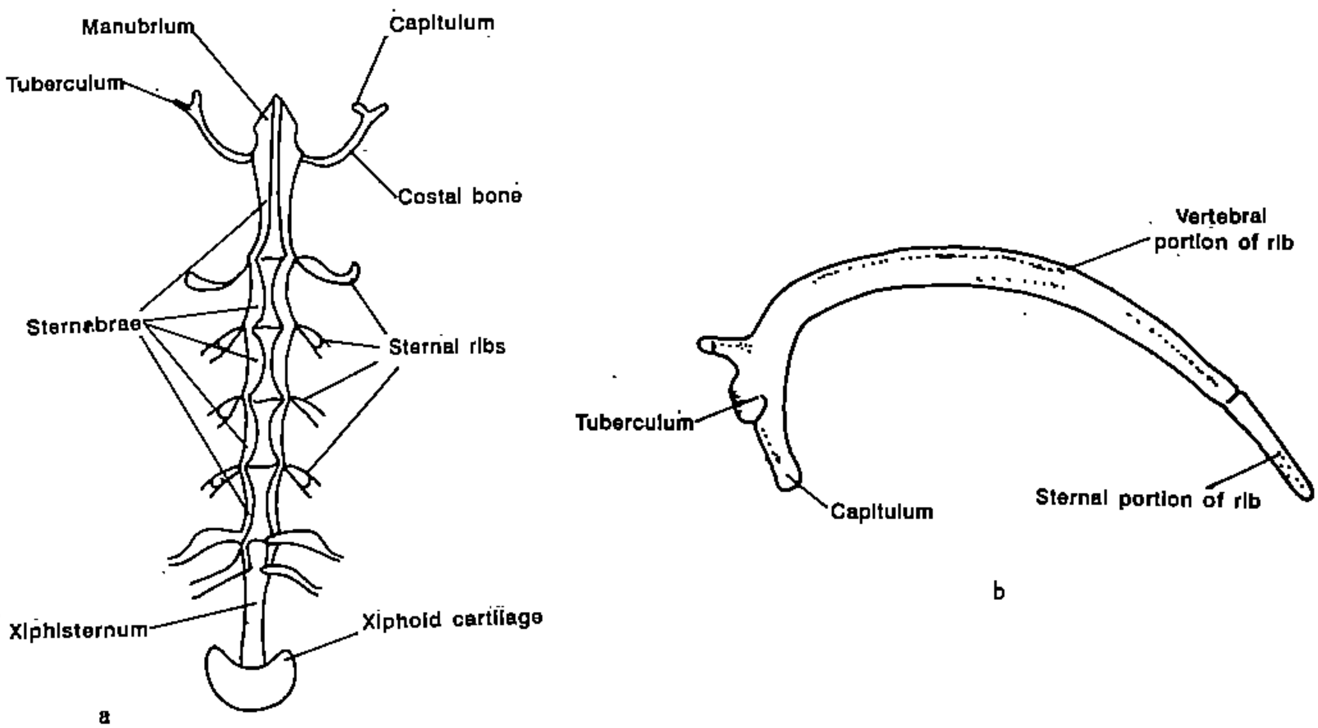


Fig. 11.10 Mammal: Sternum (a) and rib(b).

Sternum is a shield or rod shaped bone or group of bones found in the midventral side of the thorax of tetrapods. Sternum is also commonly called the breast bone. The ventral ends of the ribs are attached to the sternum in amniotes. The sternum develops as an expansion of the medial ends of the ribs. Sternum with the ribs and the vertebral column contributes to the formation of a skeletal framgwork around the thorax enclosing and protecting the thoracic organs, (Fig. 11.10). The sternum of birds is broad and develops a ventral keel-like projection and provides a surface for the attachment of wing muscles,(Fig. 11.11). Sternum is usually found in vertebrates adapted for limb locomotion. Snakes which have lost limbs also have lost the sternum.

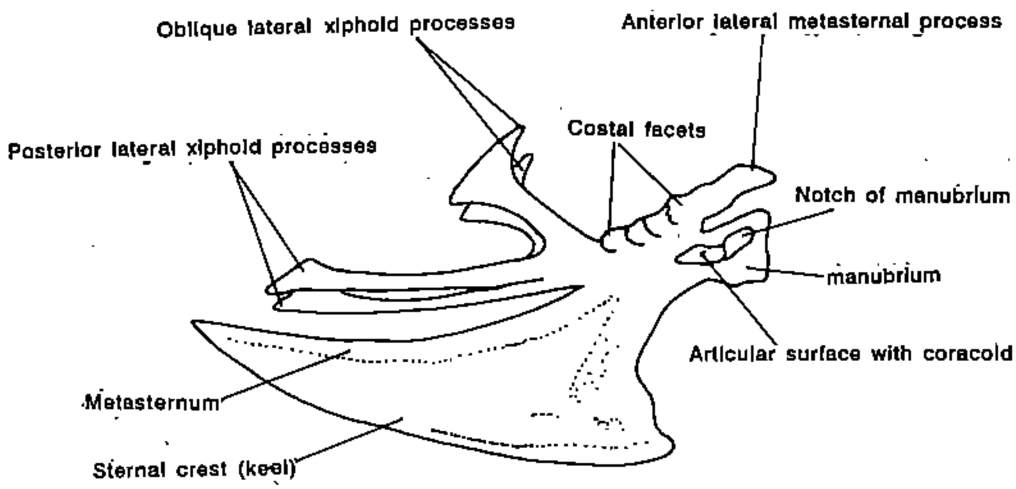


Fig. 11.11 Sternum of bird (lateral view).

SAQ 1

a. Match the statement given in column 'B' with the caption of the column 'A'.

A		B
a) Cartilage and bone	i)	The haemal arch contains the haemal canal which encloses the blood vessels.
b) The skull	ii)	The tetrapod limbs are typically pentadactyl being provided with five digits each.
c) The vertebral column	iii)	The matrix is composed mainly of mineral salts mostly of calcium combined with phosphates and carbonates.
d) Appendicular skeleton	iv)	The olfactory capsules are present on the anterior end and the auditory capsule are present on the posterolateral sides of the cranium.

b. Fill in the blanks

i) Procoelous centrum of a vertebra bears concavity in .... and a convexity ....

ii) .... centra appear dumble shaped in the lateral view.

iii) .... centra are described as .... shaped.

iv) Acoelous centra are usually .... without any bulging or ....

11.4 SKELETON OF FROG AND RABBIT

In this section we will discuss the salient features of the axial and appendicular skeletons of frog and rabbit.

11.4.1 Skull of Frog

The skull of frog is simple in structure with fewer number of bones, (Fig. 11.12) compared to other vertebrates. It is easy to study.

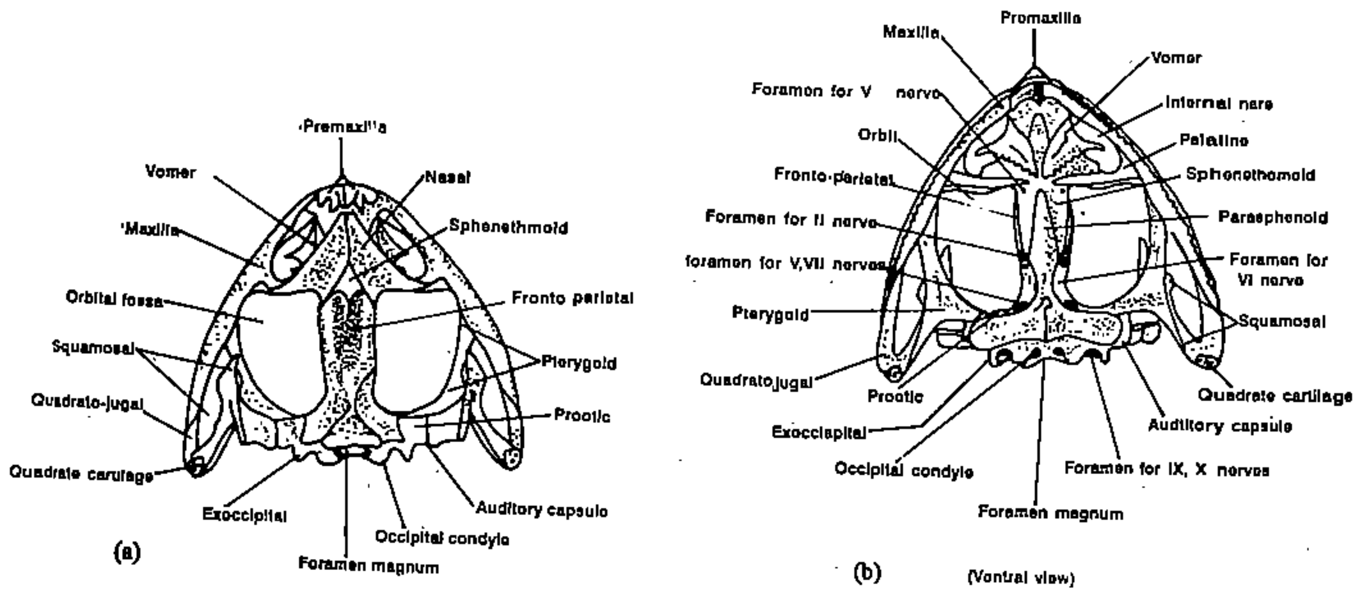


Fig. 11.12 : Frog skull. a) Dorsal view; b) Ventral view.

The cranium of frog skull is formed of just six bones, (Fig. 11.13). It is anteroposteriorly elongated. The posterior end of the cranium is called the occipital end. It consists of a large aperture the **foramen magnum**. It is surrounded by a pair of **exoccipitals**. The exoccipitals bear two bulges, the **occipital condyles**, for articulation with the first vertebra. The roof and sides of the cranium are covered by a composite pair of bones called **frontoparietals**. At the front end there is a single ring shaped bone, the **sphenethmoid**. The floor of the cranium is covered by a dagger shaped bone, the **parasphenoid**.

The auditory capsules of the frog skull are situated at the posterolateral sides of the cranium. Each auditory capsule consists of only one bone, the **pro-otic**. The rest of the capsule is covered by membranes. The olfactory capsules are found anterior to the cranium. Each olfactory capsule is covered by a **nasal** above and a **vomer** below. The two bones are bound by membranes to the cranium and to each other. There is a space anterolateral to the cranium in which eye balls are lodged. It forms the orbit. It is bound on the outer border by bones of the upper jaw, by bones of the olfactory capsule and the cranium on the inner margin and the bone of the auditory capsule behind. The floor is covered by tough membranes which bulge into the buccal cavity.

The upper jaw is horse shoe shaped. It forms the outer margin of the skull anteriorly and laterally. The upper jaw is made up of two halves united in front and free behind. Each half consists of an anterior **premaxilla**, a middle **maxilla** and a posterior **quadratojugal**, (Fig. 11.13). The two halves of the upper jaw are united at the premaxillar end. The upper jaw is fixed immovably to the skull with the help of three bones on each side. A barlike **palatine** (Fig. 11.12) connects maxilla to sphenethmoid of the cranium. There are two bones posteriorly on each side connecting the upper jaw with the auditory capsule of the respective side. Dorsally there is a 'T' shaped **squamosal**. The long limb of this bone is attached to the quadratojugal posteriorly. The inner tip of the horizontal limb is attached to the pro-otic and the other end is free. Ventrally there is a tri-radiate bone, the **pterygoid** on each side. The three ends of this bone are attached to the maxilla anteriorly the pro-otic on the mid posterior side and quadratojugal posteriorly.

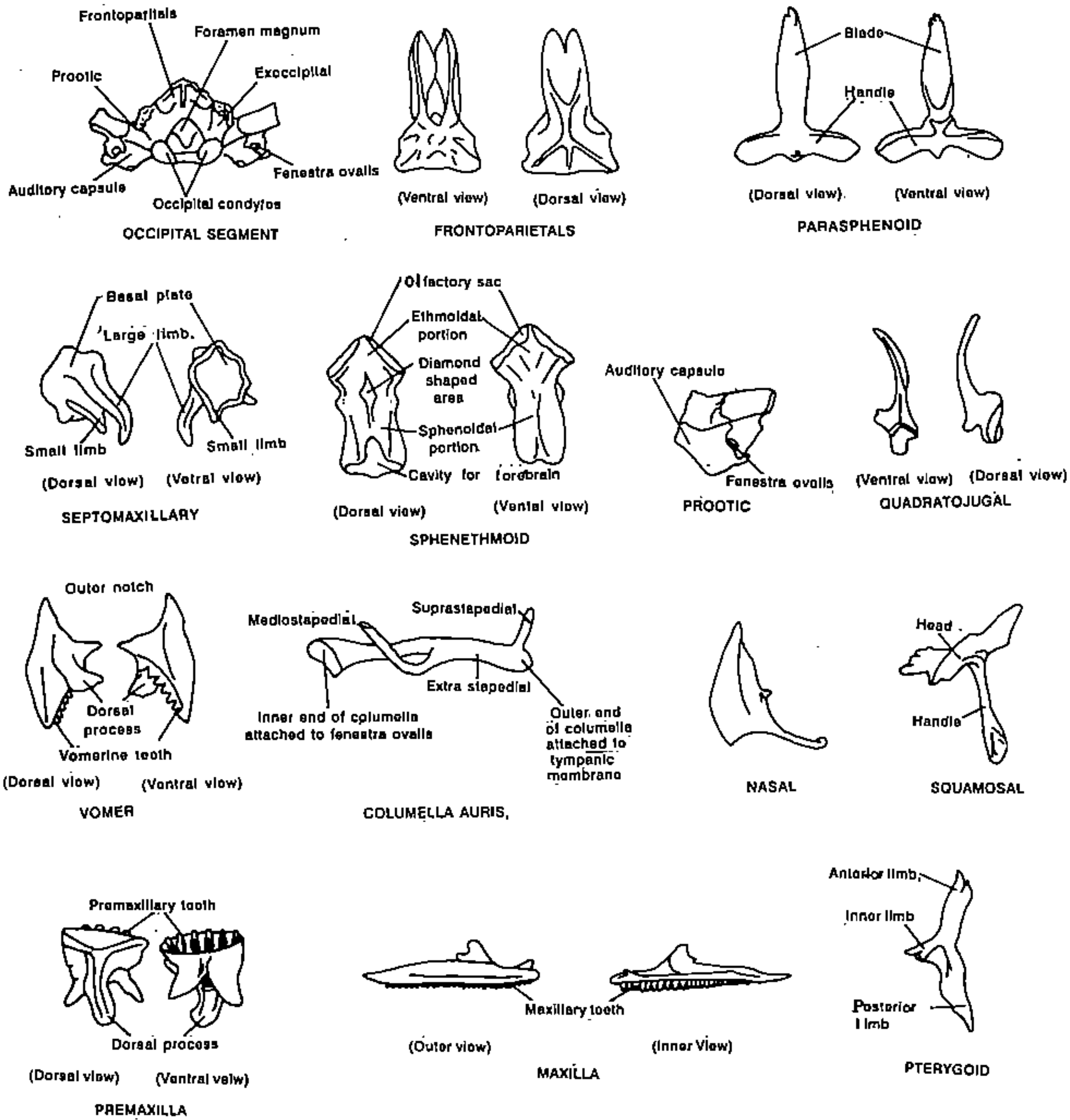


Fig. 11.13 : Disarticulated skull bones of Frog.

The lower jaw is also horse shoe shaped (Fig. 11.14). It is complementary in shape to the upper jaw. It is articulated with the quadratojugal of the upper jaw posteriorly and free rest of the way. The lower jaw also consists of two halves united at the anterior end. Each half consists of a **mentomeckelian** anteriorly, **dentary** behind and **angulosplenial** posteriorly. The two mentomeckelians of the two halves are united anteriorly and the angulosplenials articulate with the quadratojugal of the upper jaw where it fits into a concavity at the terminal end. There is a small ridge-like process infront of the concavity on the angulosplenial called **coronary process** (Fig. 11.14).

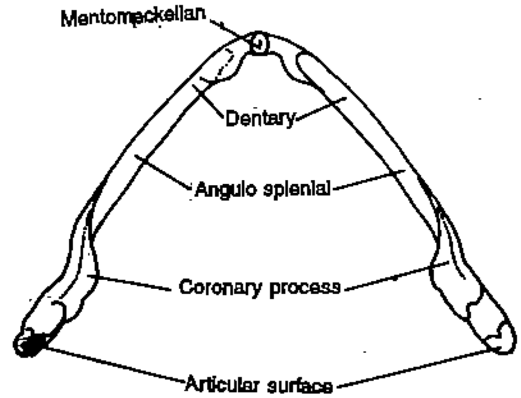


Fig. 11.14 : Lower jaw of frog.

Teeth are found on the premaxilla and maxilla of the upper jaw and also on the vomers of the olfactory capsule. Teeth project into the buccal cavity. Teeth are fused to the bones on which they are found. Teeth are arranged in a single row along the edges of the premaxilla and maxilla. The teeth on the vomers are called **vomerine teeth.** The teeth are curved inwards. They do not help in mastication but help to prevent the prey from escaping from the buccal cavity. There is a hyoid apparatus forming the support for the floor of the buccal cavity, (Fig. 11.15). It is derived from the visceral skeleton. It consists of a central plate-like body lying on the floor of the buccal cavity. It provides a surface for the attachment of the tongue. The central plate has two pairs of processes, one pair at the anterior end and another at the posterior end. They are called **anterior** and **posterior hyoid cornua** respectively. The anterior hyoid cornua are long slender cartilaginous processes curved back to extend into the auditory region of the skull where they are attached to the **collumella auris** of the middle ear. The posterior hyoid cornua are stout rod-like bones projecting backwards on either side of the glottis, the opening of the trachea on the floor of the buccal cavity.

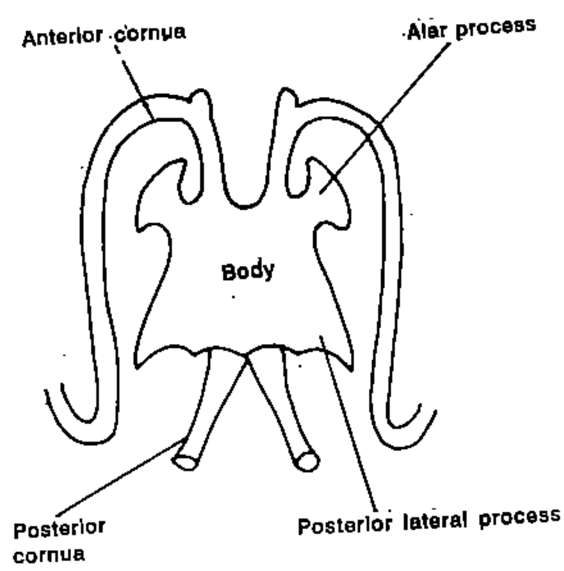


Fig. 11.15 : Hyoid apparatus.

11.4.2 Skull of Rabbit

The skull of rabbit is thick and elongated anteroposteriorly when compared to the skull of frog. The elongation of the skull is due to the prolongation of the jaws forming a snout to provide more space for the attachment of the jaw muscles. The skull of rabbit can also be studied under the same divisions like that of the frog: the cranium enclosing the brain, the sensory capsules enclosing the sense organs, the two jaws and the hyoid apparatus, (Fig. 11.16). The different parts of the skull have become more complicated in structure with addition of more bones either by ossification of pre-existing cartilages or addition of a few investing bones where only membranes existed earlier. At present mammals represent the final stage of vertebrate evolution. The complexities encountered are an adaptation to accommodate evolutionary features that have made survival on land possible.

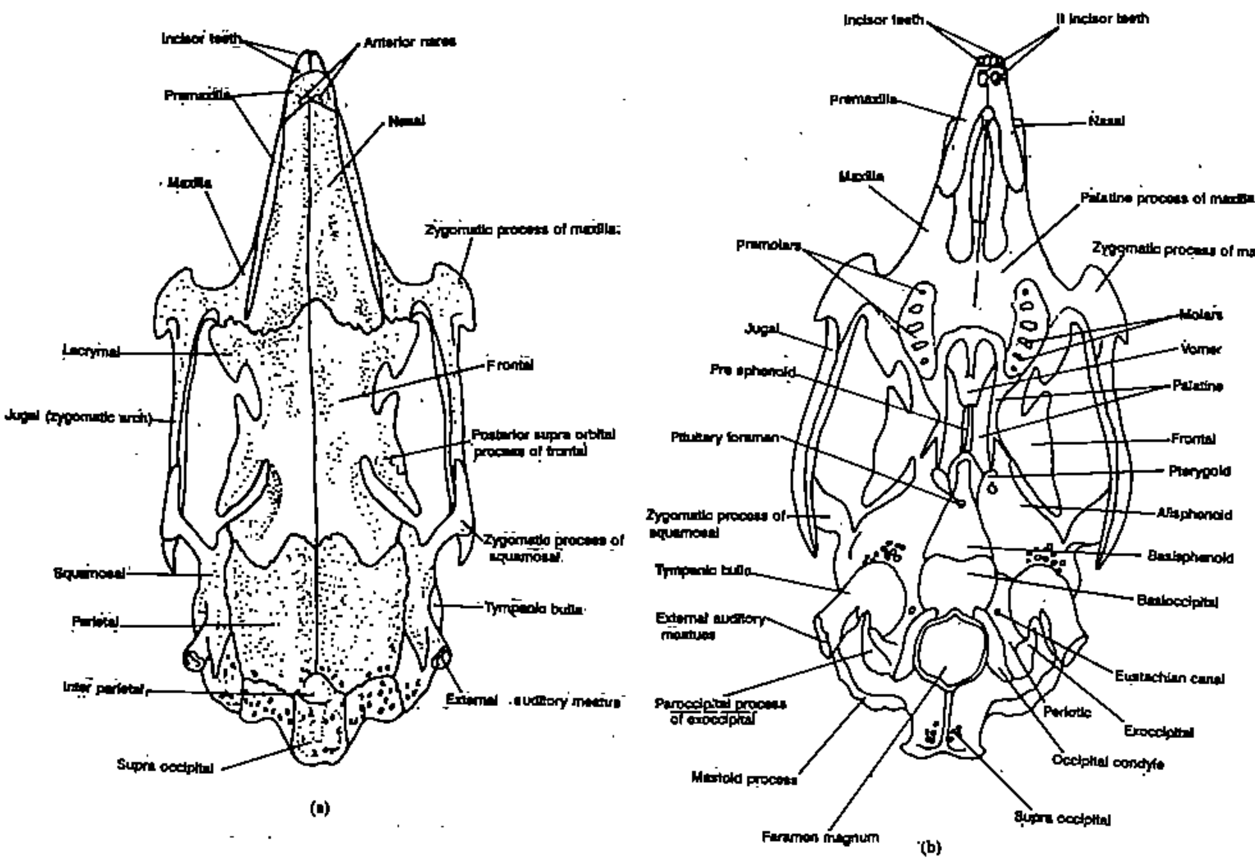


Fig. 11.16 : Mammalian skull (rabbit) a) dorsal view; b) ventral view.

The cranium is short compared to the length of the skull as a whole. The cranium is found behind the orbits. The cranium can be divided into three segments anteroposteriorly. The segments are in the form of rings placed one behind the other and they all surround the brain. The hind segment is the occipital segment. It consists of four bones surrounding the **foramen magnum** as compared to only two bones in the frog. The foramen magnum is directed downwards and not backwards as in frog. The foramen magnum is surrounded at the top by a single bone, the **supraoccipital**, a pair of **exoccipitals** on the lateral sides and a single plate-like bone, the **basioccipital** on the lower side, (Fig. 11.17). In rabbit also there are two condyles for the articulation of the skull with the first vertebra. So the skulls of both frog and rabbit are **bicondylar**. The condyles of rabbit project from the lower part of the exoccipitals. Both the exoccipitals and the basioccipitals contribute in the formation of condyles. Condyles are smooth and round and articulate with the concavities on anterior face of the first vertebra.

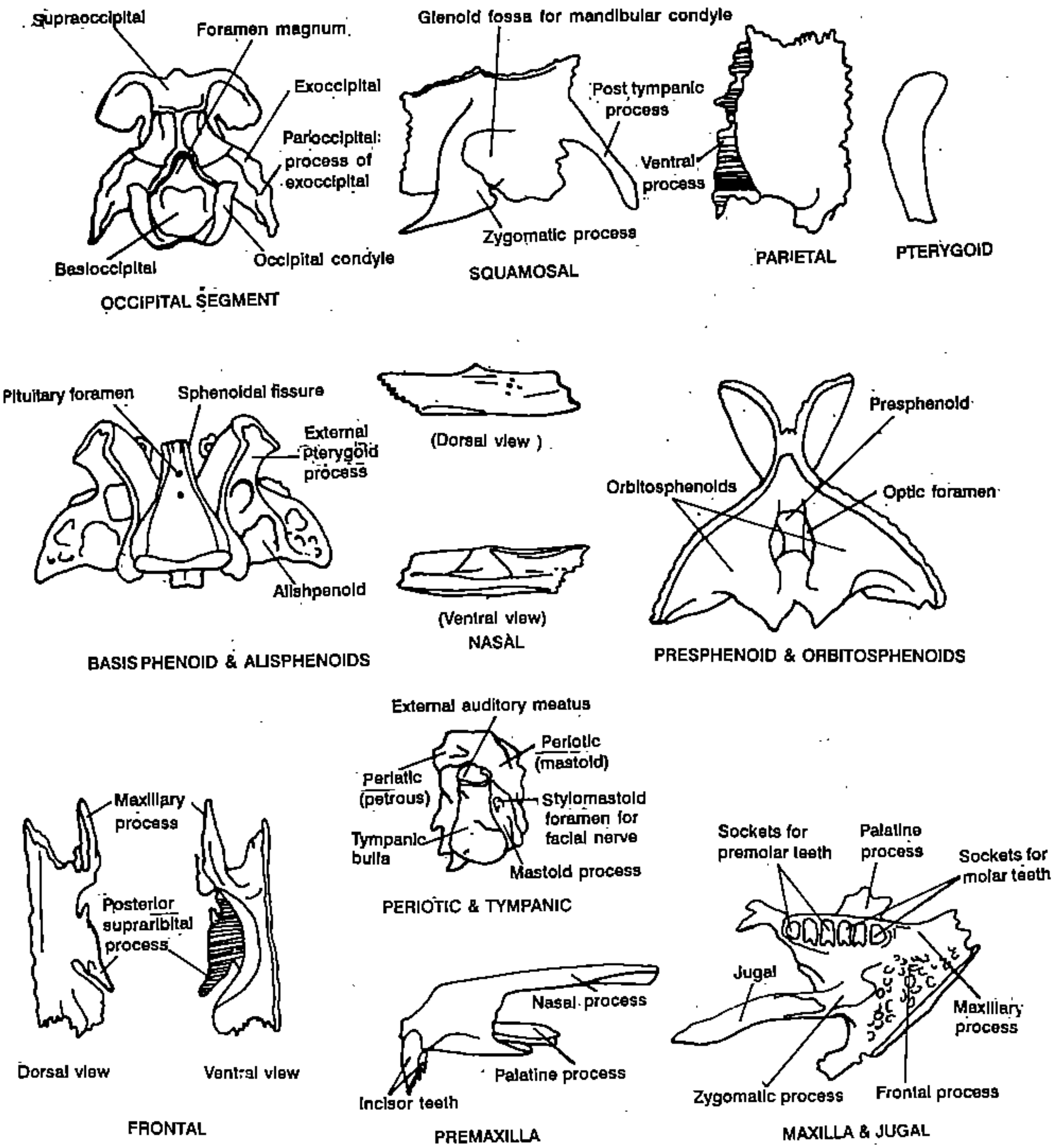


Fig. 11.17 : Disarticulated skull bones (rabbit).

The segment of the cranium infront of the occipital region is the parietal segment. It consists of six bones. A single flat triangular **basisphenoid** forming the floor infront of the basioccipital. There is a depression on the basisphenoid in which the body of pituitary lodges, known as **sella tursica or pituitary fossa.** There are a pair of bones, the **parietals** forming the roof of the segment. The two parietals are united on the mid-dorsal line. The sides of this segment are formed by a pair of wingshaped bones one on each side, the **alisphenoids,** (Fig. 11.12). They are connected to the parietals dorsally and basisphenoid ventrally. Dorsally between the two parietals and supraoccipital behind is a single wedge shaped bone called **Interparietal.** The anterior part of the cranium is the frontal segment. The roof of the frontal segment is covered by a pair of **frontals** with prominent ridges on each of them called **supraorbital** process. These processes project over the orbit on each side. There is a median **presphenoid** which forms the floor of the segment. It is found infront of the basisphenoid. There is a pair of **orbitosphenoids**, which on either side form the inner boundary of the orbit. There is a vertical plate-like bone forming the anterior boundary of the cranium called **cribriform plate**. This plate bears an aperture for the passage of the olfactory nerves.

There is a pair of membrane bones called **squamosal** which help to complete the lateral wall of the cranium posteriorly. The squamosal of each side articulates with frontal, parietal and alisphenoid of that side. A projection from the squamosal called **zygomatic process** projects outwards. It has a depression to which the lower jaw articulates. The auditory capsules are situated on the posterolateral sides of the cranium on each side between the squamosal and exoccipitals, (Fig. 11.16). Each auditory capsule is represented by a complex of bones in the adult, the **periotic**, the **epiotic** and the **opistho-otic**. The auditory capsule in addition consists of two other structures, the **tympanic bone** and the **auditory ossicles**. The periotic bone is divisible into two parts, the **petrous** which forms the internal ear enclosing membranous labyrinth and the **mastoid process** projecting outside between the periotic process and the exoccipital. The petrous bears two openings on its outer surface, the **fenestra ovalis** and the **fenestra rotundum** (Fig. 11.18). The tympanic bone lies across the auditory meatus between the basisphenoid and the squamosal and is closely attached to the periotic on its outer surface. The tympanic bone is flask shaped consisting of an outer tubular part and a lower smaller part forming the **tympanic bulla** which contains the tympanic cavity enclosing the auditory ossicles. The tubular part encloses the auditory meatus. The tympanic membrane is stretched across the cavity at the inner end of the tube. The tympanic membrane separates the tympanic cavity from the tube. The auditory ossicles consist of three small bones the **malleus**, the **incus** and the **stapes**, (Fig. 11.19). They extend between the tympanic membrane and the periotic bone. There is an eustachian aperture anteriorly on the tympanic bone opening into the eustachian canal which communicates with the pharynx.

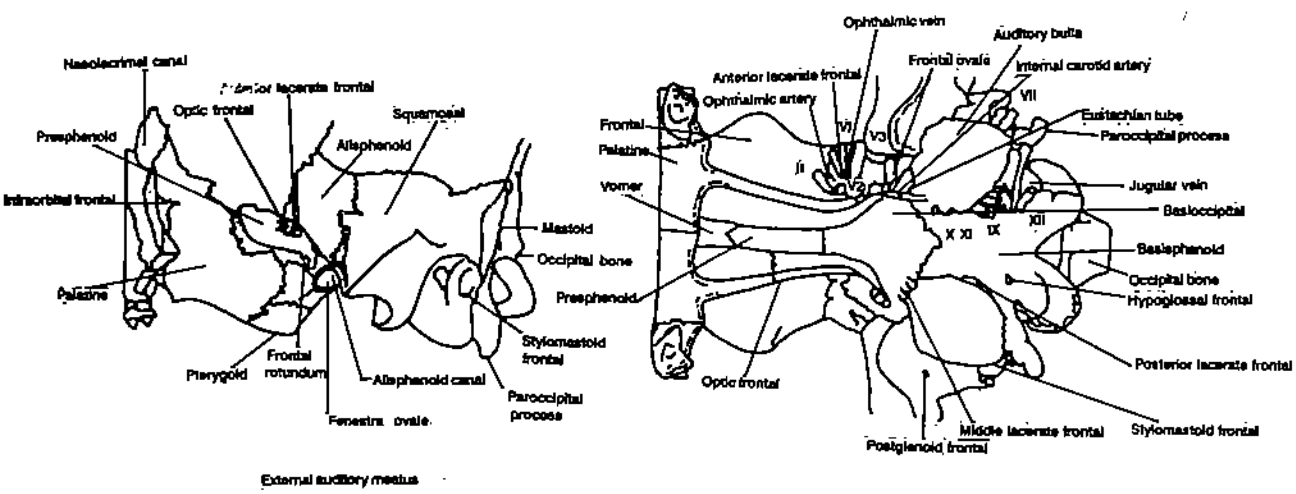


Fig. 11.18 : Braincase region of a dog in A, lateral view; B, ventral view, to show foramina. In B, the main nerves, the course of the internal carotid artery and its palatine branch, and the jugular vein are indicated.

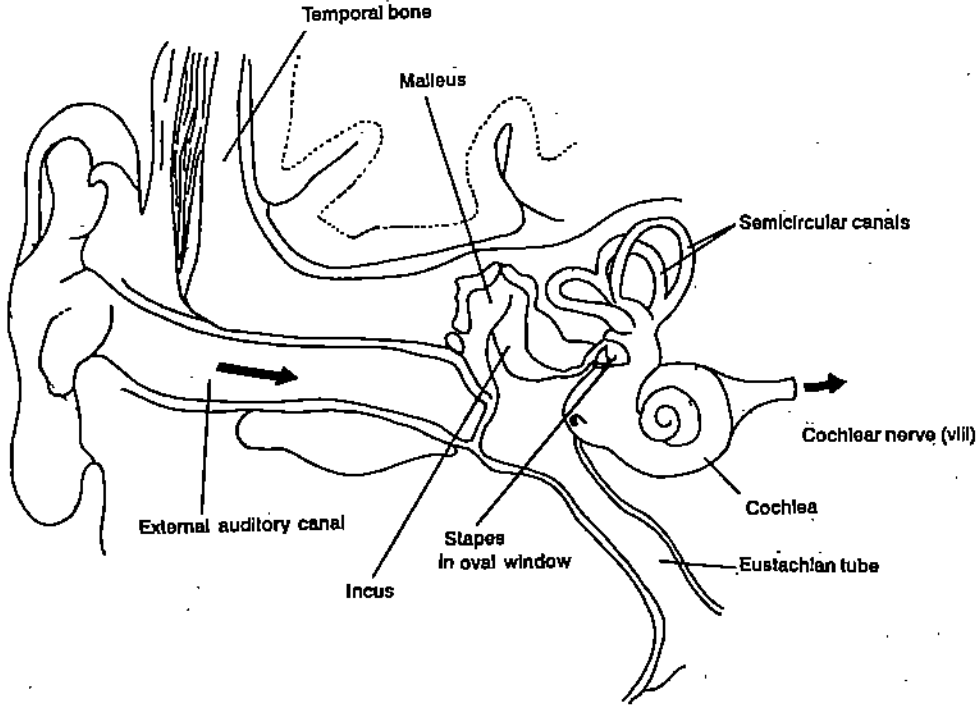


Fig. 11.19 : Major parts of the human ear.

The olfactory capsules are found infront of the cranium. They are roofed over by two flat bones, the nasals. They extend from the tip of the external **nasal** openings infront to the frontals behind. The nasal cavity is separated into two separate cavities by a vertical plate-like bone, the **mesethmoid.** It lies infront of the cribriform plate. Each nasal cavity contains a scroll-like bone the **turbinal**. The nasal cavity opens out through the external nares and internally into the buccal cavity far behind through the posterior/internal nares.

Orbits are hollow spaces which contain eye balls. They are found on the anterolateral sides of the cranium between the upper jaw and the olfactory capsule on each side. There is a small bone called **lacrymal** on the anterior wall of the orbit (Fig. 11.20). It contains an aperture, the lacrymal aperture through which the **lacrymal glands** open out into the orbit.

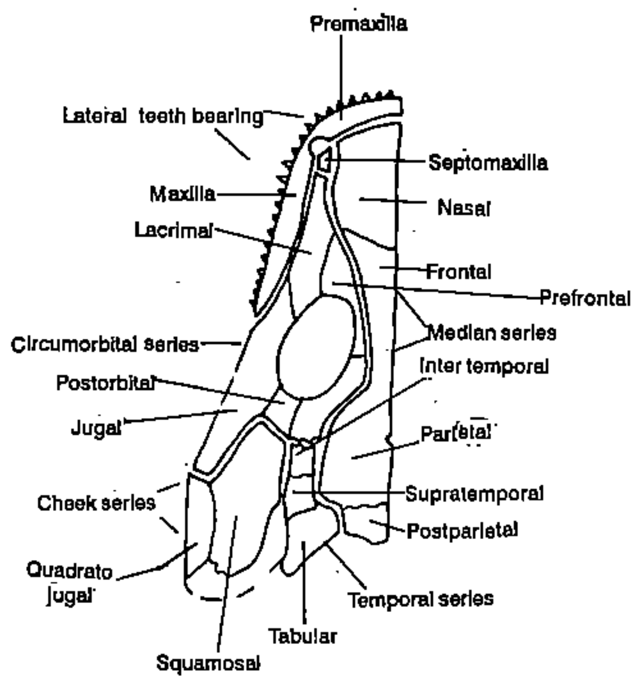


Fig. 11.20 : A diagram of the skull roof of a primitive tetrapod with the elements grouped (rather arbitrarily) into regional series. The little septomaxilla does not readily fit into any series. The stippled elements are retained as such in the skull of typical mammals; hatched elements at back appear to be fused into mammalian occipital bone; elements unshaded are lost in mammals.

The upper jaw consists of two halves united infront. Each half of the upper jaw consists of a **premaxilla**, (Fig. 11.21a), anteriorly, and a **maxilla** behind, (Fig. 11.21b). The two halves of the upper jaw are united at the premaxillae end. Premaxilla are large bones and they form anterior part of the snout. Premaxilla gives off three processes which articulate with nasals, the maxillae and the palatines. The premaxilla bears incisor teeth. The maxilla behind forms the major part of the upper jaw and bears premolar and molar teeth. From the inner margin of the maxilla a horizontal palatine process takes its origin on each side and the two meet in the centre to form the anterior part of the palate, a horizontal partition separating the nasal cavity from the buccal cavity. It forms the roof of the buccal cavity. From the outer margin of the maxilla the zygomatic process projects outwards to form the anterior border of the orbit. The maxilla extends behind the nasal cavity externally. Between the palatine and the alisphenoid on each side there is an irregular bone called **pterygoid**. There is a laterally compressed bone the **jugal** with the zygomatic process and the squamosal on each side. It is involved in the formation of zygomatic arch with squamosal and maxilla.

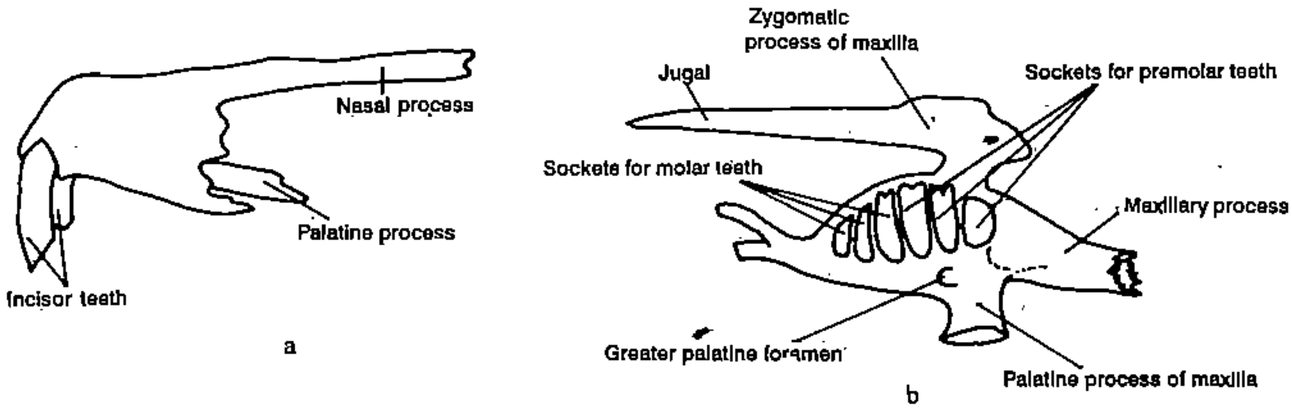


Fig. 11.21: (a) Premaxilla and (b) Maxilla of rabbit.

The lower jaw as in all mammals is made up of a single bone, (Fig. 11.15), as opposed to six bone in the lower jaw of reptiles and three in that of the frog. The bone is **dentary**. The two dentaries are joined together infront in the midline by a symphysis. Each dentary has an anterior horizontal and a posterior ascending process which end in a condyle at the upper tip. The condyle helps in articulating with the glenoid fossa on each side. The glenoid fossa is formed by the squamosal and the zygomatic process.

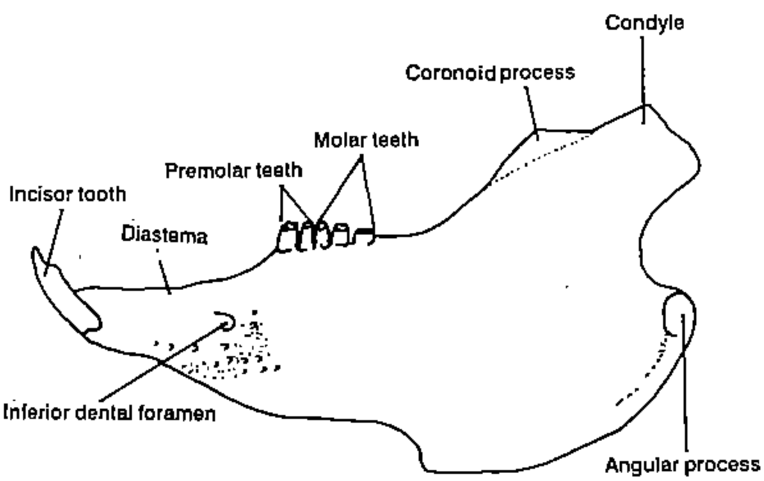


Fig. 11.22 Mandible (lower Jaw) of rabbit.

The hyoid apparatus is represented by a central plate, the **basihyal** (Fig. 11.23) which has two pairs of processes projecting backwards. The anterior cornua consists of three bones connected to the periotic and the posterior cornua to the larynx.

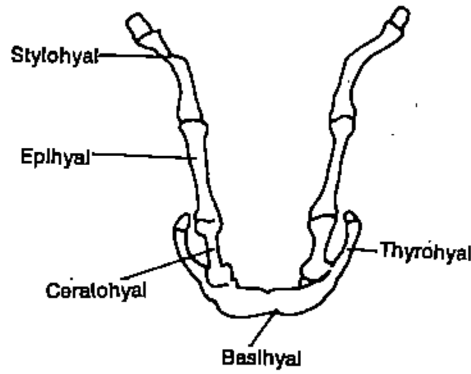


Fig. 11.23 : Mammalian Hyoid Apparatus.

The lower jaw of reptiles consists of six bones; the **articular**, the **angular**, the **supra-angular**, the **dentary**, the **splenial** and the **coronoid**. Dentary bears teeth (Fig. 11.24). Among these six bones only dentary is retained in the mammalian lower jaw. The other bones of the reptilian lower jaw have been eased out of the function of forming a part of the lower jaw and are utilised in the formation of the ear ossicles with the added function of transmitting sound waves to the internal ear.

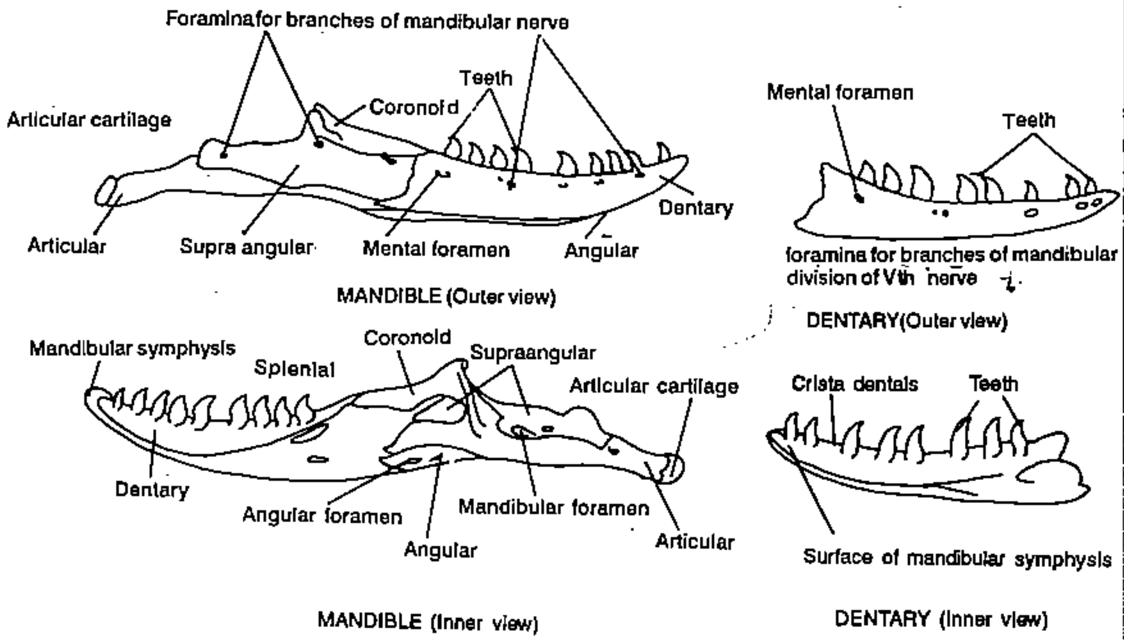


Fig. 11.24 : Mandible of Varanus.

A true palate separating the respiratory passage from the buccal cavity is formed in mammals only.

Bones of the skull of mammals are united with each other by zig-zag lines called **sutures**. It is characteristic of mammals. Sutures represent the line marking the fusion or junction between adjacent bones.

Attachment of teeth to jaw bones is different in different classes of vertebrates. In amphibians and reptiles teeth are fused to jaw bones. This condition is called **acrodont** dentition. In mammals teeth are accommodated in holes on the jaw bones. This condition is called **thecodont** dentition. The teeth of most vertebrates including frog are all of the same type, a condition known as **homodont** dentition. But in mammals there are different types of teeth of different shape and structure performing different functions. This is called **heterodont** dentition. In addition mammals have two sets of teeth during their life time, a set appearing in early life called the **milk teeth** and a relatively permanent set appearing in the adult called **permanent teeth**. This condition is described as **diphyodont** type of dentition.

11.4.3 Vertebral Column of Frog

The vertebral column of frog is simple and short, (Fig. 11.25). It consists of a total of nine vertebrae with a rod-like urostyle at the posterior end. The first vertebra is called **atlas** vertebra. It is ring shaped with a small centrum and two concavities on its front surface for articulation with two condyles of the skull. Transverse processes and the pre-zygapophyses are absent. The second vertebra as in all vertebrates is called **axis** vertebra.

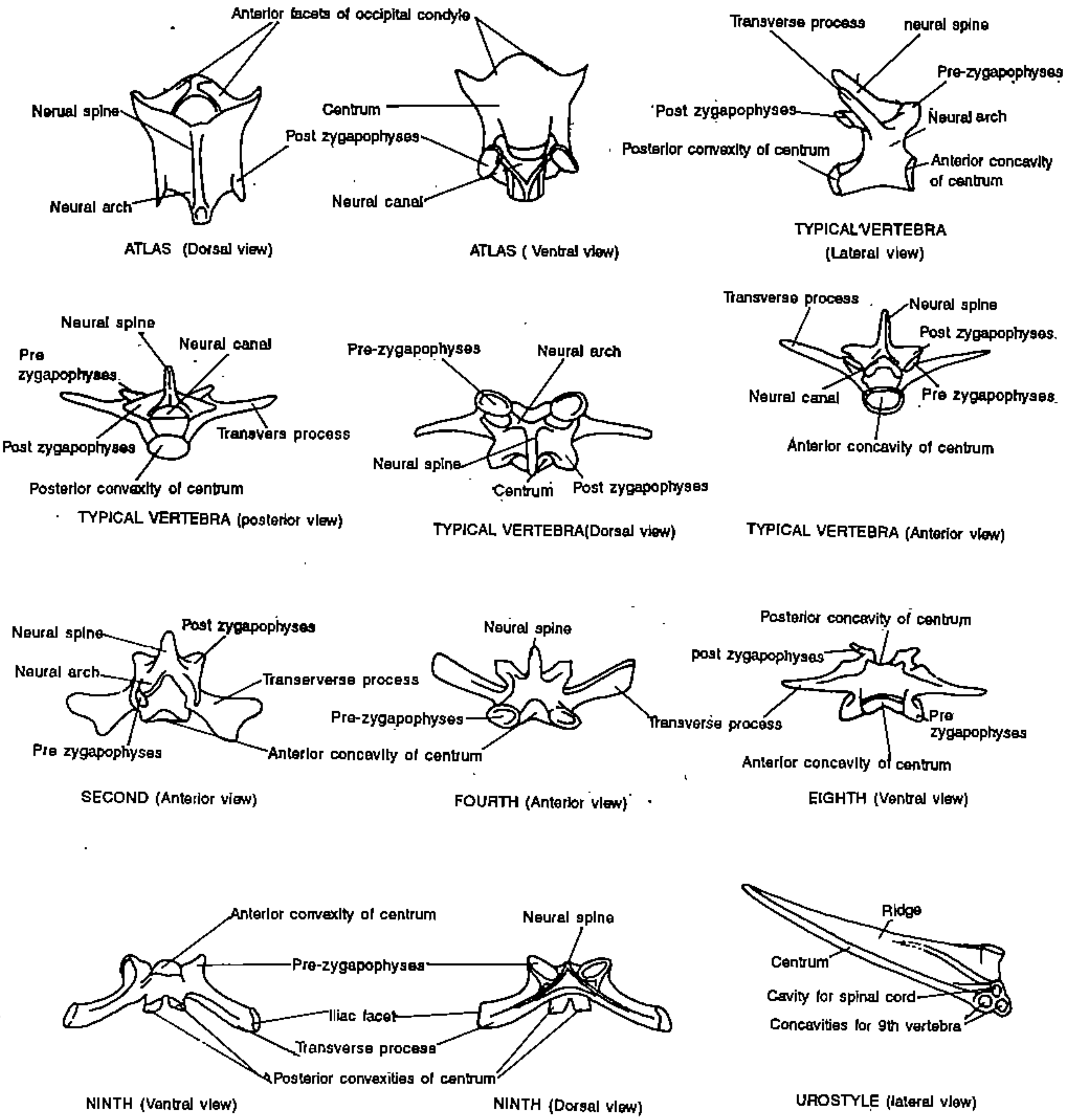


Fig. 11.25 : Vertebrae of Frog.

The vertebrae 3 to 7 are typically procoelous. They possess a pair of transverse processes, a pair each of pre- and post- zygapophyses and a neural arch dorsally enclosing the neural canal, with a backwardly directed neural spine dorsally. The prezygapophyses of the vertebra behind lie over the postzygapophyses of the vertebra infront. The eighth vertebra is biconcave with concavities both in front and behind. The ninth vertebra has a convexity infront and two knob-like bulgings behind for articulation with the two depressions on the anterior end of the urostyle. The transeverse processes of the ninth vertebra are directed backwards and the postzygapophyses are absent. The urostyle is long, slender and rod-like in structure. In fact it is as long as the length of the whole vertebral column. The anterior end of the urostyle has two concavities in front for articulation with the two convexities on the hind end of the ninth vertebra. There is a longitudinal ridge along the dorsal surface of the urostyle and this ridge encloses the terminal part of the spinal cord. Urostyle is a composite structure representing the fused caudal vertebrae of the tadpole, a consequence of the loss of the tail during metamorphosis. In between the vertebrae there are paired apertures on either side for the passage of the spinal nerves. They are called intervertebral foramina. The vertebrae are also bound together by ligaments which permit limited movement.

11.4.4 Vertebral Column of Rabbit

Compared to the vertebral column of frog the vertebral column of rabbit is long. It is divisible into five regions; the **cervical**, the **thoracic**, the **lumbar**, the **sacral** and the **caudal** regions, (Fig. 11.26). There are a total of 45 vertebrae; 7 in the cervical, 12 in the thoracic, 7 in the lumbar, 4 in the sacral and 15 in the caudal regions. The vertebrae are separated from each other by plates of fibrous cartilage known as **intervertebral discs.**

The number of vertebrae in the cervical region of mammals is constant irrespective of the neck being long as in giraffe or short as in elephant. The centra of the cervical vertebra are short, the neural spine is small and the vertebral arterial foramina (through which the vertebral arteries come out) are present at the base of the transverse processes of all cervical vertebrae except the 7th vertebra. The transverse processes of the cervical vertebrae are fused with the ribs to form a composite structure called the **cervical rib.**

The first cervical vertebra, the atlas has no distinct centrum. It is ring shaped. The neural spine is small and inconspicuous. Transverse processes are large, flattened and perforated. There is a pair of concavities on the anterior surface for articulation with the two condyles of the skull. There are small facets on the posterior surface for articulation with the second vertebra. The neural arch is large and it encloses a large neural canal which is divided into an upper part and a lower part by ligament. The spinal cord passes through the upper part and the lower part accommodates the anteriorly directed **odontoid** process of the 2nd vertebra.

The 2nd cervical vertebra or the axis vertebra has a broad centrum which produces an anteriorly directed plough-like process called the odontoid process. It fits into the lower part of the neural canal of the 1st vertebra. The neural spine is long and compressed. The transverse processes are long and the anterior zygapophyses are absent.

The transverse processes of all cervical vertebrae except the 7th are bifurcated into a dorsal and a ventral branch. The transverse processes are simple and do not possess the intervertebral foramen.

The thoracic vertebrae have a centrum, a neural arch with a backwardly directed neural spine, a pair of short and stout transverse processes, a pair of each of the pre- and post-zygapophyses. The thoracic vertebrae are movably connected with ribs through their processes. There are a pair of **metapophyses** above the anterior zygapophyses in the 9th to 12th vertebrae. The lumbar vertebrae also exhibit typical mammalian structure. They are comparatively large with shorter neural spines and longer transverse processes. There is a median ventral process called **hypapophyses** in each of the first two lumbar vertebrae. Metapophyses and anapophyses are well developed. All the lumbar vertebrae bear short lumbar ribs at the tip of the transverse processes.

The sacral vertebrae are fused together to form a composite structure called sacrum. It is found wedged between the two halves of the pelvic girdle. The neural spines are large, hypapophyses and anapophyses are absent and metapophyses are small. The anterior caudal vertebrae exhibit typical mammalian structure. They gradually decrease in size posteriorly and the more posterior vertebrae are represented by centra only.

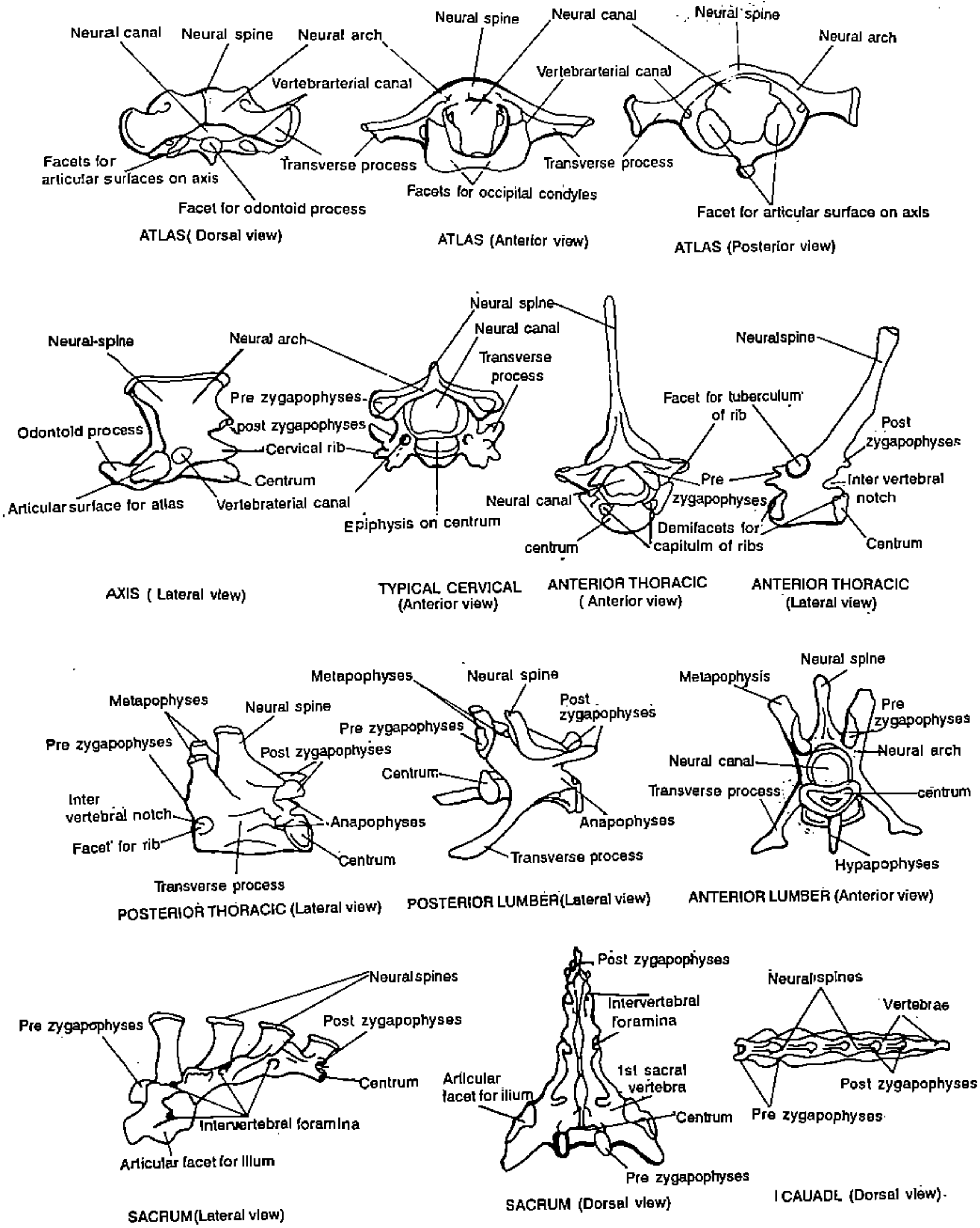


Fig. 11.26 : Mammalian Vertebrae (rabbit).

11.4.5 Ribs and Sternum of Rabbit

There are 12 pairs of ribs associated with the vertebrae of the thoracic region. The first 7 pairs are called **true ribs**. They are connected with the sternum on the ventromedian side through cartilaginous parts (Fig. 11.10). The other 5 pairs are called **false** ribs or **floating ribs**. They are not connected to the sternum. The sternum itself consists of six segments called **sternebrae**. The first segment of the sternum is called **manubrium sternae**, (Fig. 11.11). It is the largest and has a keel. The last segment of the sternum is called **xiphisternum**. It is in the form of a rounded cartilaginous plate.

11.4.6 Pectoral Girdle of Frog and Rabbit

Frog: The pectoral girdle of frog consists of two halves united in the midventral line and separate dorsally. The outer ends of the two halves are bent upwards to form an arch-like structure enclosing and protecting organs of the thorax. The dorsally bent terminal parts of each half consists of a cartilaginous triangular **suprascapula**, (Fig. 11.27). It is partially ossified. Attached to the inner end of the suprascapula found on the ventral side is a stout flat bone called **scapula**. Two bones extend from the scapula towards the midventral side from each scapula, the **clavicle** and the **coracoid**. The two clavicles and the coracoids of either side meet midventrally through a strip of cartilage called **epicoracoid**. The clavicles are slender rod-like bones. The clavicles are found anterior to the coracoids separated from it by wide space called **coracoid fenestra**. There is a depression at the junction of the clavicle, the coracoid and scapula to which the head of the humerus articulates. It is called the **glenoid cavity**.

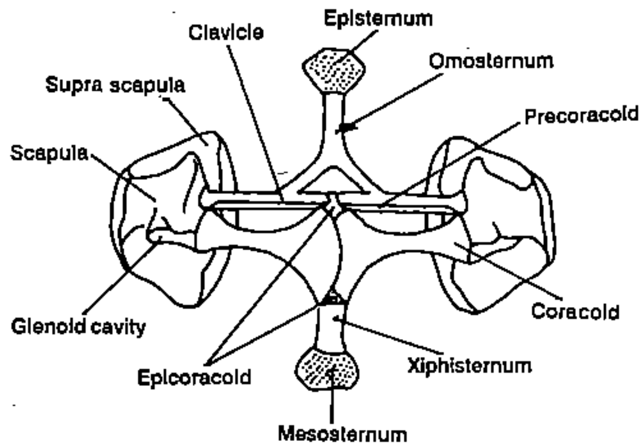


Fig. 11.27 : Pectoral Girdle and the Sternum of Frog.

The pectoral girdle of frog is joined with the sternum on the midventral line where the two halves of the girdle are joined. There are four segments of sternum found infront and behind the epicoracoid. Anteriorly there is a **omosternum** connected to the epicoracoid and a cartilaginous **episternum** infront of it. Behind the epicoracoid is the **mesosternum** and behind it a cartilaginous plate-like **xiphisternum**. There are no ribs in frog.

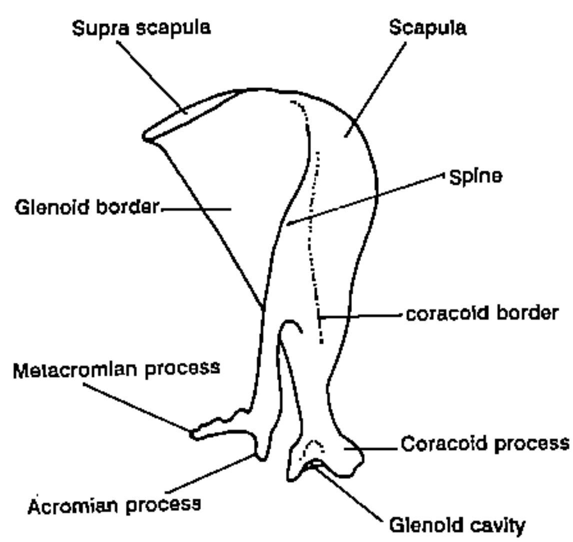


Fig. 11.28 : Pectoral girdle of rabbit (Right).

Rabbit: The pectoral girdle of rabbit consists of fewer bones when compared to that of the frog. There is a thin, flat triangular **scapula** and a slender rod-like clavicle. The glenoid cavity is present at the narrow end of the scapula where it articulates with the clavicle. The prominent coracoid of the pectoral girdle of frog is present as a small incurved process called **coracoid process**. It is fused to the scapula at the narrow end immediately infront of the glenoid cavity. There is thin strip like **suprascapula** at the dorsal edge of scapula, (Fig. 11.28). There is a ridge on the outer surface of scapula called the spine. The scapula ends in a process called **acromian process** at its free ventral end. It gives off a branch like process posteriorly called **metacromian**. It projects backwards. The **clavicle** lies obliquely between the presternum and the scapula.

11.4.7 Pelvic Girdle of Frog and Rabbit

Frog: The pelvic girdle of frog is simpler and contains fewer bones compared with the pectoral girdle. It consists of two halves fused at one end to form a 'V' shaped structure. Each half is made up of three bones, *ilium*, *ischium* and *pubis*, Fig. 11.29). The free ends of the pelvic girdle are in the form of curved bars free at the front end where they are articulated with the transverse processes of the ninth vertebra. These free ends represent the ilium. The ilium with the other two bones of the pelvic girdle unite to form the disc-like structure at the hind end. The disc bears at its two flat surfaces on either side cup-like structures called the acetabulum. The proximal heads of the femur, the thigh bone articulates with the acetabulum. All the three bones of the pelvic girdle are involved in the formation of the disc and the **acetabulum**. The three bones of the pelvic girdle are distinct and separate during early developmental stages and become united in the adult. The fusion is assisted by cartilage or bone and this is known as **symphysis**. In the pelvic girdle of frog there is both **pubic** and **ischiatic symphysis**.

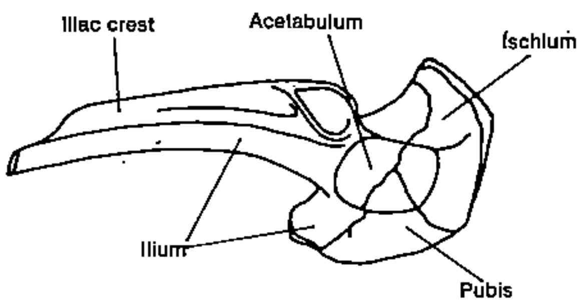


Fig. 11.29 : Pelvic Girdle of Frog (Lateral view).

Rabbit: The pelvic girdle of rabbit also consists of two halves united together by symphysis. Each half is composed of the same three bones found in the pelvic girdle of frog, the **ischium**, the **pubis** and the **ilium**, (Fig. 11.30). Ischium and the pubis are united ventrally in the midline by symphysis. The acetabular cavity is found on the out side at the union of **ischium** and **ilium**. The three bones are separate in young animal and become completely fused into a single bone in the adult. This united structure is called **innominatum**. **Ilium** is dorsal in position and is found in front of the **acetabulum**. It has a rough inner surface which is expanded and wing-like to which the transverse processes of the 1st sacral vertebra are articulated. Ischium lies posteriorly and dorsally. They continue downwards and meet to form ischial tuberosity at the **ischiatic symphysis**. Pubis is the smallest of the three bones. It lies anteriorly and is directed downwards. It is separated from the ischium by a wide foramen called **obturator foramen**. The two pubis unite midventrally in a **pubic symphysis**. The acetabulum is bound by a small bone called **cotyloid bone**.

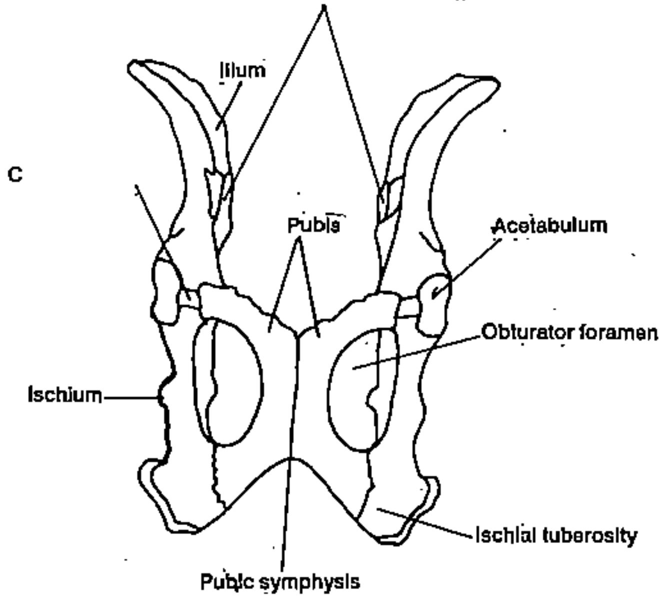


Fig. 11.30 : Pelvic girdle (Ventral view) of rabbit.

11.4.8 Skeleton of Limbs

The pattern of skeletal support to the different segments of the limbs of both frog and the rabbit are the same as in all vertebrates with little variations.

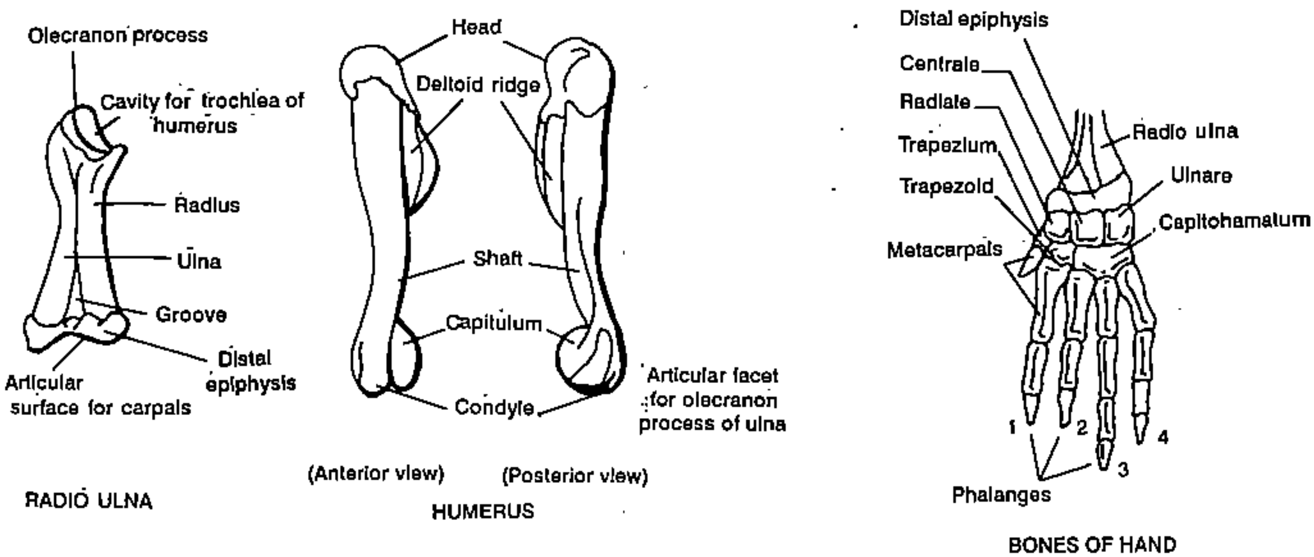


Fig. 11.31 : Forelimb bones of Frog.

Skeleton of the Forelimb of Frog

There is a single bone in the upper arm, the **humerus**, (Fig. 11.31). It is a stout long curved shaft-like bone with two swollen ends. The head at the proximal end is round and fits into the glenoid cavity of the pectoral girdle to form the shoulder joint. At the other end there is a round prominance in the centre with two projections on either side. There is a ridge called **deltoid ridge** extending from the proximal end to the middle of the shaft on the inner side of the humerus. Presence of deltoid ridge is characteristic of humerus in all tetrapods. There are two bones in the lower arm, the **radius** and **ulna**. These two bones are fused in frog to form a **radio-ulna**. There is a concavity at the proximal end of radio ulna to which the distal head of the humerus articulates. At this joint there is a backwardly directed **olecranon process**. This is the elbow joint. The distal end of radio-ulna is expanded into two articular surfaces. There are six carpals in the wrist of frog. They are arranged in two rows of three carpals each. The carpals of the proximal row are named **radiale**, **centrale** and **ulnare**. The radiale is at the tip of radius, ulnare at the tip of ulna, and centrale in between the two. These three carpals articulate with radio-ulna. The carpals of the distal row are fused and articulate with the metacarpals of the hand. The innermost metacarpal is reduced and rudimentary. The other metacarpals are long. There are four fingers in the hand of frog. They are supported by phalanges. The first finger corresponding to the thumb of other tetrapods is absent in frog. There are two phalanges each in fingers 2 & 3 and three phalanges each in fingers 4 & 5.

Skeleton of the Forelimb of Rabbit

The number and the nature of bones in the different segments of the fore limb of rabbit are the same as that of frog. Humerus of the upper arm is a shaft-like bone with two extremities, (Fig. 11.32). There is a rounded head at the upper end and this fits into the glenoid cavity of the pectoral girdle. There are two tuberosities at the outer border of the proximal head. They provide the surface for the attachment of bicep muscles. The two tuberosities are separated by a groove called **bicipital groove**. The two tuberosities are of different size. The inner and the outer are called **lesser** and **greater tuberosities** respectively. The tendons of the muscles are inserted along the groove between the tuberosities. The humerus has the deltoid ridge on the anterior surface of the proximal part of the shaft. There are two articular surfaces at the lower end of the shaft for articulation with the two bones of the lower arm. One of the articular surface is in the form of a large pulley-like **trochlea** for articulation with ulna and the smaller **capitulum** for articulation with radius. The shaft laterally has an internal and an external prominences called **epicondyles**. The two bones of the lower arm, the **radius** and the **ulna** are immovably articulated to each other all along their length. The radius is shorter of the two and lies on the inner side of the lower arm. The radius is articulated proximally with the humerus and distally with two carpals of the wrist, the **scaphoid** and the **lunar bones**. Ulna is larger and lies on the out side of the lower arm. It extends beyond the elbow joint as **olecranon process**. At the base of this process there is a groove called the **sigmoid notch** for articulation with trochlea. There are nine carpal bones in the wrist of rat compared to six in frog. Eight of them are arranged in two rows, the proximal and the distal rows. The ninth carpal called **centrale** is found in between the two rows. The carpals of the proximal row are named from inside to outside as **scaphoid**, **lunar**, **cuneiform** and **pisiform**. The carpals of the distal row are named **trapezium**, **trapezoid**, **magnum** and **unciform**. The metacarpals of the hand are narrow and elongated. The first inner metacarpal is shorter than the others. There are five fingers as opposed to four in frog. Each finger in rabbit is provided with three phalanges each except the first finger which has only two phalanges. The distal phalanges of all the fingers are provided with grooves for the insertion of claws.

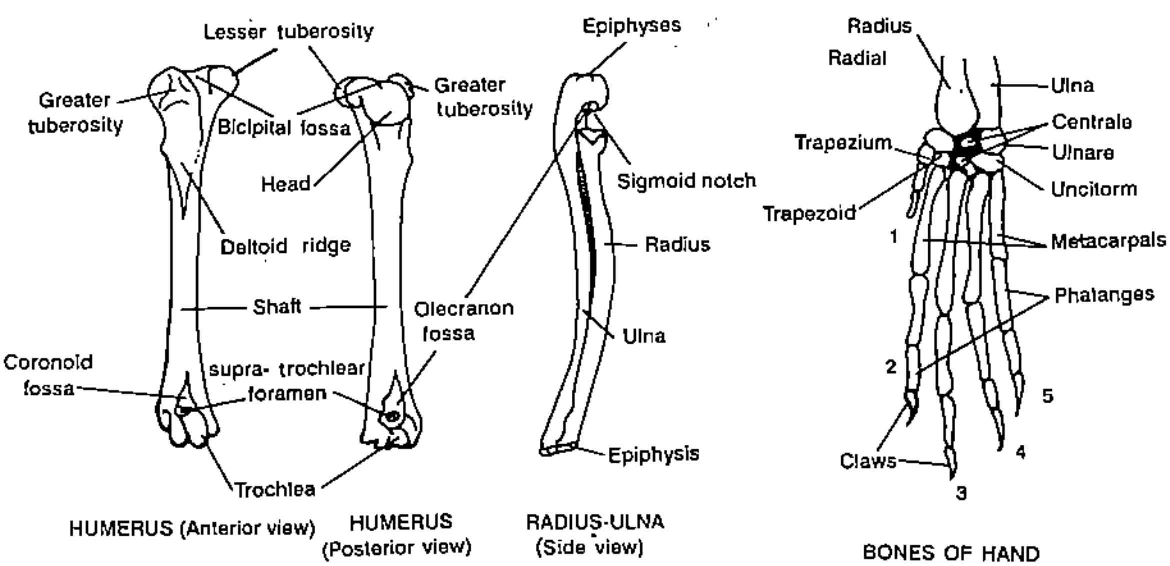


Fig. 11.32 : Forelimb bones of mammal (rabbit).

Skeleton of the Hindlimb of Frog

In the skeleton of the hind limb there is a single bone the **femur** in the thigh region, (Fig. 11.33). It is long and slightly curved shaft-like with both ends swollen. The round proximal end fits into the acetabulum of the pelvic girdle forming the hip joint. The distal end of femur is flat, laterally expanded and articulates with the two bones of shank. As in the lower arm there is a single **tibio-fibula** formed by the fusion of the tibia and the fibula. Both ends of tibio-fibula are expanded. It articulates with the femur proximally and with tarsals distally. The ankle joint is formed by the articulation of tarsals with tibio-fibula. There is an elongated extra joint adding to the lengthening of the hind limb of frog. This is helpful in the hopping type of locomotion. There are four tarsals arranged in two rows of two each. The tarsals of the proximal row are longer. The inner is **astragalus** and the outer stouter **calcaneum**. These two tarsals are united at the ends and separated in the middle. The distal row of tarsals are small and fused with the metatarsals. There are five long metatarsals in the foot. The foot bears five toes. There are two phalanges in the 1st and 2nd toes, three phalanges in the 3rd and 5th toes and four phalanges in the 4th toe. There is a supplementary 6th toe in the form of a calcar formed of two short bones.

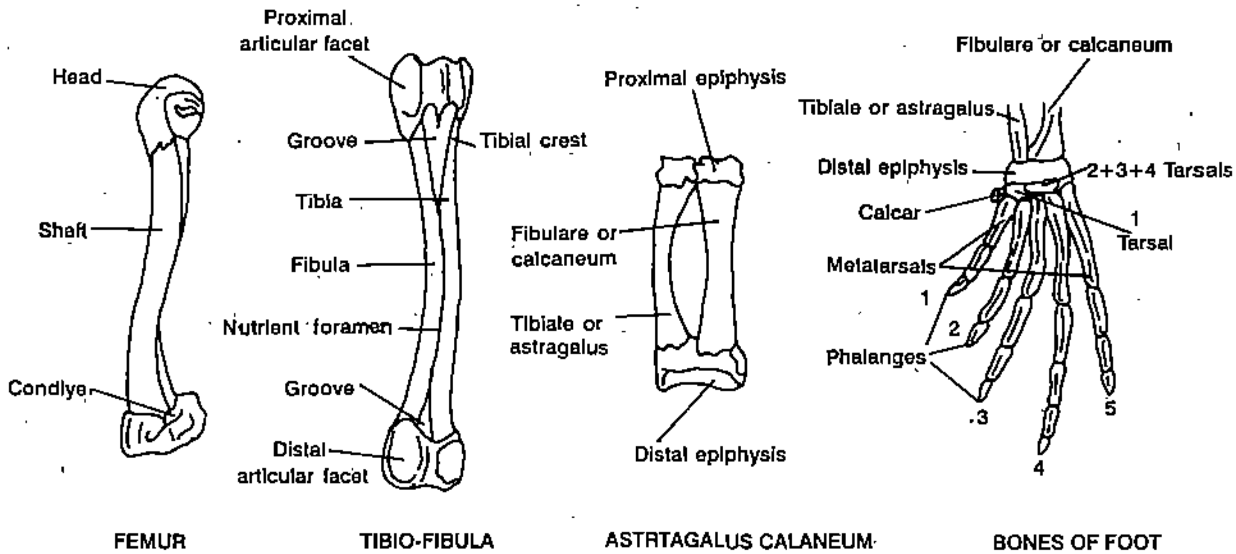


Fig. 11.33 : Hindlimb bones of Frog.

Skeleton of the Hindlimb of Rabbit

The femur in the hind limb of rabbit is a long stout bone with a prominent head at the proximal end for articulation to the acetabulum. There are three protuberances just below

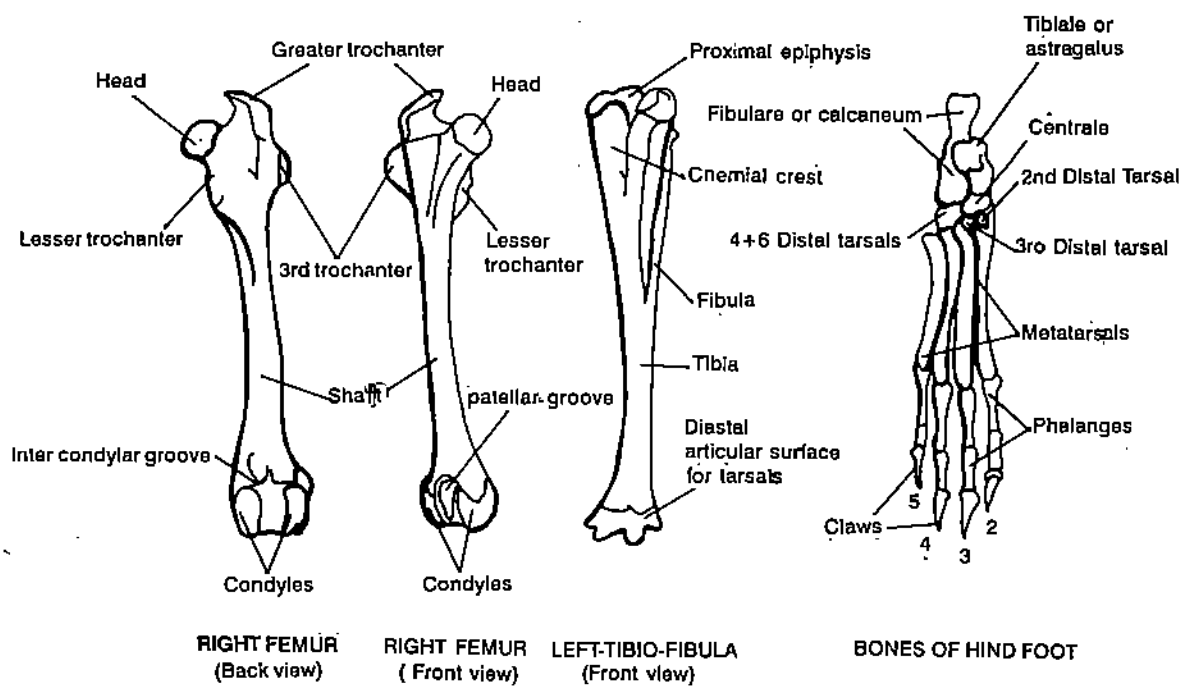


Fig. 11.34 : Hindlimb bones of rabbit.

the head called **greater, lesser** and **third trochanter** directed externally, internally and below the greater trochanter respectively (Fig. 11.34). The lower end of femur has two condyles separated by a groove in the middle. This articulates with **tibia** and **fibula** below. The tibia and fibula of rabbit are separate as opposed to fused ones in frog. Tibia and fibula are free above and fused below. The knee joint has a larger bone the **patella** also called the **knee cap**, characteristic of mammals. There are two articular surfaces at the upper end of tibia for articulation with the condyles of the femur. The tibia has two articular surfaces at the lower end for articulation with tarsals. The internal articular surface articulates with **astragalus** and the outer with **calcaneum**. Fibula is a slender bone completely fused with tibia distally. There are six irregularly shaped tarsals in the ankle region as opposed to four in frog. They are arranged in two rows with one tarsal in between the rows, called **navicular, astragalus** and **calcaneum** form the proximal row. The three tarsals of the distal row are **mesocuneiform, ectocuneiform**, and **cuboid**. There are four toes consisting of metatarsals and three phalanges each.

SAQ 2

Identify the following statements as true or false. Write **T** for the correct statement and **F** for the wrong statement.

a) There is a space posterolateral to the cranium in which the eye balls are lodged.
b) There is a large ridge like process infront of the convexity on the angulosplenial called coronary process.
c) The foramen magnum in rabbit is directed downwards and not backwards as in the frog.
d) There are a pair of bones, the parietals forming the roof of the brain segment.
e) Premaxillae are large bones and they form the anterior part of the snout.
f) The teeth of most vertebrates including rabbit are all of the same type, a condition called homodont dentition.
g) The first cervical vertebra of the rabbit, the atlas has a distinct centrum.
h) In rabbit the knee joint has a larger bone the patella also called knee cap, characteristic of mammals.

11.5 FUNCTIONAL ADAPTATIONS OF SKELETON

The development of terrestrial habits brought about a revolution in vertebrate locomotion. With the new requirements and stresses placed on the vertebral column by terrestrial locomotion, the vertebrae become regionally specialised. The ancestral vertebrates like fishes were originally aquatic animals. They have developed a powerful tail which is the primary locomotor organ in the aquatic vertebrates. It is the lashing movement of the tail that drives the fishes forward in water. The fishes are also provided with fins, both median unpaired and lateral paired fins, which help them in steering during locomotion in water. These fins are provided with skeletal support to help them function effectively. It is the paired fins that are believed to have given rise to paired limbs of tetrapods. There is paleontological evidence to trace the origin and evolution of paired limbs from paired fins. The tetrapod limbs have undergone modifications to assist the type of locomotion adapted by the respective vertebrate animals. There is a wide veriety of locomotion seen among different tetrapods; digging as in moles, swimming as in whales and seals (a secondary adaptation), walking as in man (bipedal), running as in horse, climbing as in squirrels, leaping as in kangaroo (also in frogs), gliding as in *Draco* (flying lizard) and flying as in birds and bats. The hind limbs of frog are longer than the fore limbs. This has been effected by elongating two tarsal bones which have provided an additional segment. This is adaptation for jumping or leaping type of locomotion. In addition the toes are webbed to help in swimming. Similarly, the fore limbs of whales are modified into broad paddle-like structures which are helpful in swimming. The paddle shape is achieved by increasing the number of digits in the limbs (a condition called **hyperdactyly**) and increasing the number of phalanges in each digit (a condition called **hyperphalangy**). These digits are enclosed in a common integument to form a broad paddle-like structure. The limbs of elephants have become large and pillar-like with hoof like nails to be able to carry the weight of the body during its semiplantigrade type of locomotion.

The point of foot contact or foot posture bears on the length of the limb. Some animals can effectively increase the limb length and therefore they stride length by rising up on the toes. For example, some mammals such as bear who normally walk on the flattened sole or palm, are called **plantigrade** whereas faster walkers or runners among amniotes, who raise the sole or palm off the ground to run on the ventral side of the toes are called digitigrade. Other mammals take this a step further by walking and running on the tips of the **permanently elevated** toes. Toe walking requires strenghened toes and modification of keratinized claw into a hoof. Thus, the development of the **ungulate** foot is accompanied by a reduction and elimination of digits. In most ungulates, the thumb was early lost and a four toed manus was characteristic of forms as dissimilar as ancestral horses and cows. Further reduction, however, followed two different paths as shown in Figure 11.35. Several extinct orders of mammals paralleled these changes to varying degrees.

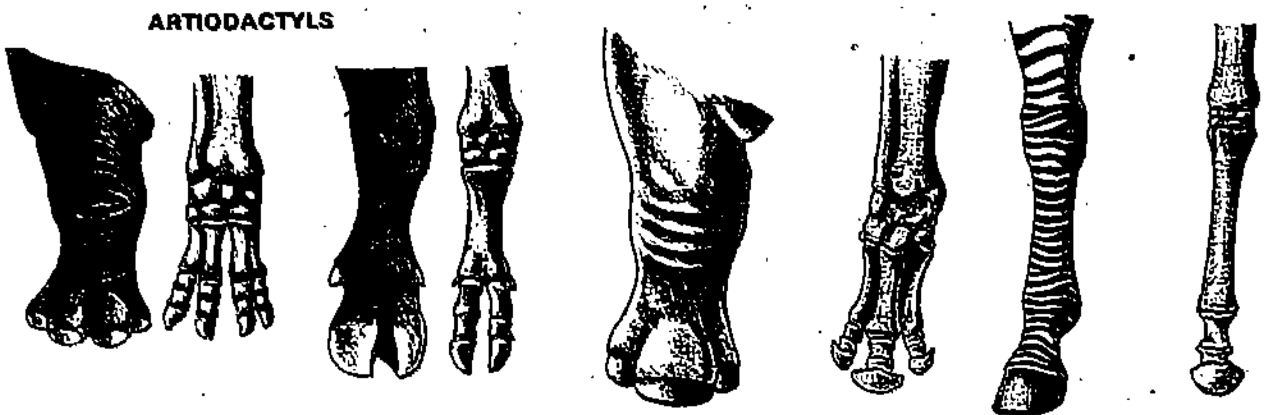


Fig. 11.35: Lengthening of the limbs and the reduction in the number of toes has enabled certain species to become fast runners. Hippopotamus and African buffaloes are artiodactyls-even-toed ungulates-with remarkable jumping ability. In most artiodactyls the two main metapodials are fused into a canon bone. In perissodactyls the axis runs through the third toe. The four toes remain in modern rhinoceros, the fifth toe has disappeared in zebras, the second and fourth are reduced to splints. The zebra is a perissodactyl or odd toed ungulate, who relies on speed to escape pursuers.

Speed and stability in locomotion of horse are illustrated in Fig. 11.36. Advanced tetrapod runners, such as the horse, have many anatomical modifications that permit quick recovery from momentary instabilities. Tripodal stability is often violated. As the illustration shows, two, three, and even all four feet may be off the ground simultaneously, yet such instabilities are quickly overcome by high speed and well-coordinated movements. Runners tend to opt for manoeuvrability rather than long-term stability.

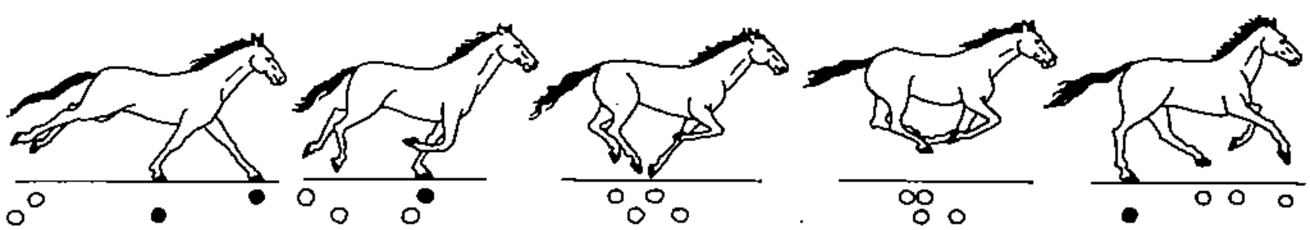


Fig. 11.36: Speed and Stability in locomotion of horse.

In the limbs of horse the number of digits is reduced to one, usually the 3rd digit is retained, (Fig. 11.37). The limbs are elongated by fusion of persisting metacarpals to form cannon bones. This has resulted in unguligrade type of locomotion. Since the part of the limb contacting the ground is reduced there is less friction and this has helped in attaining greater speed. Thus horse is able to gallop at greater speed.

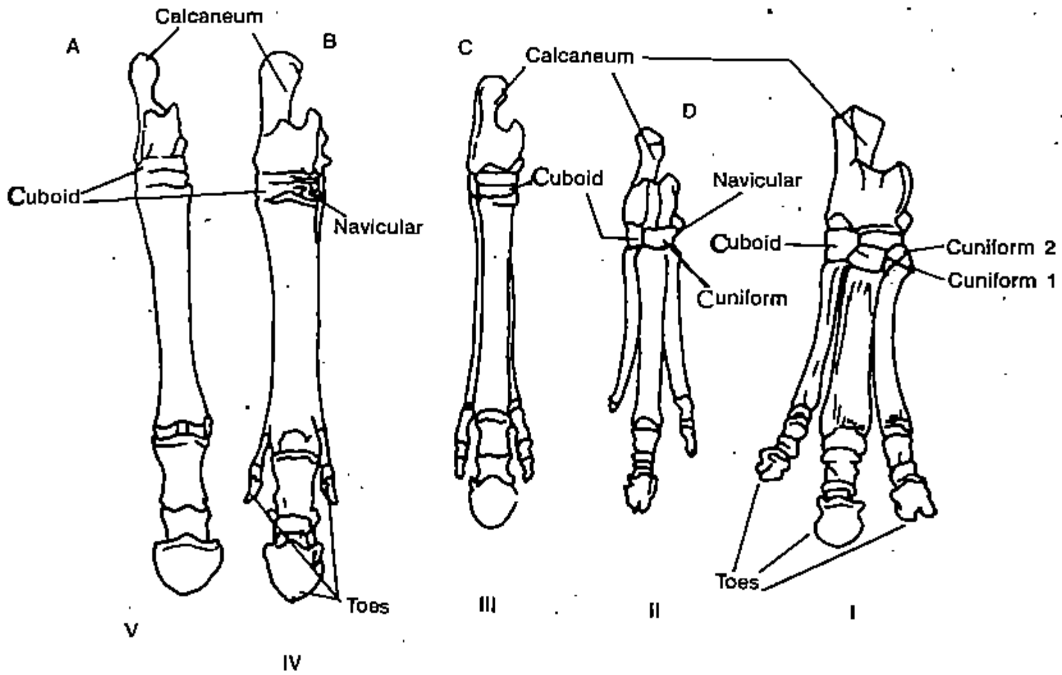


Fig. 11.37 : Progressive specialisation of limbs in equidae: I. *Palaeotherium*, II. *Paloplotherium*, III. *Anchitherium*, IV. *Hipparion*, V. *Equus*.

In the case of bats the fingers (Phalanges) have been elongated with a fold of skin stretching between them and between the two limbs forming the wing. The fore limbs are also provided with hooks at the tip of the fingers with which they hang themselves when roosting (Fig. 11.38).

Fig. 11.38: Bat showing the arrangement of phalanges between the two limbs forming the wing.

In birds there is a reduction of number of digits in the fore limb.The fore limbs have been modified into wings which form the principal locomotor organs for flying. The humerus is large and strong with a greatly expanded head and a prominent ridge for insertion of pectoral muscle. The radiale and ulnare among the carpals are large and free. There is a composite structure the carpo-metacarpus formed by the fusion of distal carpals and three metacarapals, (Fig. 11.39). The carpometacarpus consists of two rods which are fused at the extremities. The reduced first finger has only one phalanx and the 2nd digit has two phalanges. The feathers are arranged along these bones. In order to carry the full weight of the body while walking or running pelvic girdle has become fused with vertebrae of lumbar, sacral and caudal to form **synsacrum**, (Fig. 11.40). This is characteristic of birds. Even in the hind limbs tibia and tarsus of the shank segments are fused to form tibiotarsus, (Fig. 11.41). This is articulated to an elongated bone the tarso-metatarsus formed by the union of metatarsals and tarsals. This has helped in adding to the lengthening and strengthening of the limbs for running and walking.

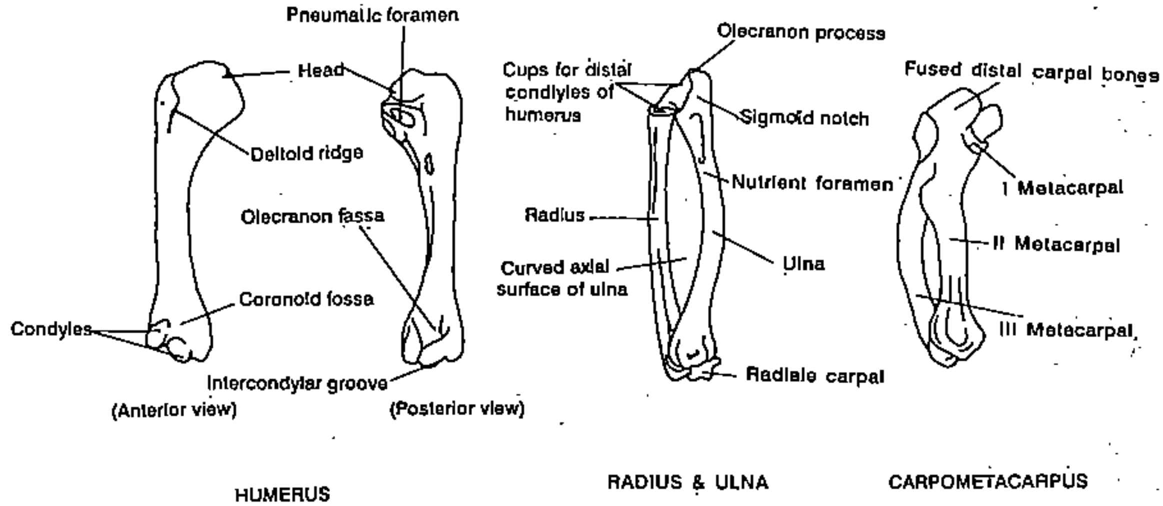


Fig. 11.39 : Forelimb bones of Fowl.

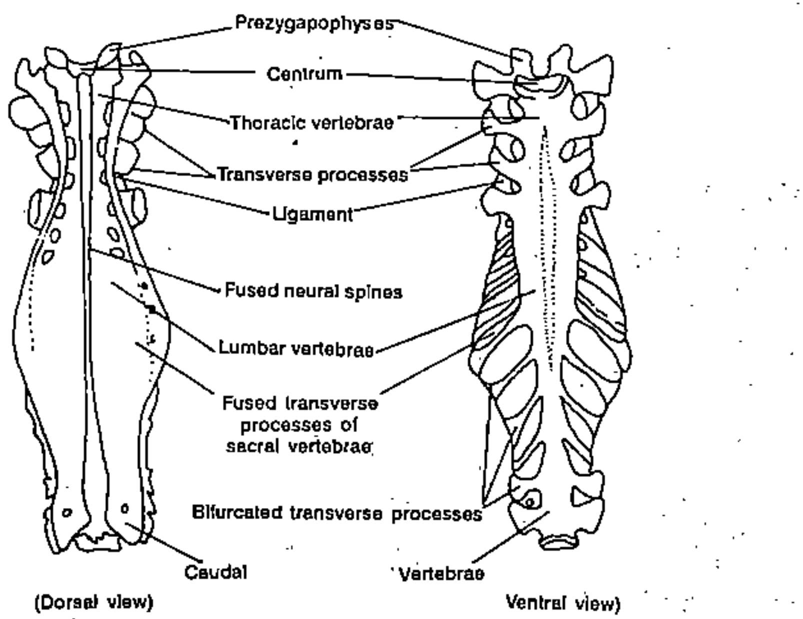


Fig. 11.40: Synsacrum.

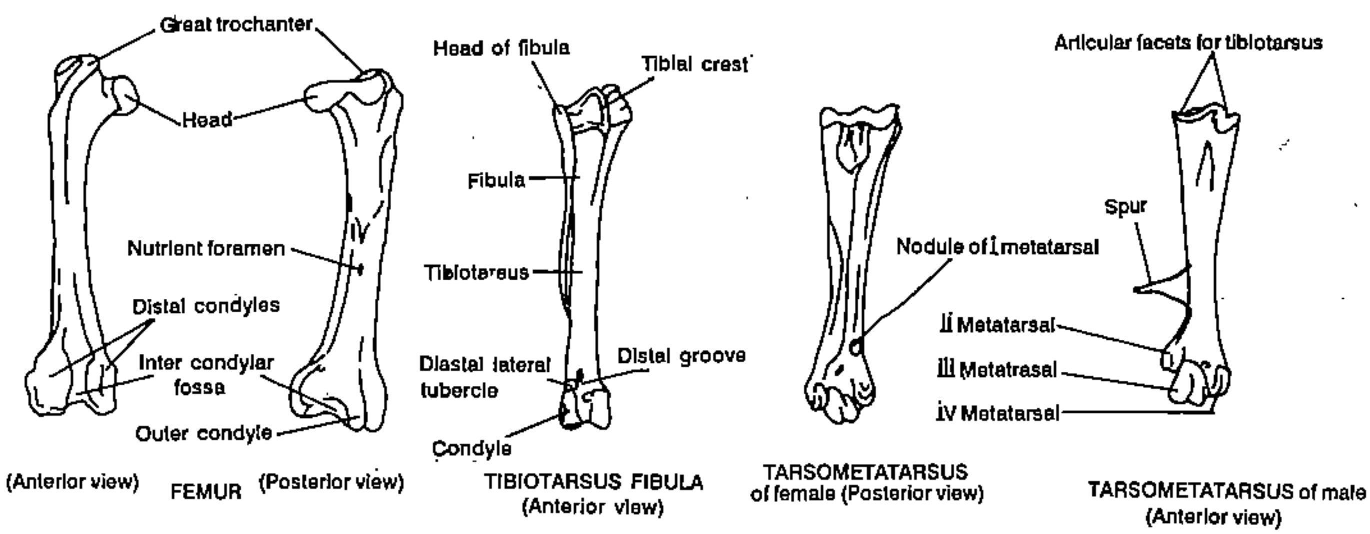


Fig. 11.41: Hindlimb bones of Fowl.

Thus the skeletal support of the fore limbs of various vertebrates indicates differences in their apparent structure even though they exhibit a common plan of organisation. Comparison of the skeleton of the forelimbs of different vertebrates adapted to different modes of locomotion provides evidence of their common ancestry and adaptive divergent evolution.

In addition the sternum of vertebrates adapted for true flight has developed a ventral keel-like structure providing surface for attachment of flight muscles, (Fig. 11.11). This is the case in both bats and birds adapted for flight. This is further evidenced in the case of flightless birds which have lost the capacity for flight, reduction of wings and a consequent reduction of keel of the sternum. Further the skeleton of birds are pneumatic, i.e., they are spongy with a number of air cavities filled with air making them light. This helps in lifting the body of the bird during flight.

Flight adaptation of birds demands high level of development of the eye and brain for coordination and direction of action. So the birds have developed large orbits and large brain case. The bones are relatively thin and spongy. There is a fusion of bones and this has lead to strengthening of the brain case.

Several bones of the reptilian lower jaw and visceral skeleton are no longer part of the lower jaw of mammals. Of the six bones found in the lower jaw of reptiles only the dentary is retained to function in the lower jaw of mammals. The rest of the bones which became superfluous became involved in the mammalian middle ear structures. There are three ear ossicles in the middle ear of mammals assisting in conducting sound vibrations from the ear drum (tympanum) to the inner ear. **Stape,** one of the three ear ossicles is derived from the hyoid arch. **Incus** represents the reptilian quadrate. **Malleus** is formed by the fusion of two bones of the lower jaw of reptiles, the prearticular and articular. The **tympanic** bone is derived from the angular of the reptilian lower jaw.

Skull is the part of the skeleton that has been most completely preserved in fossils. So more information is available on the structure and evolution of skull in the vertebrates. In fact, this information has been utilised to describe the phylogeny of vertebrates, particularly of the lower tetrapods. It has helped in the classification of fossil reptiles, and derivation of the living reptiles and birds and mammals from them.

Temporal Fossae and their significance

The roof of the skull is complete in lower vertebrates. The only opening being the nares and the orbits. In higher vertebrates certain vacuities or fossae appear in the posterolateral region of the cranium identified as the **temporal region.** The vacuities of this region are known as **temporal fossae** (fossa- singular). These fossae are bound by certain bones whose arrangement is in the form of bars called **arcades.** The appearance of fossae and arcades is believed to be associated with firm attachment of jaw muscles which allow easy and stronger movement of jaws. The early reptiles in which these are well formed are believed to have depended on their jaws for obtaining food and defence against enemies.

Three different types of fossae have been identified on the basis of their position and the types of arcades binding them. The different groups of fossils are named on the basis of the presence or absence of fossae, if present the number and their position and the nature of arcades. The ancestral and most primitive group of reptiles have a skull with a complete bony roof without any fossae. Cotylosauria the stem reptiles represent this group which is called **Anapsida** (Fig. 11.42). This group seems to have given rise to other types. Chelonia among the living reptiles represent the sole group Anapsida and have remained unchanged for millions of years.

The group **Synapsida** has only one fossa on each side (Fig. 11.42). The name is a misnomer because it does not represent any union or fusion. The bones postorbital and squamosal meet above the fossa and squamosal meets the jugal on the lower side with the quadratojugal abutting between them. This condition is found in extinct mammal-like reptiles. This fossa is named **infratemporal fossa.** Extinct reptiles like dinosaurs have two fossae on each side. They are called **Diapsida.** The two fossae are present on the upper and lower region and thus they are called **supratemporal** fossa and infratemporal fossa. But the infratemporal fossa of diapsida is different from the infratemporal fossa of synapsidans. The bones surrounding them and their arrangements are different. The two fossae of the diapsidan skull are separated by an arcade formed by postorbital and squamosal, called **supratemporal arcade.** This type of skull is found in **Rhynchocephalia** and **Crocodilia** among the living reptiles. Lizards, snakes and modern birds are believed to have evolved from diapsid ancestors.

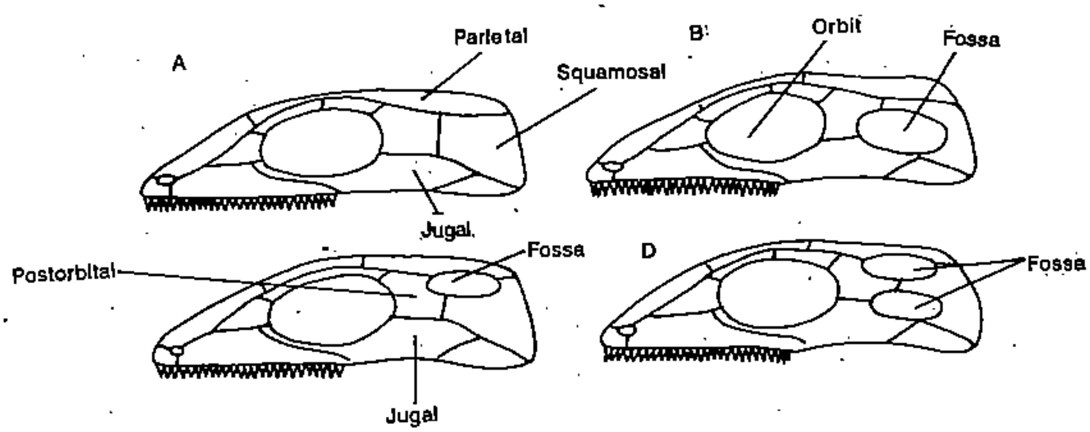


Fig. 11.42: Diagrams to show types of temporal openings in reptiles. A) Anapsid type (stem reptiles, turtles); B) synapsid type (mammal-like reptiles); C) euryapsid type (extinct plesiosaurs, and so forth); D) diapsid type (rhynchocephalians, ruling reptiles; lizards and snakes derived by loss of one or both temporal arches).

Another group also has a single fossa on each side. But it is different from that of the synapsidal infratemporal fossa. It is characterised by postorbital and squamosal meeting below the fossa not above as in synapsida. This type is called **parapsid,** the group as **parapsida.** This type of skull is found in extinct Mesosaurs and Ichthyosaurs.

SAQ 3

Fill in the blank by choosing the appropriate word from the parentheses.

a) There is .... evidence to the origin and evolution of paired limbs from paired fins. (archaeological, palaeontological, embryological)
b) In the limbs of horse the number of .... is reduced to one. (tarsals, metatarsals, digits)
c) In order to carry the full weight of the body while walking or running the pelvic girdle has become fused with vertebrae of lumbar, sacral and caudal to form .... (sacrum, cranium, synsacrum)
d) Comparison of the skeleton of the forelimbs of different vertebrates adapted to different modes of locomotion provides evidence of their common .... and adaptive divergent evolutions. (hierarchy, ancestry, heredity)
e) Stapes, one of the three ear assicles is derived from the .... arch. (visceral, aortic, hyoid)
f) In birds there is fusion of bones and this has lead to strengthening of the .... case. (body, brain, thorax)

11.6 SUMMARY

- The study of skeleton of vertebrates, both living and extinct is important from the point of view of comparative anatomy. It is fortunate that the skeletal structures have been preserved as fossils and this is because they are hard and because of their peculiar chemical composition. Much of the fossil evidence available is therefore of skeleton and mostly of head skeleton. This has helped in tracing not only vertebrate evolution but also trends in evolution. Because of the skeletal evidence it has been possible to trace the evolution of groups like birds and mammals and particularly of man. A knowledge of skeleton is a must for an understanding of the phylogeny of vertebrate groups and their interrelationships. Skeletal system is the only system that provides an overview of structural changes that have occurred in vertebrates. The head skeleton is the most informative part because it completely reflects the divergent changes that have occurred during evolution of vertebrates. There is a common ancestral pattern of bone and their arrangement from which the living vertebrates have evolved.

- Chondrocranium is the cartilaginous fore-runner of the skull bone. It shows variations in the form during different stages of development since it changes its functions at different ages of the animal. Similarly the stiff rigid rod like notochord which appeared in the early chordates to provide stability and rigidity to the body got replaced by a segmented vertebral column to provide mobility. The folds of skin which helped provide steering capacity to vertebrate locomotion became replaced by paired appendages. These have become variously modified to suit the different modes of life adapted by the vertebrates.

11.7 TERMINAL QUESTIONS

1. Name the two types of skeleton found in animals.

....

....

....

2. Mention the two types of endoskeletal structures found in vertebrates.

....

....

....

3. Fill in the blanks in the following sentences by selecting an appropriate word from those given in the brackets after each sentence:

   a) The skeleton of the head is known as .... (vertebral column, pelvic girdle, skull)
   b) Cranium encloses and protects the .... (eye, heart, brain)
   c) The brain within the cranium is in contact with the spinal cord through .... an aperture found at the hind end of the cranium (fenestra ovalis, foramen magnum, external nares).
   d) The vertebra with concavity infront and convexity behind is called .... type (amphicoelous, procoelous, opisthocoelous).
   e) The bone humerus of the upper arm articulates with the pectoral girdle at .... cavity (glenoid, acetabulum, zygapophysis).
   f) Radio-ulna a composite bone is found in .... (rat, bat, frog).

4. Names of some bones are given in column A and the part of the skeleton in which these bones occur in column B. Match them.

Column A	**Column B**
a. Parietal	A. Pectoral girdle
b. Vomer	B. Cranium
c. Maxilla	C. Olfactory capsule
d. Dentary	D. Upper jaw
e. Clavicle	E. Pelvic girdle
f. Pubis	F. Lower jaw

5. State whether the following sentences are true (T) or false (F).

   a. Cranium is a part of the vertebral column.
   b. Jaws are derived from the visceral skeleton.
   c. Axis is the name of the first vertebra.
   d. The bone in thigh segment of the hind limb is femur.
   e. Glenoid cavity is found in the pelvic girdle.
   f. Deltoid ridge is found on the humerus.

6. How many bones are found in the lower jaw of rat?

....

....

....

....

7. Mention the names of bones bearing teeth in the skull of frog.

....

....

....

....

8. The different segments of the fore limb and hind limb of vertebrates are given in list A. The names of bone occurring in the limbs are given in the subsequent list B. Select the appropriate bone and write it against the segments of the limbs.

List A

Fore Limb: a. upper arm .... b. lower arm ....
c. Wrist .... d. palm/hand ....
Hind limb: e. Thigh .... f. Shank ....
g. Ankle .... h. Foot ....

List B

Tarsal, Carpal, Humerus, Femur, Radius, Tibia, Fibula, Ulna, Metatarsals, Metacarpals.

9. The different parts of the skull of rat are given in column A and names of some bones that occur in these parts are given in column B. Match them.

Column A	Column B
a. Cranium	A. Dentary
b. Olfactory capsule	B. Frontal
c. Upper jaw	C. Nasal
d. Lower jaw	D. Periotic
e. Auditory capsule	E Premaxilla

11.8 ANSWERS

Self-assessment Questions

1. A. (a) iii (b) iv (c) i (d) ii
   B. (i) front, behind (ii) Amphicoelous (iii) Heterocoelous, saddle (iv) flat. depressions.
2. (a) F (b) F (c) T (d) T (e) T (f) F (g) F (h) T
3. (a) palaeontological (b) digits (c) synsacrum (d) ancestry (e) hyoid (f) brain

Terminal Questions

1. Exoskeleton and Endoskeleton
2. Cartilaginous and bony
3. a. skull; b. brain; c. foramen magnum; d. procoelous; e. glenoid; f. frog
4. a & B; b & C; c & D; d & F; e & A; f & E
5. a. false b. true c. false d. true e. false f. true
6. One
7. Premaxilla, Maxilla and Vomer
8. Column A Column B a. humerus b. Radius and Ulna c. Carpals d. Metacarpals e. Femur f. Tibia and Fibula g. Tarsals h. Metatarsals.
9. a & B; b & C; c & E; d & A; e & D.

UNIT 12 ENDOCRINE SYSTEM

Structure

12.1 INTRODUCTION

In the previous unit you have learnt about the nervous system of vertebrates. The nervous and endocrine systems function to integrate the activities of the organisms. This is done by their ability to synthesise and release chemical substances in the body. Certain nerve cells, also known as neurosecretory cells produce substances, the neurohumours that act locally. The secretions of the endocrine glands, the hormones, have a wide range of action. In could be said that while regulation by nervous system is localised and rapid, regulation by endocrine system is more general and relatively slow. The regulatory functions of the hormones include homeostasis or the maintenance of the constancy of the internal environment, general metabolism, morphogenesis, mental abilities, initiation and maintenance of reproductive processes and behaviour associated with sex, that includes courtship, nest building, parental care and migration.

In this unit, we shall first study the endocrine glands of the mammals, the hormones they secrete and the functions they perform. This would be followed by a study of the endocrine glands in different classes of vertebrates.

Objectives

After reading this unit you should be able to:

- describe the location, structure and functions of the endocrine glands of humans,
- list the secretions of the different endocrine glands in mammals,
- describe the endocrine structures of sub-mammalian species,
- discuss the variation in structure and function of endocrine glands of mammals and other vertebrates.

12.2 ENDOCRINE GLANDS IN MAMMALS

A detailed description of endocrine glands of animals groups is provided in unit 10 of Block 2, Physiology course (LSE-05) which you might have completed by now. In the same unit the role of the hormones in energy metabolism is also discussed. In unit 15 of Cell Biology course.(LSE-01) you studied about the cellular mechanisms of hormone action. It is advisable that you may go through these units before you begin a study of this unit. In the present unit we shall describe the structure and functions of major endocrine organs of vertebrates. We shall begin with the description of the endocrine structures as found in mammals.

12.2.1 Pituitary

The pituitary gland is a small unpaired structure found attached to the ventral side of the brain. More specifically, the organ, also known as **hypophysis cerebri** is found attached to the hypothalamus on the floor of diencephalon by a narrow stalk and is located in a depression, sella turcica in the sphenoidal region of the skull (Fig.12.1).

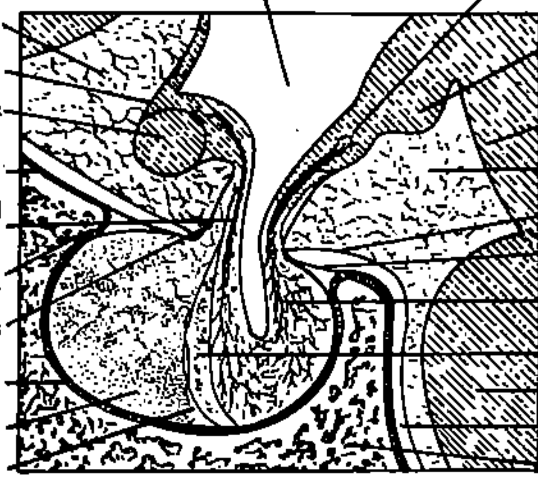


Fig. 12.1: Diagrammatic representation of a section through the hypophysis cerebri of human being showing its relationship to adjacent structures.

The pituitary consists of two major parts, a larger anterior part, the **adenohypophysis** (pars buccalis) and a smaller posterior part, the **neurohypophysis** (pars nervosa). Both the structures are ectodermal derivatives. The hypophysis originates from two sources, one as an outgrowth from the floor of the diencephalon - the infundibulum and the other as an evagination of the roof of the stomodaeum - the Rathke's pouch. The distal part of Rathke's pouch becomes separated form it and comes into close contact with the infundibular outgrowth to develop into adenohypophysis (Fig.12.2). The infundibular outgrowth is connected with the brain by the infundibular stalk and forms the neurohypophysis.

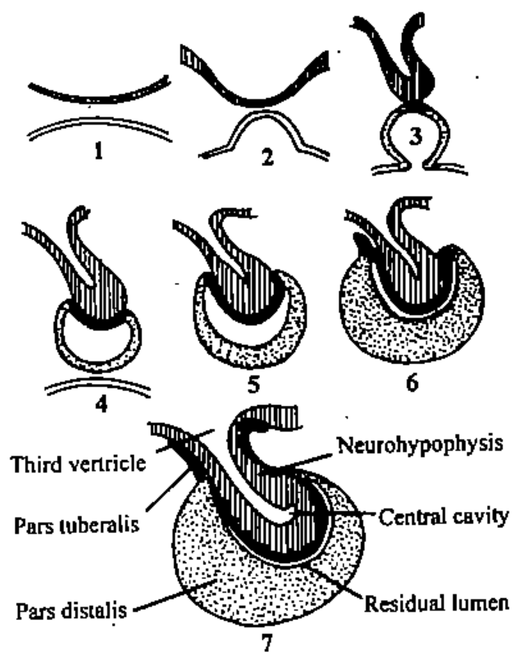


Fig. 12.2: Stages in embryonic development of pituitary.

The adenohypophysis itself shows further divisions. The part of the adenohypophysis that is in immediate contact with neurohypophysis is **pars intermedia** and the rest of it is greatly thickened to form **pars distalis**. The highly vascular adenohypophysis is formed of cells arranged in a chord-like trabaculae separated by thin walled sinusoids. There are two types of cells, the secretory, granular chromophil cells and the non-secretory, non-granular chromophobe cells. The neurohypophysis is differentiated into **pars nervosa**, the **infundibular stem** and the **median eminence** (Fig. 12.3). Pars nervosa, though derived from the brain does not contain any nerve cells, but consists of neuroglial cells and pigmented cells called pituicytes (Fig. 12.3). The infundibular stem connects the pars nervosa with the brain. The median eminence containing a rich supply of blood capillaries is the swollen base of the infundibulum. The pars intermedia and the pars distalis together form anterior pituitary, and the pars nervosa, infundibular stem and median eminence collectively form the posterior pituitary. The anterior lobe has two sources of blood supply. One source is the internal carotid artery and the other source is the hypophysial portal vein. The posterior lobe is supplied with inferior hypophysial artery.

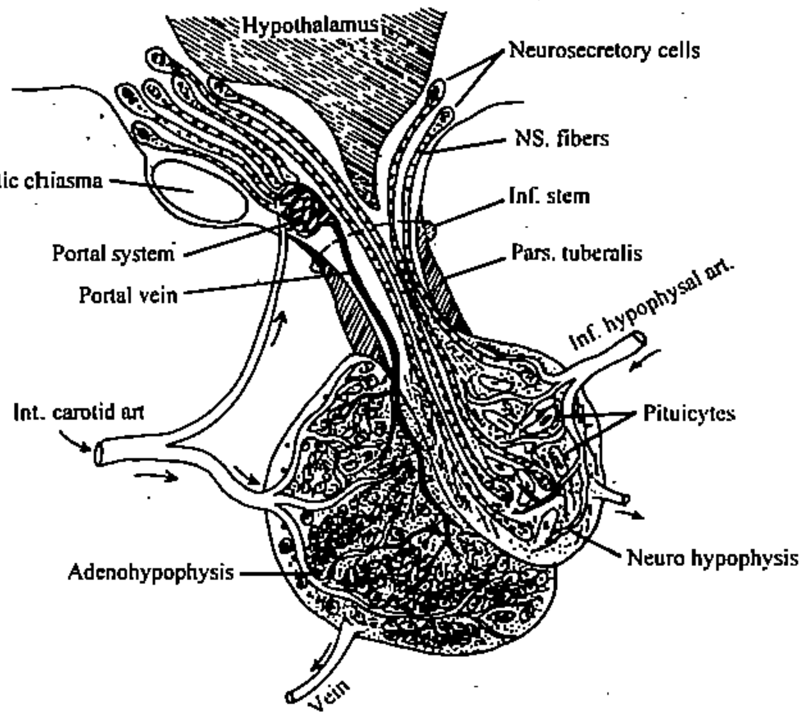


Fig. 12.3: The pitutary gland – blood circulation.

The secretion of pituitary hormones is regulated by the neurosecretion from hypothalamus, which lies on the floor of diencephalon. The neurosecretory materials from the neurosecretory cells of hypothalamus are transported by the axons and enter into the median eminence. The portal vein from the median eminence transports the materials to the anterior pituitary where they regulate the secretion of specific hormones such as adrenocorticotropic hormone, somatotropic hormone, follicle stimulating hormone and lutinizing hormone. Certain other neurosecretory fibres travel through the infundibular tract and enter into the posterior lobe and release into it the neuropeptides oxytocin and vasopressin. Table 12.1 provides the list of hormones secreted from pituitary gland, the site of synthesis and their possible functions.

Table 12.1: Hormones of the pituitary gland.

Region	Hormone	Site of synthesis	Functions
Pars Distalis	Somatotropin (STH) Growth hormone	Acidophil cells	Promotes protein synthesis and deposition of glycogen in muscles and liver. Mobilises fats from tissues. Promotes growth of bones and muscles.
	Adrenocorticotropin (ACTH)	Basophil cells	Stimulates secretion of adrenocortico steroids such as glucocorticosteroids and mineralocorticosteroids by adrenal cortex.
	Thyrotropin (TSH)	Basophil cells	Stimulates thyroid gland to synthesise and release thyroid hormone, the thyroxine.

	Gonadotropins (GH) (a) Follicle stimulating hormone (FSH)	Basophil cells	Promotes gametogenesis and secondary sexual characters. Stimulates growth of ovarian follicles and ovulation in females; stimulates testicular development in males.
	(b) Lutinizing hormone (LH)	Basophil cells	Along with FSH stimulates ovarian follicles and estrogen and progesterone production; helps in the formation of corpus luteum; in males stimulates interstitial cells of testis and secretion of androgens.
	(c) Prolactin or luteotropic hormone (LTH)	Acidophil cells	Stimulates development of mammary glands and milk secretion. Essential for the maintenance of corpus luteum.
Pars intermedia	Melanophore stimulating hormone (MSH) Melanotropin		Stimulates production of melanin pigment in fishes and amphibians; in mammals tyrosine activation by the hormone induces melanin production.
Neurohy-pophysis	Vasopressin or anti-diuretic hormone (ADH)	Hypothalamic neurons	Aids in the resorption of water in kidney tubules. Also acts as a vasoconstrictor.
	Oxytocin	Hypothalamic Neurons	Causes contraction of smooth muscles of mammary glands, Uterine wall.

Before we begin describing other endocrine glands, you may attempt the following SAQ.

SAQ 1

I. Fill in the blanks by using suitable words.

(a) .... is found attached to hypothalamus on the floor of diencephalon by a narrow stalk.

b) The two major parts of pituitary are .... and ....

c) The two divisions of adenohypophysis are................................ and ....

d) The three regions of posterior pituitary are ...., ... and ....

e) The two hormones stored in neurohypophysis are .... and ....

II. List the hormones secreted by anterior pituitary and their functions.

....

....

....

....

....

....

12.2.2 Thyroid

Thyroid gland is generally located in the region of the neck. It is a two lobed structure, the two lobes being connected by an isthmus on the ventral side of the larynx. Thyroid is derived from endoderm and it arises as an unpaired median evagination of the floor of the pharynx at the level of the first pair of pharyngeal pouches. Subsequently it detaches itself from the pharynx and becomes a bilobed structure. The gland is formed of a number of spherical follicles, each follicle having a central lumen which is surrounded by secretory epithelial cells (Fig.12.4). The secretions of the cells are kept stored in the lumen until they are released. In between the adjacent follicles, that is, in the interfollicular spaces, there is a rich supply of blood vessels. The hormone thyroxine secreted by the thyroid gland is a derivative of the amino acid tyrosine. The follicular epithelial cells of the thyroid gland absorb the diffusible iodide ions (derived from the food) from the blood vessels and convert them into iodine molecules. The free iodine is then incorporated into tyrosine residues of thyroglobulin molecules leading to the synthesis of triiodothyronine (T_3) and thyroxine (T_4). The T_3 and T_4 molecules are then enzymatically released from the thyroglobulin molecule.

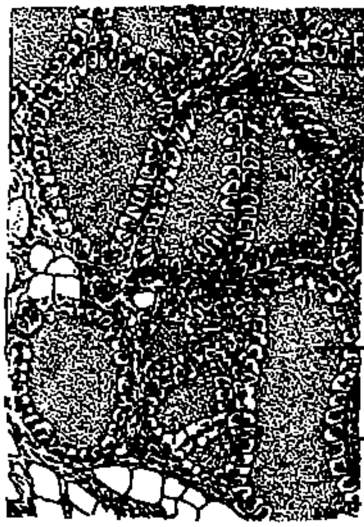


Fig. 12.4: Thyroid gland, a portion enlarged. a) stained section, b) diagrammatic representation.

Thyroid secretions play a significant role in the maintenance of the normal metabolism of the organism. It accelerates the rate of oxidative metabolism in the cells by uncoupling oxidation from phosphorylation. Thyroid also regulates the growth and morphogenesis . Metamorphosis is controlled by thyroxine in frogs. Thyroid facilitates carbohydrate utilisation by promoting glucose release form glycogen molecules. Thyroidectomy in young tadpoles prevents metamorphosis; similarly precocious metamorphosis is witnessed on administration of thyroxine to young tadpoles. Thyroid is also known to regulate water and salt content of the body in conjunction with the anti-diuretic hormone of the pituitary gland. Thyroid also maintains normal activity of gonads and the excitability of nerves and muscles.

12.2.3 Parathyroids

Parathyroid glands are found in close proximity to thyroids and are found generally in two pairs in mammals including man. They are endoderm derivatives from the third and fourth pharyngeal pouches of the embryo and lose their connection with the walls of the clefts in adults. The glandular epithelium is made of columnar cells and they release their secretions in the numerous sinusoids or blood spaces between the columns and from there, they are carried to target organs. There are two types of cells; large and non-granular chromophobe cells and the granular eosinophil cells (Fig. 12.5). Parathyroid glands secrete two types of hormones – the **parathormone** and **calcitonin**. The two hormones are involved in the regulation of calcium metabolism of the body and are antagonistic in their functioning.

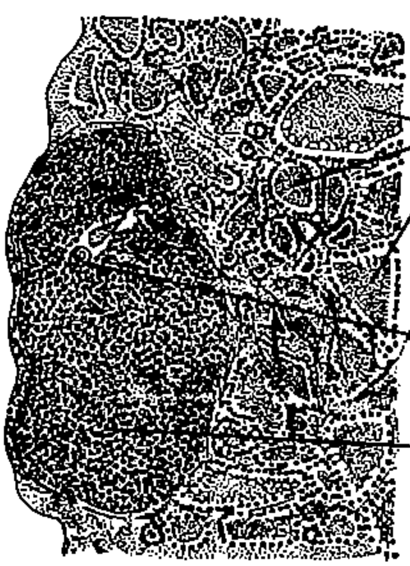


Fig. 12.5: Section of parathyroid gland surrounded by thyroid follicles.

Whereas parathormone regulates the uptake of calcium and its deposition in bones, calcitonin mobilises calcium from bones and promotes restoration of calcium levels of the blood.

12.2.4 Pancreas

Pancreas has both exocrine and endocrine elements in it. The acinar tissue produces pancreatic juice that is released into intestine for performing digestive functions. The endocrine functions are performed by the **islet tissue**, the hormones of which are released into blood stream. The tissue, more specifically known as **islets of Langerhans** (Fig.12.6) has two types of cells, the **alpha** and **beta** cells, each of which produces a specific hormone. Pancreas arises as an evagination of the gut and is thus endodermal in origin.

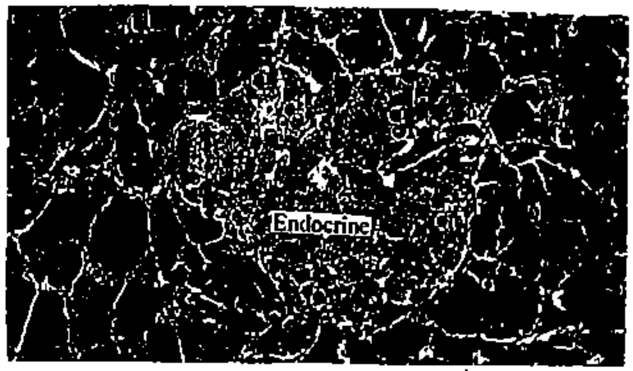


Fig. 12.6: Section through rat pancreas showing both exocrine (pancreatic acclni) as well as endocrine tissue (islets of Langerhans).

The alpha cells produce a hyperglycemic hormone **glucagon** and the beta cells produce a hypoglycemic hormone **insulin**. The two hormones in conjunction regulate the glucose metabolism of the organisms. Insulin also promotes fatty acid synthesis in liver.

12.2.5 Adrenals

Adrenal glands in general lie in close association with the anterior end of kidneys. The glands show two distinct regions, the outer cortex and the inner medulla. In primitive vertebrates, like agnathans and fishes, the two regions are spatially separated, but in higher forms the cells are interspersed. In mammals, the medulla is encapsulated in the cortex (12.27 a). Nevertheless, the two regions of the gland differ in their origin, structure and function.

Adrenal cortex

In mammals cells of adrenal cortex are budded off from the mesodermal inter-renal tissues. The cells are arranged in masses known as the inter-renal bodies in non-mammalian vertebrates. In mammals they surround the medulla to form cortex. The cortex shows three regions, the outer glomerulosa, the middle fasciculata and the inner reticulosa (Fig.12.7 b). The cortical tissue designated as steroidogenic tissue secretes steroidal hormones, the glucocorticoids and mineralocorticoids. Glucocorticoids, such as cortisol play a significant role in carbohydrate and protein metabolism. They promote gluconeogenesis. Mineralocorticoids, on the other hand regulate water and electrolyte balance of the body. Desoxycorticosterone and aldosterone are the two mineralocorticoids. Essentially, they cause the retention of sodium and increased elimination of potassium and phosphates. They also cause a resorption of sodium in kidney tubules and a reduction of resorption of potassium.

Adrenal medulla

Adrenal medulla arises from the neural crest cells of the neurectoderm. A group of cells budded off from the neural crest cells, the phaecochromoblasts, become glandular and form the cells of adrenal medulla (Fig.12.7). The medullary cells have a characteristic histochemical reaction, staining dark brown with chromates and hence known as chromaffin cells and the tissues composed of them is known as chromaffin tissue. The secretions of these cells, known as catecholamines, are adrenaline and noradrenaline (also known as epinephrine and norepinephrine respectively). Both the hormones are derived from tyrosine.

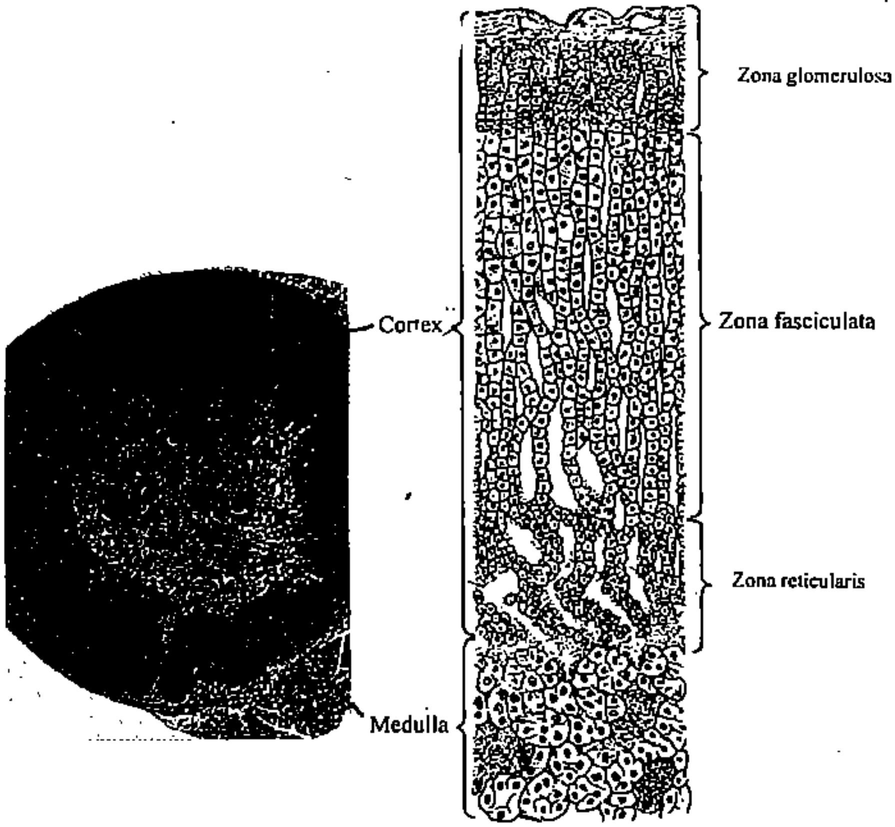


Fig. 12.7: A section through part of adrenal gland in a mammal, with division into cortex and medullary regions; a) stained section, b) diagrammatic representation.

The effects of both the hormones are more or less the same. They cause a rise in blood pressure by vasoconstriction. Adrenaline constricts vessels of the visceral area and the skin; in small doses it dilates the vessels of muscles and in large doses constricts them. It has no effect on pulmonary and cerebral circulation and it dilates the coronary arterioles. Noradrenaline has a constriction action on muscles of blood vessels. In man the peripheral resistance is increased by noradrenaline and lowered by adrenaline. Both the hormones stimulate the constriction of spleen thus causing an increase in the circulating blood volume and the concentration of erythrocytes in circulation. Both the hormones also increase the rate of heart beat. The two hormones cause an increase in blood sugar levels, by effecting glycolysis in liver. Adrenaline also promotes indirectly carbohydrate metabolism by stimulating the release of ACTH from pituitary. The ACTH in turn releases glucocorticoids which regulate carbohydrate metabolism. The secretion of adrenaline is regulated by sympathetic nervous system.

12.2.6 Gastrointestinal Hormones

There are a few gastrointestinal hormones, polypeptides in nature, that are secreted by the mucosa of gut and are concerned with the regulation of gastrointestinal activity in mammals. Some of these polypeptides are **gastrin, secretin and cholecystokinin.** Many other polypeptide hormones are being added to the list but their functions are not clearly defined.

Gastrin secreted by gastric mucosa regulates the secretion of HCl in the stomach. The hormone is stimulated to be produced by the distension of the stomach as well as by some of the food substances and is released into blood. Gastrin in turn acts on the parietal cells to release HCl into the stomach. The HCl secreted serves as a feedback to inhibit further gastrin production. Thus gastrin serves to regulate the volume of HCl production in the stomach. The proper concentration of acid determines the peptic activity within the stomach.

Both secretin and cholecystokinin are secreted by duodenal mucosa. Secretin is released when the stomach pH is low or in the presence of digested fat or bile. The hormone initiates the release of large quantities of enzyme rich pancreatic juice. Cholecystokinin is secreted under the stimulation of partially digested proteins. The two hormones inhibit stomach motility and secretion. Once the chyme leaves the stomach and arrives at intestine, the activity of the stomach slows down and hormones production is inhibited.

12.2.7 Gonadal Hormones

Gonads, the testis and ovary, perform dual functions. One, they are the sites of gametogenesis, the sites at which the sperm and ova are produced respectively; and two, they are the centers of intense endocrine activity – namely, they are the sites at which the hormones which regulate the reproductive activity of the organism are synthesised and secreted.

Testis

Testis is composed of seminiferous tubules in which sperm are produced and interstitial cells or Leydig cells(Fig.12.8) which secretes the male hormones. Testosterone and androsterone, the androgens, derived from testis play a significant role in male reproduction and of the two, testosterone is seven to ten times more potent than androsterone. Androgens promote growth and stimulate the synthesis of cell proteins. They stimulate the adrenal mineralocorticoids and cause the retention of sodium, potassium, phosphorus and sulphur that are utilised in the building up of tissues. The synthesis and release of and organs is under the control of lutinising hormone, otherwise known as interstitial cell stimulating hormone (ICSH), a gonadotropic hormone. Reciprocally, the androgens regulate the secretion of the gonadotropins, either by stimulating their synthesis or as in most cases, inhibiting their secretion. Androgens in low titers are essential for spermatogenesis and in high titres suppress the gonadotropin release.

Fig. 12.8: Section of rat testis. IC, Interstitial cells of Leydig, TT, Testis Tubule.

Ovary

Ovary consists of a fibrous tissue, the stroma and the Graafian follicles in which ova develop. Besides the production of ova, ovary is also an endocrine centre. The two steroid hormones produced by ovary are estrogens and progesterone. Ovary also secretes a proteinaceous hormone, relaxin.

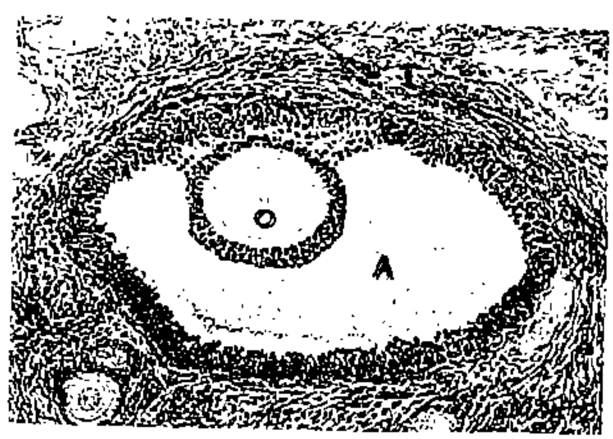


Fig. 12.9: Section of rat ovary to showing Graafian follicle with granulose cells (G) and fluid filled antrum (A), thecal cells (T).

Estrogens are a group of related chemical compounds; the important ones are estradiol, estriol and estrone. Estradiol is more potent than the other two. Estrogens regulate the development and maintenance of the morphological and functional state of the reproductive system. They also regulate the development of accessory genital organs and secondary sexual characters, such as the development of uterine tubes, vagina and the mammary glands. Ovulation and the preparation of the endometrium for the implantation of the ovum are other functions controlled by estrogens. Besides, estrogens also influence nitrogen and electrolyte metabolism, water balance and formation of bones. Estrogens also promote the retention of water and sodium chloride, decrease phosphate levels in blood and reduce the elimination of calcium and phosphorus.

Progesterone is secreted by corpus luteum under the influence of luteotropic hormone from pituitary. It is the ruptured follicle of the ovary that transforms into an yellowish coloured corpus luteum and assumes an endocrine function. Progesterone is also secreted by placenta, later during pregnancy. In pregnant women it can be detected in urine. Like estrogens, the progesterone also performs a variety of functions. It prepares the uterine wall for the implantation of fertilised ovum and maintains gestation. Progesterone supplements the estrogen activity in the development of mammary gland.

Relaxin is a polypeptide hormone secreted under the influence of estradiol and progesterone. The hormone relaxes the pubic symphysis at the time of parturition.

Thus far we made a general survey of some of the important endocrine secretions. Now let us begin the study of hormones in specific groups of vertebrates. Before we do so, please attempt the following SAQ.

SAQ 2

State whether the following statements are true or false.

a) Thyroid is derived form ectoderm and arises as an unpaired median evagination on the floor of the pharynx. ☐

b) Thyroxine is a derivative of the amino acid tyrosine. ☐

c) Thyroidectomy of young tadpoles promotes metamorphosis. ☐

d) In mammals parathyroid glands are paired structures. ☐

e) Parathormone mobilises calcium from bones and calcitonin regulates the uptake of calcium as well as its deposition in bones. ☐

f) The alpha cells of pancreas produce a hypoglycemic hormone and the beta cells produce a hyperglycemic hormone. ☐

g) Adrenal cortex is a derivative of neuroectoderm and adrenal medulla is derived from inter-renal mesodermal tissue. ☐

h) Cortisol regulates carbohydrate and protein metabolism. ☐

i) The regulation of secretion of HCl in the stomach is carried out by a hormone, the secretin. ☐

j) Secretin and cholecystokinin are secreted by duodenal mucosa. ☐

k) Synthesis and release of androgens are under the control of follicle stimulating hormone produced from anterior pituitary. ☐

l) Estrogen, progesterone and protein are the steroid hormones produced from the ovary. ☐

12.3 AGNATHA

In agnathans pituitary and adrenals are present and function as endocrine organs. In lampreys (Fig.12.10) pituitary is located and pressed against the underside of hypothalamus. A hypothalamo-hypophysial portal system making a neurovascular link between hypothalamus and hypophysis does not appear to be present. Essentially the pituitary functions independently in lampreys. Pituitary lacks a median eminence but a posterior thickening of the infundibular floor forms a neural lobe, the pars nervosa – a structure comparable with the neural lobe of higher vertebrates. The neural lobe of the pituitary, the neurohypophysis (Fig.12.10) contains a hormone that regulates the water content of the body. The hormone, arginine vasotocin is produced in the neurosecretory cells of the preoptic nucleus of the brain, carried down the axons and stored in the neural lobe. Thus the lamprey pituitary may show many of the main features found in higher vertebrates, although it may not secrete full complement of hormones. The control system also appears to be a simple one. The pituitary is not regulated by the hypothalamic regulating factors but is controlled by feedback from other tissues.

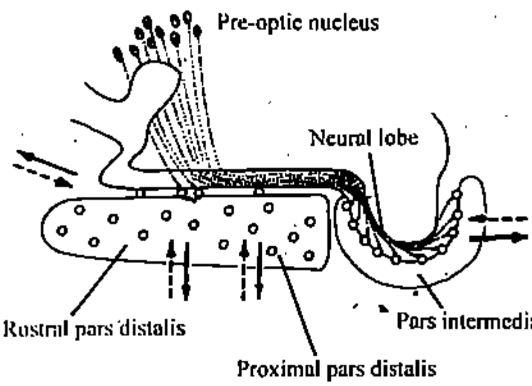


Fig. 12.10: Pituitary of lamprey.

Adenohypophysis, the glandular portion of the pituitary, shows three distinct regions. One, the rostral and two, the proximal regions of the par distalis are separated from the third region, the posterior region, the pars intermdeia by a connective tissue. Pars intermedia is shown to secrete as in other vertebrates, the melanocyte stimulating hormone (MSH) and the secretion appears to be under the control of the pineal eye by way of hypothalamus. Removal of hypophysis results in the non-development of gametes and secondary sexual characters, suggesting that the pituitary is the source of gonadotropic hormone. The basophil cells of the proximal pars distalis secrete the gonadotropic hormone. The acidophil cells of the proximal pars dilstalis produce a corticotropic hormone. The basophil cells located at the rostral parts of pars distalis tend to proliferate at the time of metamorphosis, and were thought to be thyrotropes; but there is no evidence of thyrotropin presence and metamorphosis does not appear to be under the control of thyroid gland.

Lampreys do not possess compact adrenal glands, but cells which represent cortical and medullary parts in higher vertebrates are present. The interrenal cortical cells are present as a group in the region of pronephros just beneath the cardinal veins. Nevertheless there is no evidence of their secreting any steroid hormones nor such hormones have been detected in blood. The suprarenal medullary cells, in the form of chromaffin cells are found in the walls of heart and large blood vessels. These cells answer positively for the presence of catecholamines. Adrenaline and noradrenaline have been shown to be present in the tissues of the heart.

12.4 FISHES

12.4.1 Elasmobranchs

Pituitary

In elasmobranchs, usual parts of the pituitary, the pars distalis (anterior), the pars intermedia and the neurohypophysis are present. In addition, the pituitary also has a ventral lobe that is partly separate (Fig. 12.11). The ventral lobe is believed to be part of anterior pituitary, containing a gonadotropin and thyrotropin. Removal of the ventral lobe causes regression of the gonads in dogfish. Adenohypophysis is known to contain lactotropic hormone and adrenocorticotropic hormone. The neurointermedia receives a number of fibres from neurohypophysial tract. This region contains melanophore-stimulating hormone (MSH). Arginine vasotocin that regulates water metabolism is also known to be present. Besides, three neural octapeptides of unknown function are also present.

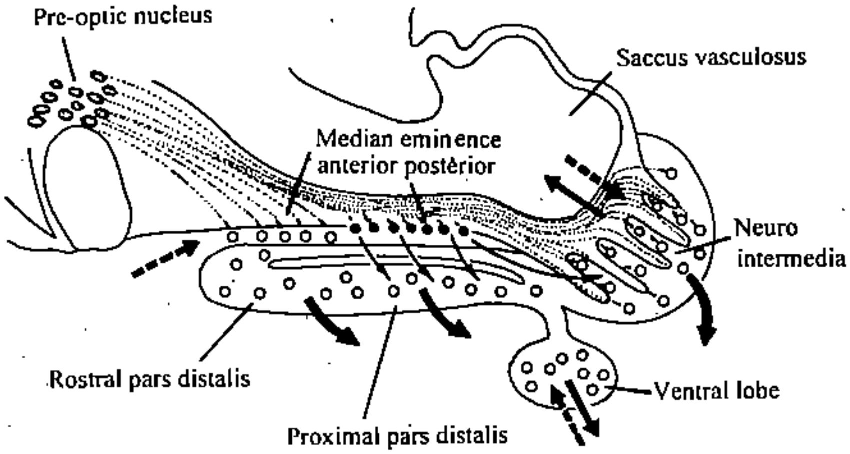


Fig. 12.11: Selachian pituitary. Soild arrows show veins, broken arrows – arteries and thin arrows portal veins.

Regulation of the pituitary is carried out by hypothalamus by way of a portal system that passes through the median eminence (Fig.12.13). But the portal system does not reach the ventral lobe of the pituitary. It is believed that the regulation of ventral lobe is achieved by way of the systemic blood stream by a relay in the pars distalis. In elasmobranchs, unlike teleosts, there is no direct innervation of pars distalis.

Thyroid and Parathyroids

Thyroid in elasmobranchs arises as a downgrowth from the floor of the pharynx. It remains attached to the floor of the pharynx by a narrow stalk containing a small ciliated pit. The functions of thyroid in elasmobranchs are not clearly known, but the gland shows cyclical changes related to migration and reproduction. In dogfishes, removal of thyroid results in non-deposition of yolk in eggs.

In fishes there are no parathyroids. Follicular structures known as ultimobranchial glands are known to produce calcitonin, a hormone that regulates calcium metabolism.

Adrenals

In elasmobranchs, unlike in mammals, the cortical and medullary parts of the adrenal glands are found widely separated. The part corresponding to medullary tissue is known as **suprarenal bodies**. They occur as segmental series of glands and project into the dorsal wall of the posterior cardinal sinus. The more anterior ones are fused to form an elongated structure on either side of oesophagus. These structures are shown to be rich in noradrenaline. The segmental series of suprarenal bodies continue along the whole length of the abdomen, and more posteriorly they are embedded in the kidney tissue (Fig.12.12). The posterior renal bodies, larger in males as compared to females stain positively for the presence of adrenaline.

Interrenal bodies located in the kidney region represent the region corresponding to adrenal cortex. In some species they are unpaired and located medially, and in others they are paired. The interrenal bodies are not associated with the suprarenal bodies in anyway and it appears that the functioning of the two bodies is not interdependent in elasmobranchs. The gland is stimulated by stress or by mammalian ACTH. Removal of the interrenal bodies results in the death of the organism, but extracts of the tissue can prolong the life. Secretions of interrenal bodies have been shown to regulate carbohydrate metabolism of the animal and activity of the gonads; apparently they have no role in electrolyte balance. The steroid secreted by the interrenal bodies has been shown to be 1-α-hydroxycorticosterone and there is no evidence of aldosterone being secreted.

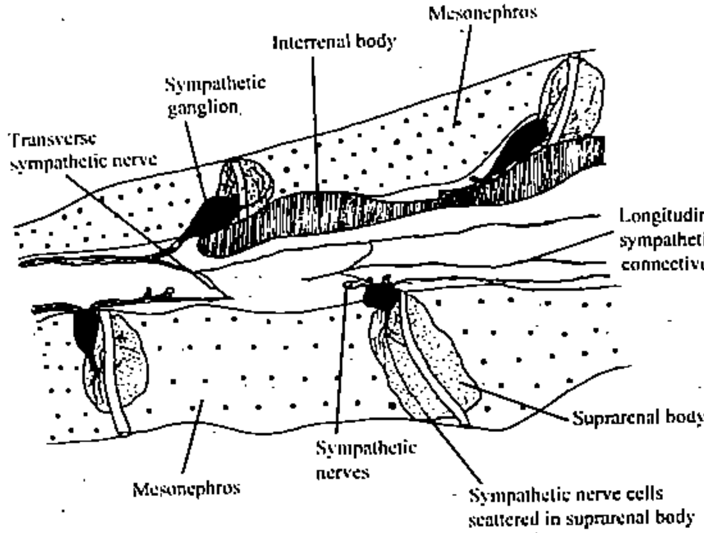


Fig. 12.12: Suprarenal and interrenal bodies in hinder mesonepheric region of dogfish.

Pancreas

Pancreas in elasmobranchs does not occur as islets, as it occurs in mammals but as outer layer of some of the ducts. The pancreas of elasmobranchs secretes both insulin and glucagon.

Gonads

As in mammals, in elasmobranchs also, the gonads have endocrine tissue that produces steroid hormones. The interstitial cells of the testis secrete testosterone, androstenedione and progesterone. Similarly ovarian follicles are shown to produce progesterone.

12.4.2 Bonyfishes

Pituitary

Pituitary of bonyfishes, like other vertebrates shows two regions, the adenohypophysis and the neurohypophysis. The adenohypophysis surrounds the neurohypophysis and interdigitates with it. It shows three divisions, the pars rostral distalis and the pars proximal distalis and pars intermedia, the last region surrounding neurohypophysis (Fig.12. 13). Rostral pars distalis contains acidophil lactotropes, corticotropes and the basophilic thyrotropes. The internal carotid artery that supplies arterial blood to the pituitary forms the primary capillary plexus in the anterior neurohypophysis. It then continues into the pars distalis region as a system of sinusoids among the secretory cells, forming the secondary capillary plexus. Such an arrangement of blood supply in bony fishes is in contrast to the one found in other vertebrates in which long external portal vessels are found instead of a portal system of short capillaries.

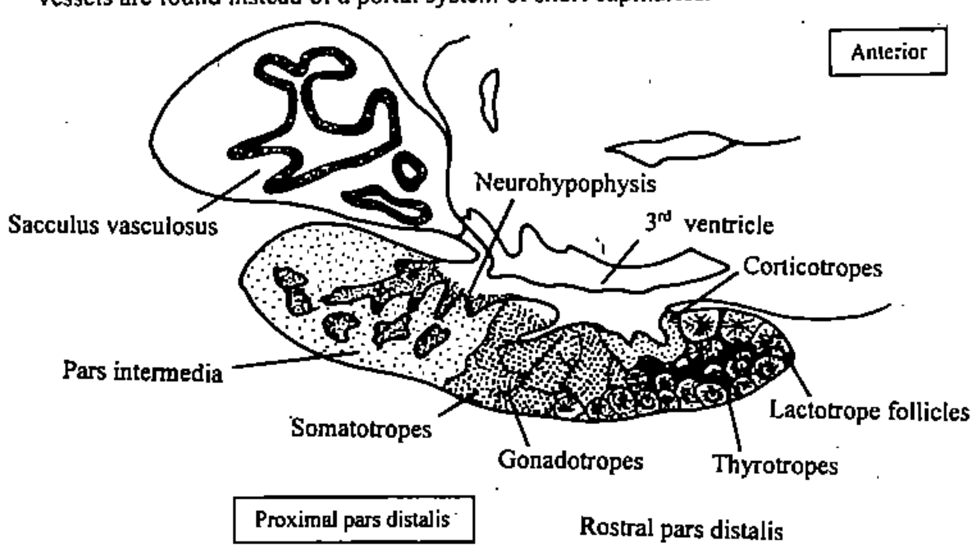


Fig. 12.13: Pituitary of eel, mid sagittal section.

Two types of nerve fibres enter into pituitary from hypothalamus. Type A fibres. Type A peptidergic fibres end mainly around the capillaries or the cells of the neurohypophysis. Type B cells that are mainly aminergic pass on to innervate the cells of pars distalis. Fishes possibly produce only one gonadotropin, the lutinizing hormone (LH). Interestingly, injection of a fish gonadotropin into mammals produces some effects of both FSH and LH; but only mammalian LH and not FSH induces gametogenesis and steroid secretion in fishes.

Lactotropes, cells that secrete prolactin, are not regulated by hypothalamus. This is evidenced by the fact that the lactotropes of the pituitary transplanted ectopically (away from the brain) are activated when transferred from dilute seawater to fresh water. Prolactin of fishes is concerned with osmoregulation. It reduces the exchange of sodium across the surface of the body and gills. In some fishes, prolactin facilitates water permeablity of the gills and enhances renal water excretion. The activity of lactotropes increases and the prolactin titres are high in blood when migrant fishes move from seawater to fresh water.

The pars intermedia produces melanophore-stimulating hormone that regulates the colour changes. Pars intermedia has two types of cells and besides controlling colour changes, the lobe is also known to regulate other activities such as water and electrolyte balance, calcium levels of blood and probably reproduction as well.

Two octapeptides have been identified from the neurohypophysis of the bonyfishes. One is the arginine vasotocin and the other is the isotocin or ichthyotocin, a homologue of oxytocin. Both these peptides are secreted from the neurosecretory A fibres of pituitary. But the functions of these hormones in bonyfishes are not known.

Thyroid

Thyroid gland is not a compact body but appears as scattered masses of tissue along the ventral aorta. The thyroid secretes both triiodothyronine and thyroxine, hormones, which are identical to those, found in mammals. The functions of thyroid in bonyfishes remain uncertain. Thyroid tissues may occur in several parts of the body, kidneys, heart, eye and other parts as well, particularly in those fishes that are deprived of iodine. The cyclic activity of thyroid corresponds with the maturation of gonads implying a role for thyroid in the reproductive process. However, thyroid does not appear to have any role in the respiratory metabolism of bonyfishes, nor in growth or osmoregulation.

Adrenals

The suprarenal and interrenal tissues of adrenal gland of bonyfishes are found in masses around the thickened walls of the posterior cardinal veins. Relatively little is known about the functions of the adrenal tissues of bonyfishes. Removal of the adrenal glands results in the loss of sodium in freshwater and gain of sodium in seawater. In both cases, the organisms fail to survive. Although adrenal tissues produce a number of steroids, there is no evidence of aldosterone production. Dorsal to kidneys, a group of cells called corpuscles of Stannius which do not produce any steroids, but which may be involved in the regulation of calcium levels is present.

Ultimobranchial glands

Bonyfishes lack parathyroid glands. Calcitonin, which in higher vertebrates is produced by parathyroid glands, is produced by a mass of cells developed from the floor of the last branchial pouch, the ultimobranchial glands. The calcitonin of bonyfishes differs markedly from that of mammals in the amino acid composition and is 25 times more potent than the latter. Although the definite function of the calcitonin of fishes is not clear, it is believed that it facilitates calcium transport.

Pancreas

Endocrine pancreas known as Brockerman bodies lie isolated from the exocrine tissue and may occur scattered in the abdomen, in spleen and even in ovaries. Both insulin and glucagon are produced by the specific types of cells.

Urophysis

Urophysis (Fig.12.14) refers to masses of secretion produced by neurosecretory cells at the hind end of the spinal cord. These cells produce masses of neurosecretion. The function of the cells appears to be regulation of the salt content of the body. At least two hormones have been isolated from urophysis, urotensin I and urotensin II. These hormones appear to regulate several aspects of the physiology of the organism including osmoregulation, cardiovascular functions and reproduction.

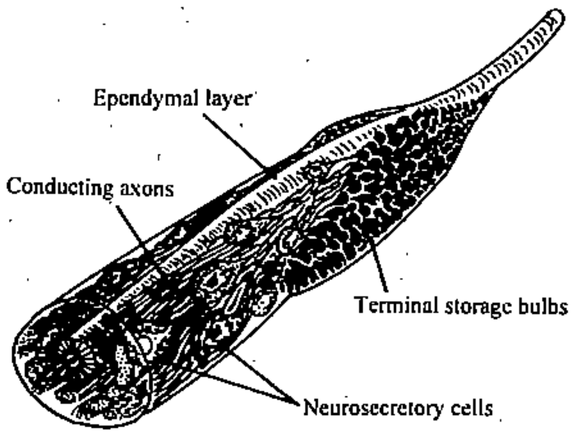


Fig. 12.14: Urophysis in eel.

SAQ 3

Choose the correct word(s) from the alternatives provided.

a) In agnathans a hypothalamo-hypophyseal portal system linking hypothalamus and anterior pituitrary is **present /absent.**
b) In lampreys pituitary is regulated by **hypothalamic regulating factors/feed back from other tissues.**
c) The pituitary of lampreys **produces/does not produce** a gonadotropic hormone.
d) Lampreys and mammals **have/do not have** a similar type of compact adrenal gland.
e) The dorsal/ventral lobe of pituitary in elasmobranchs secretes a gonadotropin and a thyrotropin.
f) **Adrenal cortex/medulla** in elasmobranchs is known as suprarenal bodies.
g) The steroid hormone secreted by the interrenal bodies of elasmobranchs is **aldosterone/1-alpha-hydroxycorticosterone.**
h) Melanophore stimulating hormone of the bony fishes is secreted from the pars **distalis/pars intermedia** region of the pituitary.
i) Thyroid gland in bony fishes occurs as **a compact body in the neck region/ scattered masses of tissue along the ventral aorta.**
j) Removal of adrenal glands in bony fishes results in **loss/gain** of sodium in freshwater fishes.

12.5 AMPHIBIANS

Pituitary

In amphibians the three main parts of the pituitary, pars distalis, pars intermedia and pars nervosa are clearly distinguishable. Pars distalis lacks any divisions as witnessed in fishes and resembles that of other tetrapods. The releasing factors of the hypothalamus pass through the median eminence via the portal system and control the secretions of pars distalis. Pars distalis is known to produce two growth hormones (1) lactotropin (LTH), a hormone that controls larval growth and (2) somatotropin (STH), that controls adult growth. Metamorphosis is regulated by thyroxine whose secretion is regulated by thyrotropin (TSH) secreted by pituitary. The secretion of thyrotropin itself is regulated by a releasing factor of hypothalamus, the TRF. ACTH is also secreted by pars distalis and its secretion is regulated by hypothalamic ACTH-RF. Pars distalis also produces two gonadotropins, FSH and LH.

The intermediate lobe of pituitary produces a melanophore-stimulating hormone(MSH) under inhibitory control from the hypothalamus. In frogs and toads, the neural lobe of pituitary produces arginine vasotocin and mesotocin, which enhance water uptake by the skin. Both in urodeles and anurans the hormones are known to reduce the glomerular filtration. Such functions are more pronounced in landforms than the aquatic ones suggesting that the evolution of these hormones have facilitated land life.

Thyroids and Parathyroids

Amphibians possess paired thyroids. These are located in close association with the external jugular vein, one on each side. Thyroxine controls growth and metamorphosis in amphibians. Thyroidectomy in young tadpoles keeps them in larval state throughout their lives, but when fed on thyroid metamorphosis resumes and adult form emerges. In amphibian adults there is no evidence that thyroids stimulate oxygen consumption.

Among vertebrates, parathyroids for the first time appear in amphibians as regulators of mineral metabolism by secreting parathormone. The parathyroids are derived from pharyngeal pouches. Parathyroidectomy in frogs results in reduction of the calcium levels of blood and increase in phosphorous levels. It is believed that parathyroids might have evolved by the modification of the chloride secreting cells, the ionocytes of the gills of fishes. Ultimobranchial bodies that develop from the floor of the last pharyngeal pouch secrete calcitonin, a hormone that has antagonistic functions to that of parathormone. The hormone functions by mobilising calcium from the endolymphatic sacs, particularly at the time of metamorphosis.

Adrenals

In amphibians, the ectodermal, adrenaline secreting chromaffin tissue of the suprarenals is closely associated with steroid secreting mesodermal interrenal tissues. In fact amphibians are the first vertebrates in which such an association is found. Whereas in anurans the adrenals appear as compact orange masses on kidneys, in urodeles they form an extended series. The action of amphibian adrenaline is similar to those of mammals, namely, that it accelerates heart beat, enhances blood pressure and dilates lungs. It also causes hyperglycemia and dilates pupils of eyes and causes the contraction of melanophores. Adrenal cortex appears to have a role in carbohydrate metabolism as well as in maintaining the water balance of the body. The details of hormones secreted are not known.

Pancreas

Pancreas of amphibians contains both exocrine and endocrine tissues. The islets of Langerhan's, which constitute the endocrine tissue, contain both α and β cells which secrete glucagon and insulin respectively. The action of insulin in lowering blood sugar levels and that of glucagon in enhancing it have been well demonstrated in amphibians.

12.6 REPTILES

Pituitary

As in amphibians, in reptiles also the pituitary contains the usual three parts. There is also the portal system that carries blood from capillaries in median eminence to pars distalis. Also as in amphibians the pars distalis contains five different types of chromophilic cells that secrete different tropic hormones. Lactotropes that secrete prolactin, somatotropes that secrete growth hormone, basophilic thyrotropes that secrete thyrotropin, corticotropes that secrete corticotropin and gonadotropes that secrete gonadotrpins are the five types of cells.

The pars intermedia that is distinctly large in those reptiles which change colour, secretes melanophore stimulating hormone (MSH). In burrowing forms, the organ is very small. The colour changing mechanism is very pronounced in certain lizards such as chameleon and *Anolis (also* known as American chameleons). The colour may change with the environment and thus serves the lizards to conceal themselves. Colour changes also occur during courtship or when the organism is under threat. Changes in temperature or environment are other factors that bring about varied colour patterns. The physiology of colour changing mechanism varies with lizard. In *Anolis* the melanophores are not innervated. Darkening effect is caused by MSH from pituitary and paling effect is caused by adrenaline. In chameleons, however, the colour changing mechanism is under the control of sympathetic nervous system. Colour changes are largely controlled through eyes, and probably by some local control mechanism as well, as the covered areas of the skin tend to become pale. Reptiles, like other tetrapods secrete the two gonadotropins, FSH and LH. The neurohypophysis contains arginine vasotocin, the main anti-diuretic hormone and mesotocin. It appears that oxytocin-like hormone is present in neurohypophysis, as the injection of the extracts of the organ to the viviparous lizard *Lacerta vivipara* results in premature oviposition.

Thyroids and Parathyroids

Reptiles have well-developed thyroid glands but their metabolic function is not clearly understood. Injection of thyroxine (T_4) causes marked enhancement of oxygen consumption at 30° but has no effect at 20°. Apparently the higher temperature is the most preferred temperature for the activity of thyroxine. Thyroid have a role in moulting, reproduction and egg-laying of lizards and snakes.

Parathyroids of reptiles are structurally similar to those of mammals. Parathyroidectomy in lizards causes the blood calcium levels to be reduced to half its normal level and phosphate levels to rise. In the absence of parathyroid gland, the animal becomes hyperexcitable and has tetanic convulsions after exercise. Injections of the extracts of parathyroid gland restore normalcy in the animal. Essentially there is a definite mechanism for the regulation of calcium levels in the blood but the details are not as clearly understood as in the case of mammals.

Adrenal glands

The adrenal glands are located very close to the gonads except in the case of turtles. The gland is a mixture of steroid secreting and catecholamine secreting tissues and the two areas are not very clearly defined. As in mammals, the steroid secretion is under the control of pituitary and hypophysectomy invariably causes atrophy of the steroid secreting tissues.

Thymus

Reptiles have well-developed thymus glands. Thymus glands, as you are aware, are closely associated with immune functions of the body. In reptiles also, the introduction of any foreign material into its body results in the proliferation of cells as well as antibody production. Challenging of the animal by a second injection of the foreign material heightens the immunological response suggesting that there is immunological memory as well. Such responses have been shown to be partly dependent on thymus. Thymectomy or the removal of the thymus gland from young reptiles reduces the capacity for adaptive response.

12.7 BIRDS

Pituitary

In birds the pars distalis of the pituitary lies away from the brain. It shows two regions, the cranial and caudal regions. The median eminence is a separate structure and is also divided into two parts. The anterior part receives the fibres of the hypothalamo-hypophyseal tract and these fibres reach the pars nervosa to release the hormones arginine vasotocin and mesotocin, a derivative of oxytocin. These hormones are involved in the regulation of water balance, heart rate and reproduction. Mesotocin is also involved in enhancing fatty acids and sugar in the blood. The distal lobe of the pituitary has been shown to contain the following hormones: Growth hormone or somatotropin, prolactin, thyrotropin, follicle stimulating hormone, lutinizing hormone, adrenocorticotropic hormone and melanotropin. Pars intermedia in other vertebrates produces the last two hormones. Whereas the function of melanotropin is not clear, the other hormones have the same actions as in other vertebrates. Prolactin influences the production of brood pouches and broodiness, and in pigeons stimulates the production of milk in both sexes.

Adrenals

The cortical and medullary cells of adrenals may be found separately or intermingled with one another. Corticosterone is the main cortical hormone in birds and aldosterone may be secreted in small amounts. Marine birds have large adrenal glands.

Thyroids and Parathyroids

The paired thyroid glands produce T_3 and T_4 hormones. The turnover rate of both the hormones is much higher than in mammals. This could be attributed to higher body temperature and metabolism. Thyroids also control growth and moulting and possibly have a role in migration and reproduction. Birds have large parathyroids, which develop from fifth and sixth branchial pouches and generally remain separated from thyroid. The parathormone of birds is a potent hormone and probably regulates the mobilisation of calcium from bones to the eggshells at the time of egg laying.

Pancreas

Bird pancreas produces both insulin and glucagon as in mammals; and ten times less insulin is produced than glucagon, which mobilises sugar from the liver and raises its level in blood. Glucagon also promotes a strong lipolytic action. Essentially hormonal activities in birds commensurate with their high metabolic demands.

SAQ 4

Match the endocrine gland with the hormone it secretes.

	A		B
a)	Pars distalis of pituitary	1)	Triiodothyronine
b)	Parathyroid	2)	nor-epinephrine
c)	Pancreas	3)	anti-diuretic hormone
d)	Adrenal medulla	4)	calcitonin
e)	Neurohypophysis	5)	glucagon
f)	Thyroid gland	6)	somatotropin

12.8 SUMMARY

After a study of this unit you have learnt:

- About the endocrine glands of different groups of vertebrates. We began the study with the description of the endocrine glands of mammals. In mammals the unpaired pituitary gland consists of two major parts, the adenohypophysis and the neurohypophysis. The adenohypophysis shows further divisions, the pars intermedia and the pars distalis. The neurohypophysis is differentiated into pars nervosa, the infundibular stem and the median eminence. Pars distalis secretes a number of tropic hormones that regulate the secretion of various endocrine glands in the body. Pars intermedia secretes melanotropin and the neurohypophysis releases two neuropeptides, oxytocin and vasopressin.
- That agnathans lack a hypothalamo-hypophyseal portal system and pituitary appears to be independent of hypothalamus. Pars intermedia secrete melanophore-stimulating hormone and the pituitary appears to secrete a gonadotropin as well. In elasmobranch fishes the anterior pituitary secretes thyrotropin and a gonadotropin. Lactotropic hormone and ACTH are the other tropic hormones secreted by the pituitary. Neuropeptide arginine vasotocin is secreted by the neurohypophysis. Pituitary of bony fishes has adenohyphysis and neurohypophysis, and the adenohypophysis shows three regions, pars rostral distalis, pars proximal distalis and pars intermedia. Lactotropin, corticotropin and thyrotropin are the three tropic hormones secreted from rostral pars distalis. Lutinising hormone is the only gonadotropin that is produced. Arginine vasotocin and isotocin are the two neuropeptides secreted from the neurohypophysis and the function of these hormones is not well understood. Amphibian pituitary shows three main parts of the pituitary, pars distalis, pars intermedia and pars nervosa. Amphibian pituitary secretes all the tropic hormones produced by a mammalian pituitary including the two gonadotropins. The secretion of thyrotropin and ACTH are regulated by the respective regulating factors produced by the respective releasing factors released from the hypothalamus. The neural lobe of the pituitary produces vasotocin and mesotocin, the two hormones that regulate water metabolism. The reptilian pituitary is more or less similar in structure and functioning to that of amphibians. In birds the pituitary shows cranial and caudal regions. While the pars nervosa releases neuropeptides such as vasotocin and mesotocin, the pars distalis secretes a number of tropic hormones including

melanotropin and ACTH, two hormones, which are, produced by pars intermedia in other vertebrates.

- That thyroid gland, an endoderm derivative, synthesises and releases a tyrosine derivative, thyroxine. Thyroxine regulates growth and morphogenesis as well as accelerates the oxidative metabolism. Thyroid does not appear to be present in Agnatha , and both in elasmobranchs and bony fishes although it is present, its functions are not clearly known. In amphibians thyroid gland regulates metamorphosis. In reptiles, it appears higher temperature favours thyroid activity. And in birds thyroid produces both T_3 and T_4 hormones. The turnover rate of both the hormones is higher in birds than in mammals.
- That parathyroids, which are found in close proximity to the thyroids, produce two hormones that function antagonistically, the parathormone and calcitonin. The two hormones regulate calcium and phosphate metabolism. Parathyroids are absent in agnathans. In fishes also there are no parthyroids, but structures known as ultimobranchial glands derived from the floor of the last branchial pouch secrete calcitonin that regulates calcium metabolism. In amphibians, parathyroids derived from pharyngeal pouches appear to regulate calcium levels of blood. Parathyroids of reptiles are structurally very similar to those of mammals and their removal causes lowering of blood calcium levels in them. Further parathyroidectomy causes hyperexcitability and tetanic conditions; administering extracts of parthyroids can restore normalcy. Parathormone of the birds besides regulating blood calcium levels also mobilises calcium for deposition into eggshells.
- That pancreas have both exocrine and endocrine tissue the exocrine tissue produces digestive enzymes while the endocrine tissue or islets of Langerhans produce glucagons (by α cells) and insulin (by β cells). Pancreas are absent in jawless fishes pancreas of bony fishes and elasmobranchs secrete both glucagons and insulin though no islets cells are present. Pancreas of amphibians reptiles and birds are similar to mammals in action.
- That adrenal glands are present in all groups of vertebrates. The two regions of which the gland is composed of, the cortex and medulla, are spatially separated in Agnatha and lower fishes; but in higher forms the cells of the two regions are found interspersed. The cortex, a mesodermal derivative, secretes steroidal hormones – glucocorticosteroids and minealocorticoids. Glucocorticoids are concerned with regulation of carbohydrate metabolism and mineralocorticoids are concerned with the regulation of sodium and potassium metabolism. Adrenal medullary region secretes two catecholamines; the adrenaline and noradrenaline. Adrenaline acts as a vasodilator in small doses and as a vasoconstrictor in large doses. Both the hormones cause an increase in heart rate, blood volume and concentration in erythrocytes. Adrenaline also regulates carbohydrate metabolism. In Agnatha although cortical cells could be located in the region of pronephros, no steroid hormone has been identified. Medullary tissue represented in the form of chromaffin cells are found in the walls of heart and large blood vessels. Catecholamines have been shown to be present in the tissues of heart. In fishes interrenal bodies located in the kidney region represents the cortical tissue. They may be either paired or unpaired. The steroid secreted by the cortical cells, identified as 1-alpha-hydroxycorticosterone regulates carbohydrate metabolism but steroids that regulate mineral metabolism have not been identified. In amphibians the cortical and medullary tissues are found to be closely associated as in other higher vertebrates. Although the details of the hormones secreted by the amphibian adrenals are not known, the glands are known to regulate both carbohydrate and mineral metabolism. Adrenals in reptiles is a mixture of steroid secreting and catecholamine secreting tissues. The steroid secreting tissue appears to be under the control of a pituitary hormone. In birds the cortical and medullary tissues may be found separately or together. Both corticosterone and aldosterone have been identified.
- That ovary and testis are the two endocrine centres that secrete the hormones that regulate the reproductive activity of the vertebrates. Leydig cells of testis secrete male hormones, testosterone and androsterone. The synthesis and release of these androgens are under the control of the gonadotropic hormone, the interstitial cell stimulating hormone from pituitary. Similarly the ovary synthesises and releases two steroids estrogens and progesterone, besides a peptide hormone relaxin. Estrogens maintain the functional state of the reproductive system, besides regulating the development and functions of accessory reproductive structures and secondary sexual organs. Progesterone secreted under the influence of luteotropic hormone

from pituitary is released from the ruptured follicle of the ovary that transforms into corpus luteum. Progesterone besides preparing the uterine wall for the implantation of the ovum, also maintains gestation.

12.9 TERMINAL QUESTIONS

1. Describe the structure and functions of pituitary gland of mammals.

....

....

....

2. Give a comparative account of thyroids of vertebrates.

....

....

....

3. Briefly write the functions of the following hormones.
   (a) Adrenocorticotropic hormone (b) parathormone (c) aldosterone
   (d) Testosterone (e) progesterone.

....

....

....

....

....

....

4. Briefly describe the structure and functions of adrenal cortex and medulla.

....

....

....

12.10 ANSWERS

Self-assessment Questions

1. I. (a) Hypophysis cerebri, (b) adenohypophysis and neurohypophysis, (c) pars distalis and pars intermedia, (d) pars nervosa, infundibular stem and median eminence, (e) oxytocin and vasopressin
   II. Refer to Table 12.1.
2. a) F, b) T, c) F, d) T, e) F, f) F, g) F, h)T, i) F, j) F, k) F
3. a) absent
   b) feedback from other tissues
   c) produces
   d) do not have
   e) ventral
   f) medulla
   g) 1-alpha-hydroxycorticosterone
   h) pars intermedia
   i) scattered masses of tissue along ventral aorta
   j) loss
4. a) 6, b) 4, c) 5, d) 2, e) 3, f) 1

Terminal Questions

1. Refer to section12.2.1
2. Refer to sections 12.2.2, 12.4, 12.5, 12.6 & 12.7
3. Refer to section12.2.1, 12.2.3, 12.2.5 and 12.2.7
4. Refer to section 12.2.5.

GLOSSARY

Acinar: Having rounded compartments.

Acuity: Sharpness or resolution in sensory perception especially vision and hearing.

Adrenaline: Epinephrine.

Adrenal gland: An endrocrine gland next to kidney; suprarenal gland.

Afferent artery: An artery that carries blood towards an organ.

Aldosterone: An adrenal corticosteroid that regulates sodium, potassium and water balance by the kidneys.

Amacrine cells: Special neurons of the retina that interact with the transmission of impulses between photoreceptor cells and bipolar cells or between bipolar cells and ganglion cells.

Ampulla: Any membranous enlarged vesicle such as the ones on semicircular ducts of the inner ear.

Androgen: Any hormone that possesses masculinising activities, such as testosterone or any of the other male hormones.

Antonomic: Self controlling, independent of outside influence.

Archinephric duct: The collecting duct of the archinephros or primitive kidney or pronephros.

Arcualium: An embryonic, cartilaginous analogue parts of the adult vertebra.

Areola: The area around the mammary nipple that can be distinguished, often by colour, from the nipple.

Auditory: Pertaining to the perception of sound.

Autostyle: Jaw suspension in which the jaws articulate directly with the braincase.

Axon: The process of a neuron that transports the nerve impulse away from the cell body.

Basilar membrane: A basal membrane of the inner ear of mammals that supports the organ of Corti and subdivides the cochlear channel into two subdivision, the scale media and scale tympani.

Bipedal: Walking or running by means of only two hind legs.

Bipolar cell: A type of neuron that has processes at two ends.

Braincase: The part of the skull containing the cranial cavities and housing the brain.

Blind spot: The nonsensory area of the retina through which the axons of ganglion cell coalesce and turn inward to form the optic nerve.

Centrum: The body or base of a vertebra.

Cephalic: Pertaining to head.

Cerebellum: The part of vertebrate hindbrain that coordinates body posture and equilibrium.

Cerebrum: A major part of vertebrate forebrain; the two cerebral hemispheres united by corpus callosum form the largest part of vertebrate brain in mammals and integrate most of the sensory impulses and motor responses.

Chondrocranium: The part of the skull formed by endochrodal bone or cartilage that underlies and supports the brain; also includes the fused or associated nasal capsules.

Choroid: Relating to a coat or membranes.

Choroid plexus: Any of the several convoluted vascular structures that projects into lateral, third, and fourth ventricles of the brain, and that produce cerebrospinal fluid.

Chromaffin cells: Any cells that stain with chrominum salts, especially cells of suprarenal glands, adrenal medulla, paraganglion and carotid bodies. Chromaffin cells are derived from neural crest.

Cochlea: The elongated and often coiled portion of inner ear of crocodiles, birds and mammals containing sound receptive cells.

Coelom: A body cavity that develops within mesoderm as it migrates between endoderm and ectoderm.

Commissure: Bond of tissue connecting corresponding halves of brain or spinal cord.

Cone cells: Photoreceptor cells in the vertebrate retina that are differentially sensitive to light of different wavelengths.

Cornea: Transparent layer of skin that covers the eye in terrestrial animals; with the crystalline lens forms the complex lens of the eye.

Corpus callosum: A broad band of nerve fibres that links right and left cerebral hemispheres.

Corpus luteum: A yellow glandular mass in the vertebrate ovary formed by the cells of an ovarian follicle that has matured and discharged its ovum; secretes progesterone.

Cortex: The outer part of a structure or organ that overlies (surrounds the medulla).

Crystalline lens: The lens of the eye, so named to distinguish it from the cornea, which in tetrapods also functions as lens.

Cupula: A gelatinous cap over a group of hair cells.

Decussation: A crossing of nerve fibres that carries impulses to or from one side of the body from or to the opposite side of the brain.

Deferent duct: The part of the mesonephric tubule that carries sperm away from epididymus; vas deferens.

Dendrite: Any fibre of the nerve cell that carries an impulse towards the cell body.

Dentition: A set of teeth.

Echolocation: The location of objects by detecting echoes reflected from them.

Efferent artery: An artery that carries blood away from a structure.

Efferent duct: A mesonephric duct that carries sperm away from the testis.

Endocrine: Secreting internally; applied to a ductless gland that secretes into blood or lymph a substance that has a specific effect on another target organ or tissue.

Endoskeleton: The supportive or protective framework within the body that lies beneath the integument.

Epididymis: The mostly convoluted tubule that drains the efferent ducts of the testis into the urethra; the epididymis is derived from the mesonephric or Wolffian duct and efferent ducts.

Epinephrine: Hormone secreted by adrenal medulla of mammals that mobilises glucose in the tissues, among other functions; derived from the methylation of norepinephrine.

Estrogens: One of a group of female steroid sex hormones of which estradiol is the most common, synthesised by placenta and ovary. Responsible for development of female secondary sex characteristics and for maturation and functioning of female reproductive organs.

Fenestra: An opening within the bony braincase.

Fossa: A pit or cavity.

Fovea: A small depression; fovea centralis.

Fovea centralis: Area of the vertebrate retina containing only cone cells, where the most acute vision is achieved at high light intensities.

Free nerve endings: The terminal or sensory end of an afferent neuron that is not ensheathed.

Funiculus (pleural funiculi): Any marginal part of the spinal cord that contains nerve fibres that carry impulses up and down the cord. It is the white or myelinated column of tetrapods.

Ganglion: A knott like mass of cell bodies of neurons located outside the nervous system in vertebrates; in invertebrates includes the swellings of the central nervous system.

Ganglion cell: A cell type that forms the outermost layer of retina and the optic nerve.

Genitalia: Sexual organs, especially copulatory organs, genitals.

Glans penis: Head or tip of penis.

Hemipenis (plural, hemipenes): One of the paired, grooved intromittent organs of reptiles.

Hermaphrodite: An individual that has both male and female organs; monoecious; bisexual.

Heterodont: Dentition in which the teeth are different in general appearance throughout the mouth.

Homodont: Dentition in which the teeth are similar in general appearance throughout the mouth.

Hormone: Substance produced in cells in one part of the body that diffuses or is transported by blood stream to cells in other part of the body, where it regulates and coordinates their activities.

Hypothalamus: A region of the forebrain, the floor of the diencephalon, that contains centres controlling viseral activities, water balance, temperature, sleep etc.

Hypothalamus Releasing Hormone: A hormone secreted in the anterior pituitary by hypothalamic neurons that terminate there and that stimulates the release of other hormones.

Incus: The middle ear bone of mammals derived phylogenetically from the quadrate.

Interstitial tissue: Tissues that lies between other structures or tissues.

Intervertebral body: A pad of cartilage or fibrous connective tissue between articular ends of successive vertebral centra.

Intervertebral disc: A pad of fibrocartilage in the adult mammal that has a gel like core derived from the notochord and is located between articular ends of successive vertebral centra.

Jaws: Skeletal elements of bone or cartilage that reinforce the lower borders of the mouth.

Labia majora, Labia majus (singular): Two lateral folds that surround the vulva.

Labia minora, Labium minus (singular): Two small folds on the medial surface of the labia majora that surround the vulva.

Lacrimal (Lachrymal): Of or pertaining to tears, tear glands, or ducts.

Lateral line: The line or lines along the body of fishes and other aquatic vertebrates that contain mechanoreceptors that detect movement.

Lateral line organs: Any complex of mechanoreceptors in the lateral line; neuromest, neuromost organ.

Leydig cells: Interstitial cells of the testis that produce testosterone.

Macroglia: The astrocyte component of neuroglia.

Malleus: One of the three middle ear bones in mammals that is phylogenetically derived from the articular bone of the lower jaw; hammer.

Meatus: Canal or channel.

Mechanoreceptors: A sensor that detects mechanical changes such as motion, pressure, tension and compression.

Medulla: Central region of an organ or structure.

Melanin: The dark brown pigment produced by the pigment cells of many vertebrates.

Meninges: Sheets of tissue enclosing the central nervous system. In mammals these are the dura mater, arachnoid and pia mater.

Microglia: Small neuroglial cells.

Myelin: The fatty substance that forms a sheath around axons of nerve cells in the white matter of the central system and in most peripheral nerves.

Nephrotome: A narrowed mass of intermediate mesoderm (mesomere or nephromere) that develops into kidney structures.

Nerve: A bundle of neuron axons connecting the central nervous system with peripheral receptors and effectors.

Neural crest: Embryonic cells unique to vertebrates, associated with the neurectoderm but subsequently widely migrating to participate in the formation of many tissues and structures which are characteristic of the subphylum.

Neurocranium: That part of the brain case that contains cavities for the brain and associated sensory capsules (nasal, optic, otic).

Neuroglia: Connecting and supporting cells in the central nervous system.

Neurosecretion: Production of hormone like substances by nerve cells.

Nidamental gland: Any of various maternal glands of the oviduct that secrete material that covers an egg or cluster of eggs; shell gland.

Norepinephrine: A neurosecretion produced by axon terminals of post-ganglionic motor neurons of sympathetic nervous system that mobalises glucose in tissues.

Ossification: The process of calcium deposition in tissue.

Osteon: A highly ordered arrangement of bone cells into concentric rings with bone matrix surrounding a central canal through which blood vessels and nerves run, the Haversain system.

Oviduct: The tube that conveys egg cells to the exterior or to the uterus.

Parietal eye: A median eye with an aperture that is surrounded by the parietal bone. The parietal eye forms the pineal gland.

Pars recta: The straight part of some structures, such as kidney tubules.

Pecten: A comblike process of the retina of reptile and birds.

Perichondrin: The sheet of fibrous connective tissue around cartilage.

Peritoneal canal: A canal off the abdominal coelom.

Peritoneal funnel: A funnel like opening from the coelom.

Peritoneum: A membrane that covers the abdominal viscera and inner abdominal wall.

Portal system: Portion of the venous system specialised for the transportation of substances from the site of production to site of action. A portal system begins and ends in capillary beds.

Ptaguim: A stretched fold of skin that forms an airfoil or flight control surface.

Quadrapedal: Walking or running by means of four legs.

Rete testis: The network of anastomosing tubules that carries sperm from testis.

Receptor: Sensory nerve ending in skin or sensory organ.

Rods: Photoreceptor cells in vertebrate retina specialised to function effectively under conditions of dim light.

Sacculus: Small pouch; smaller of the two sacs in inner ear.

Sclera: Tough outer coat of eye.

Stapes: One of the three middle ear bones in mammals that is phylogenotically derived from the columella (hyomandibula).

Suprarenal gland: Adrenal gland.

T_3: Triidothyronine.

T_4: Tetraiodothyronine.

Tapetum lucidum: (1) A reflective choroid in the eyes of nocturnal animals (2) A nervous pathway in the roof or the lateral ventricles of cerebrum.

Tympanum: The eardrum or tympanic membrane.

Utriculus: Larger of the two sacs in the inner ear.

Vertebra: One of the several bones or cartilage blocks firmly joined into a backbone that defines the major body axis of vertebrates.

Zygapophysis: The projection of a neural arch that articulates with the adjacent neural arch.

FURTHER READING

1. The Life of Vertebrates J.Z. Young (Third Edition) ELBS, Oxford University Press.
2. The Vertebrate Body A.S. Romer and T.S. Parson (Sixth Edition) CBS College Publishing.
3. Chordata Anatomy and Evoultion D. Jacob, A Sharma and K. Nandchahal (1994). Ramesh Book Depot, Jaipur.

Uttar Pradesh
Rajarshi Tandon Open University

UGZY -02
ANIMAL,DIVERSITY-II

Block

4

ADAPTATIONS AND BEHAVIOURAL PATTERNS

BLOCK 4 ADAPTATIONS AND BEHAVIOURAL PATTERNS

In Block – 4 of the Animal Diversity course (LSE-09) we familiarised you with some of the behavioural adaptations and patterns seen in non-chordates. You learnt about various tropisms and the interesting ways in which non chordates respond to their environmental conditions or requirements for courtship and mating. Among chordates too we find a vast array of different behaviours. To understand animals we must first understand their functional biological principles. The first three block of this course Animal Diversity – II explain these principles in relation to chordates. This last block now deals with adaptations and behavioural pattern in chordates.

A study of animal behaviour attracts us because it is so varied, and seems mysterious and the strange. The unfamiliar behaviour of exotic animals is often the subject of popular television shows, however, the behaviour of familiar and ordinary animals is equally fascinating for the inquiring mind. Such behaviour can be viewed from two quite different perspectives. Animals learn everything they do or they know instinctively what to do. Neither extreme has proven to be correct.

Animal behaviour can be defined as activities, animals perform during their lifetime. These activities include feeding, capturing prey, moving from place to place in search of a suitable habitat to live and breed in, avoid predators etc. Animals also communicate and interact within their species as well as with other species. Thus we find that the subject is vast and all encompassing. This block examines some of these aspects in four units.

Unit – 13, Introduction to Animal Behaviour gives a brief history of the development of the branch of biology known as Ethology. The unit explains why it is necessary to study animal behaviour. In addition to the academic importance, there are several practical applications which are relevant to our lives. A brief survey of the bases of behaviour such as anatomical and physiological, genetic and ecological has been given.

In **Unit – 14,** Development of Behaviour you will learn that basic questions of animal behaviour fall into two categories. How and why do animals behave in different ways? The unit extends the discussion on genetic and environmental bases from the previous unit. You will learn that certain behaviour is instinctive and innate i.e., performed correctly the first time. While, certain other behaviour is performed and modified by learning and experience.

Unit – 15, Organisation of Behaviour, discusses the various mechanisms that are crucial to establishment of behavioural patterns seen in vertebrates. We discuss the significance of biological clocks and rhythms that organise behaviour on a daily and annual basis. A well known and fascinating rhythmic behaviour – migration in vertebrates has been explained with examples. In this unit you will learn that social organisation in vertebrate groups is quite different from insect societies. The most profound difference being the absence of sterile castes and the higher proportion of reproductive individuals. The various factors that organise vertebrate groups into societies have also been explained. We will also consider a few general methods of communication, in doing so perhaps we can learn something about the ways in which animals influence the behaviour of other animals.

The last, **Unit – 16,** Adaptive Behaviour discusses the ultimate causes of behaviour or the selective advantage of a particular behaviour. Animals that possess certain adaptive features, are more successful at surviving and reproducing. Interesting and fascinating examples of colouration, mimicry bioluminance, have been illustrated in the unit. You will also learn about the special adaptations for self defence, for locomotion, echolocation too as these strategies help in the ultimate survival of the animal.

Objectives

After a study of this block you will be able to:

- define animal behaviour and explain why it is necessary to study it,
- distinguish between innate and learnt behaviour,
- describe the various mechanisms of organising behaviour,

- discuss social organisation in vertebrates with examples, and
- explain the adaptive significance of colouration mimicry, bioluminescence, echolocation and defensive behaviour in vertebrates.

UNIT 13 INTRODUCTION TO ANIMAL BEHAVIOUR

Structure

13.1 INTRODUCTION

Cave paintings and ancient art objects found in excavations strongly indicate that one of the earliest fascinations of our pre-historic ancestors was the study of animal behaviour. Perhaps they were motivated by the need to save themselves from harmful animals and to hunt some others for food or skins. They continued to study animals and their behaviour and applied their primitive knowledge to domesticate selected species and derive more benefits from animals. With the advancement of man's knowledge of animal behaviour more and more benefits have been flowing and the quest is progressively increasing with unlimited prospects.

To understand living animals, not any particular aspect from a specialists' point of view but animals and their life in totality, knowledge of animal behaviours is essential. Behaviour refers to the response of an organism to signals from its environment. The basic purpose of all actions, collectively called behaviour is continued existence and well being of the concerned animals. It is, therefore, futile to study behaviour in isolation from other aspects of the animal's life. Its study requires the application of principles and techniques from various specialties, particularly anatomy, physiology, genetics psychology and even physical sciences.

In this unit you will first learn the definition of animal behaviour and the importance of its study. We will also introduce you to the anatomical, physiological, genetic and ecological bases of behaviour. Other aspects such as development and organisation of behaviour will be discussed in the subsequent units.

Objectives

After studying this unit you should be able to:

- define animal behaviour in scientific terms,
- explain why it is necessary to study animal behaviour,
- describe the bases of behaviour development,
- relate animal behaviour to environment.

13.2 BEHAVIOUR

All living-beings are characterised by their activities or functions. An animal is declared dead the moment it stops its characteristic living functions. We can, therefore, conclude that a living being is what it is by virtue of its functions and not only by virtue of its body form or structure. Thus it is obvious that for a full understanding of animals and their life, a study of behaviour is as important as any other aspect.

Behaviour is one of the most interesting and complex aspects of an animal's life and it has several dimensions. The survival of an organism depends to a very great extent on its relationship with its environment, including all living organisms and non-living things. Every living organism appropriately responds to changes in its environment. The nature of responses are basically different in plants and animals. Among plants climbers for example have thin and weak stems, they twine round the stronger stems of trees to reach out for light. They do so by growth movements and their response in that regard is irreversible. Animals however, respond differently and their responses to changes in environment, called behaviour, are active and reversible. A deer seeks shelter under a tree when it is too hot in the sun but comes out to graze in the open at dusk and dawn. The nocturnal owl becomes active in the dark but goes in hiding during the day. Each responds to the changes in its environment and these responses are reversible. Many birds and mammals may be seen fluffing their feathers or fur when the surrounding temperature suddenly drops. Fluffing increases the volume of insulating air envelope on their bodies and prevents the loss of body heat thereby, keeping them warm. Many species hibernate in severe winter season to conserve energy (heat), which is spent in normal activity and also to remain huddled in a warm place without having to go out in the cold searching for food and other requirements of an active life. These are clear responses of animals to changes in their physical environment directed towards their survival and well being and are therefore regarded as behaviour. There may be apparent similarities between many responses of animals and plants but the two are basically different. As pointed out earlier the responses of plants are **passive, slow and irreversible** (and are called tropism) while behavioural responses of animals are **active and reversible.**

The study of behaviour becomes quite complex because a living animal simultaneously responds to several stimuli in its environment and it is seldom possible to study the response to a single stimulus in isolation from other responses.

13.2.1 Definition of Behaviour

Defining behaviour in scientific terms is not as easy as many people may think because behaviour has to be studied and can be described at several different levels such as physiological, ecological or psychological. Behaviour includes gestures, postures, vocalisation, colour change, pilo-errection (hair raising) and even standing still is part of behaviour. Therefore, behaviour is a term with wide and varied connotations and its definition depends on the specific objectives of its study and description. **In a larger sense behaviour has been defined as the symphony of hormonal, neural and muscular systems.** We can, however, define behaviour as 'whatever an animal does'. Walking, resting, or chewing food are some of the simplest forms of behaviour. But mostly behaviour is far more complex, particularly when it involves intelligence, learning and experience.

Behaviour is generally described in terms of an animal's responses to stimuli arising within the body or in the external environment. Since behavioural responses are regarded as an animal's attempt to adapt itself to its changing environment, the basic objective of behaviour remains survival, continued existence and well-being.

13.2.2 Importance of Studying Animal Behaviour

The science of animal behaviour is comparatively a new branch of zoology. It was not a subject of serious study until the middle of nineteenth century. With the gradual acceptance of Darwin's theories it was realised that adaptations as a consequence of natural selection play a very important role in the process of evolution, and behaviour of animals has also evolved gradually along with morphological features. Animal behaviour received special attention of biologists when it was seen that animals get adapted to their environment largely through their behaviour and not only by structural changes. Interest in the study of animal behaviour has been increasing since then.

Traditionally three major fields of study of animal behaviour have been recognised. **Comparative psychology** is the study of mental processes and behaviour. It is the comparison of animal and human behaviour, usually under experimental conditions and mostly aimed at a better understanding of human behaviour. **Ethology** is the study of animal behaviour under natural and seminatural conditions. Ethologists usually take pains to compare their laboratory observations with observations taken under natural conditions. The third area of study which in a way integrates the other two approaches ethology and comparative psychology, is **neurobiology** – the study of the anatomy and physiology of the nervous system. Each of the three disciplines has developed a body of concepts, terminology, and methodology about which you will learn in the next unit, but since the middle of twentieth century these disciplines have reunited on several common grounds. Let us first try to understand why we need to study animal behaviour.

Many species of animals, particularly birds and mammals, have been domesticated for economic gains. Their well-being and propagation have become our concern. Maximum benefits can be derived from domesticated livestock (milk, eggs, fur, manure etc.) by good management which requires scientific knowledge of animal behaviour and there may be many more such uses of animals which are not foreseen at present.

With our growing consciousness of environmental problems; global warming, ozone layer depletion, deforestation, soil erosion etc., our attention has been focussed on the maintenance of ecological balance which depends to a great extent on the important role played by free-living animals (wildlife). We also know that many wildlife species, particularly birds and mammals, have become extinct in the past and many more are now regarded as endangered. To preserve these species and to save these from extinction it is absolutely necessary to know a great deal about their behaviour; how much space they need, what and how much they eat. What sort of cover and shelter they require and so on. All this can be known only when we study their behaviour.

There is a generally held view that knowledge of animal behaviour can be applied to understand human behaviour. Though we now know that human behaviour, if interpreted by direct application of theories developed through studies of animal behaviour, may lead to misleading conclusions, several aspects of human behaviour can certainly be understood to a limited extent by studying animal behaviour. This is the reason why studies on primates are being done in many psychology laboratories. Experiments are conducted on animals with the objective of tracing the roots of human behaviour.

Some animals, those that we consider pests, are a direct threat to us, to our health, food supplies, we must know their behaviour to be able to put a check to them. There is an interesting example to illustrate this point. A government official in the US spent $ 5000 on mothballs to keep birds away from runways of an airport where they often collided with jet planes. What he didn't know was that birds do not have a well developed sense of smell and therefore the smell of mothballs did not deter them at all!

Some interesting facts have come to our knowledge recently. Several species of animals are seen to behave in a peculiar and abnormal manner before certain natural calamities such as earthquakes or volcanic eruptions. It seems that they are able to sense the forthcoming disasters. We lack this ability. There are apparent prospects of preventing losses to human life if we are able to interpret animal behaviour prior to the occurrence of earthquakes, volcanic eruption, severe storms, and landslides.

It is, therefore, understandable that studying animal behaviour is very important from many points of view and for a variety of reasons.

SAQ 1

a) Fill in the blanks.

i) .... is the scientific study of behaviour under natural conditions from the point of view of adaptations.

ii) .... is a study of the mental processes and behaviour.

iii) All behaviour stems from the need for and continued .... to one's ....

b) List the broad objectives of studying animal behaviour:

i) ....

ii) ....

iii) ....

iv) ....

v) ....

13.3 BASES OF BEHAVIOUR

In the preceding section you have read a general description of behaviour; its definition and the importance of its study. There are two main approaches to study animal behaviour, physiological and the animal as a whole. Physiological approach is mainly concerned with how the nerves, muscles and sense organs are coordinated to produce a complex behaviour, for example, singing in birds. Those that take a whole animal approach study the factors that affect the behaviour of the animal. For example, they may be interested in the environment of the bird that prompts it to sing or why it sings at all.

The whole animal approach is used by both psychologists as well as ethologists, though psychologists make comparative studies in the learning abilities of some species of animals in laboratories. Ethologists on the other hand are more concerned with naturally occurring unlearnt behaviour of animals in their wild habitats. Now-a-days ethologist have become interested in the role of learning in the life of wild animals and psychologists are interested in the study of responses of animals to natural stimuli and both are learning from each other. However, physiologists, ethologists and psychologists, none can rely solely on one source of information to explain how or why an animal behaves as it does. Therefore, we will now consider the factors which determine an animal's behaviour and the mechanisms of its physical control. These factors, processes and mechanisms are termed here as 'bases' of behaviour. The following bases will be explained:

1. Anatomical and physiological
2. Genetic
3. Ecological

Behaviour is the composite and ultimate product of interaction between all such factors, processes and mechanisms just like the collective actions of different parts of a machine. None of these should be viewed in isolation from the others for that will be a misleading over-simplification. It is only for the sake of convenience that we describe each separately and not because these are completely independent of each other.

13.3.1 Anatomical and Physiological Basis

As has been discussed earlier in this unit, behaviour is generally explained in terms of an animal's responses to internal and external stimuli. The feeling of hunger for example is an internal stimulus and the animal responds to it by seeking food. Dim light at dusk time is an external stimulus and diurnal birds respond to it by seeking roosting sites. Thus the starting point in behaviour is perception of stimuli such as perception of characteristic feeling of hunger or perception of decreasing intensity of light.

Perception of stimuli is made possible by the presence of receptor organs which vary in different species. Receptors (called sense-organs) are connected to the nervous system and they receive stimuli i.e. they detect what goes on inside or outside the animal's body. These sense organs are of different kinds, each sensitive to a specific sort of stimulus. Eyes for instance are sensitive only to light and ears to sound.

You have already studied in Unit 10 about basic properties of nervous tissue, and the organisation of the vertebrate nervous system and sense organs. Behaviour can also be explained as a function of the nerve cells. The simplest model of the neural basis of behaviour is the vertebrate reflex. The few neurons of a reflex process information in such a way so as to give a predictable response always. Everytime a bright light flashes towards us we tend to close our eyes. Reflexes and more complex behaviour share a number of properties that are the result of the functioning of individual neurons. Complex behaviours may include many reflexes. Both show latency i.e. a time delay between stimulus and response. If a painful stimulus like a prick is given to dog in the leg, the latent period between the stimulus and the response of withdrawing the leg by the flexion reflex is between 60 to 200 m sec. The delay is not the result of the time taken for the impulse to travel, the delay occurs between the synapses.

Complex behaviour, therefore, also show latency because there are several synapses to be crossed. In case of reflexes the stronger the stimulus the shorter the latency. If the prick is strong then the withdrawal of the leg is faster. The same is true for complex behaviour. The central nervous system may add together stimuli arriving from different sense organs or at different times this is known as **summation.** We know that individual neurons are able to add up or summate excitation coming at different times or from different places. Summation can be seen at the level of reflexes as well as complex behaviour. Sherrington (see margin remark) gave several examples of summation at the level of reflexes. The scratch reflex in a dog can be elicited if an irritating stimulus is given on the saddle shaped area of its back. The hind leg on the same side automatically begins to scratch at that area. Weak stimuli say 5- 10 touch may not elicit any response but if 20 or 30 touches in quick succession are given then the scratching appears. With more complex behaviour summation often occurs between stimuli of quite different types perceived by different sense organs. Experiments showed that male rats respond sexually to a combination of visual, tactile and olfactory stimuli. Young males will not respond unless atleast two stimuli are presented while mature males with previous sexual experience will respond to one type of stimulus alone.

In the early 1900s Charles S. Sherrington studied the physiology, functions and detailed anatomy of various parts of the mammalian nervous system; identified and named the synapse as the connection between adjacent neurons.

However, studying single neurons and studying the whole animal may require very different techniques and different concepts and it may not be possible to explain all behavioural abbreviation using the reflex terminology. Let us now learn about the genetic basis of behaviour.

13.3.2 Genetic Basis

You would recall that behaviour is the result of an enormously complex interaction of nerves, muscles, sense organs and hormones. Genes can affect all of these. Genes determine how an organism will form, what anatomical characteristics it will possess, what functions it will be able to perform, what changes it will undergo from birth to adulthood and in what respects it will differ from other organisms. In short, genes determine the very nature of every living organism. Therefore, we can say that behaviour is genetically based as genes determine how an animal can and does respond to its environment.

Sometimes genes must act very specifically on the way the developing nervous system grows and forms connections. For example the song that the bulbul is able to sing is due to the appropriate connection among the neurons of the brain, genetic instruction are necessary for the growth and design of the brain. Hence genes contribute in an important way for the development of all behaviour.

Genes have more indirect and general effects by altering the amount of an enzyme or hormone secreted or the sensitivity of a sense organ. Mutations which block or alter behaviour patterns provide a useful tool in understanding how genes influence behaviour. Most experiments have been done using *Drosophila* where mutant genes for vision in males affect their ability to see as well as normal male and therefore, they have trouble in locating females. Another mutant gene alters the form of wings grossly which affects their ability to vibrate their wings which is an important part of courtship behaviour. Thus it becomes clear that these genes affect courtship behaviour by disrupting their normal vision and beating of wings and we can appreciate the indirect influence of genes on behaviour.

Studies have shown that some behaviour is linked to a single gene but most behaviour patterns involve several genes and this can be shown by hybridisation experiments. A classic experiment to demonstrate the genetic basis of nest building behaviour in lovebirds was performed by William Dilger (1962). These members of the parrot family tear strips of material from leaves to build their nests but while some i.e., the Fisher's. lovebirds carry the strips in their bills, the other species peach faced lovebirds carry the strips tucked in their rump feathers (Fig. 13.1). A cross between these two species was incapable of building a nest at all because they attempted to perform a compromise between the two methods of collecting nest building material. They tried tucking the strip between the rump feathers but either failed to let go of it or failed to tuck it properly. They could succeed only if they carried the strip in their beaks after first attempting to tuck it and after several months of trials only 41% attempts lead to nest building. Even after they learnt to carry the strip the hybrid birds always turned their heads as if to tuck the strip.

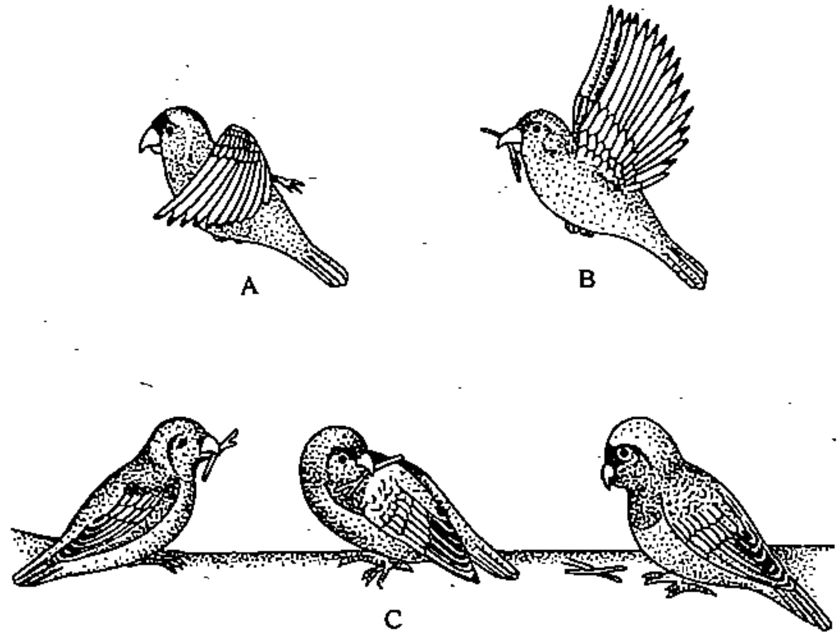


Fig. 13.1: Confused nesting behaviour in lovebirds A) Peach-faced lovebirds; B) Fischer's lovebird; C) hybrid. (Based on Dilger WC 1962 Scientific American 206(1) : 88-89).

Further, as has been explained, the starting point in behaviour is the perception of stimuli. An animal's capacity to perceive stimuli depends upon receptors (i.e. sense organs, such as eyes, ears, nose etc.) and the transmission of impulses depends upon the design of the motor apparatus. Each species has differential capacities for perception of stimuli and transmission of impulses. Elephants for example, have poor eye-sight but very keen senses of hearing and smelling, fish can see the water and can sense vibrations/waves of water by special organs called lateral line organs. Snakes do not have external ears but can perceive sound waves passing through layers of earth through the under (ventral) side of their bodies. Dolphins and bats can hear ultrasonic sound waves inaudible to human ears. This is due to differences between species in regard to the basic design and function of receptors (sense organs) and motor apparatus. The basic design of sense organs and motor apparatus is determined during embryonic development which in turn remains under the control of genes.

Males and females of most species can be distinguished on the basis of their body-size and shape or colour and many other external characters. Apart from these, behavioural differences also exist between males and females of the same species. In your day to day life you yourself can see common behavioural differences between the males and females for example, you would notice that it is the male of most song birds that sings and not the females; most courtship displays are performed by males. The peacock dances and not the peahen. Much of these behavioural differences are due to the different hormones secreted in the body of males and females as also the differences in their anatomy. Anatomical studies on some song birds reveal that the structure and size of the brain region that connects to vocal organs in males is different from that of female birds. The development of this song system is influenced by hormones. Let us take the example of zebra finch, a bird species whose sexually mature males but not females produce courtship song. During development the pre-testicular cells in males manufacture estrogen, whereas the preovarian cells in females do not. Thus estrogen acts on embryonic brain cells of males leading to development of special chain of neural elements that run from the front of the brain to the spinal cord, where it connects with the neural pathways to the syrinx, the organ that produces vocalisations. This network of the song system grows rapidly during the first 40 days after hatching while the number of cells in the corresponding part of the females brain becomes less due to cell death. As a result, the mature brain of the male is different from the female in structure and function.

At the start of the breeding season in temperate zones, testosterone is secreted from the enlarged testes. Cells of song systems have receptors for testosterone. Binding of the hormone triggers metabolic changes that enable the bird to sing after it has marked its territory to repel other males. Thus estrogen organises the song system and testosterone activates it to allow the bird to sing when properly stimulated. As both hormones and anatomy are controlled by genes, it is not difficult to understand the indirect but very important role of genes in shaping animal behaviour.

SAQ 2

Will adult female song birds sing if they receive an implant of testosterone?

....

....

....

....

....

....

....

....

13.3.3 Ecological Basis

For survival animals must maintain a positive relationship with the environment and behavioural responses are regarded as an important aspect of an organism's efforts for adjustment to a given environment. In the broadest sense, the term behaviour is used to collectively describe the overt actions of organisms to adjust themselves to environmental circumstances so as to ensure their survival and well-being. Unless behaviour is relevant to the needs arising in the environment, it will be a futile exercise leading to unnecessary wastage of an animal's energy and avoidable fatigue of its body. There are innumerable instances when even a layman can observe interesting behavioural changes and can relate them to changes in environment.

Bats, owls, jackals, hyenas, remain active mainly during night while crows, kites, vultures and many other birds and animals can be seen active during the day time. These are some examples of behavioural responses to the day and night changes in environment. Animals have adapted to different life styles to avoid conflict or to reduce competition as some remain active at night and some during the day time. Animals active at night have eyes to see at night and are unable to see in bright light which is an important ecological reason for their nocturnal activity. Kites and vultures feed mainly on carrion scattered unevenly in the environment which is difficult to spot in poor light therefore, they feed during the day time and are unable to see in dark, which is again an important ecological reason for their diurnal activity.

Other than these day and night changes, animal behaviour can be seen to change with seasons. We hear frogs croaking with the onset of monsoon but never in summer or winter. Since frogs are adapted to a partly aquatic environment and they breed only in water they come out of aestivation with the onset of monsoon and their croaking, starts as a part of their breeding behaviour. We see peacocks dancing just before and during monsoon season. The peacock's dance is a part of its courtship behaviour which precedes breeding. The species feeds on insects, lizards, small snakes, grain, vegetable shoots etc. which become abundantly available during monsoon. Peafowl breeds in that season so that the chicks get plenty to eat. There are several other factors influencing peafowl's breeding during monsoon but we can see the relation of behaviour to ecological factors.

Large flocks of migratory geese and ducks are frequently seen moving in one direction with the onset of winter and in the opposite direction towards the end of winter season (Fig. 13.2). These species migrate from the northern hemisphere habitats where food resources get covered with snow and life becomes difficult due to very low temperature. These birds come in winter to place of warmer climate in search of food and for comfortable living. Once the temperature in this region starts rising and conditions become favourable in their northern abodes, they go back. This interesting phenomenon of bird migration indicates that behaviour is related to environment. You will learn more about migratory behaviour in Unit 15.

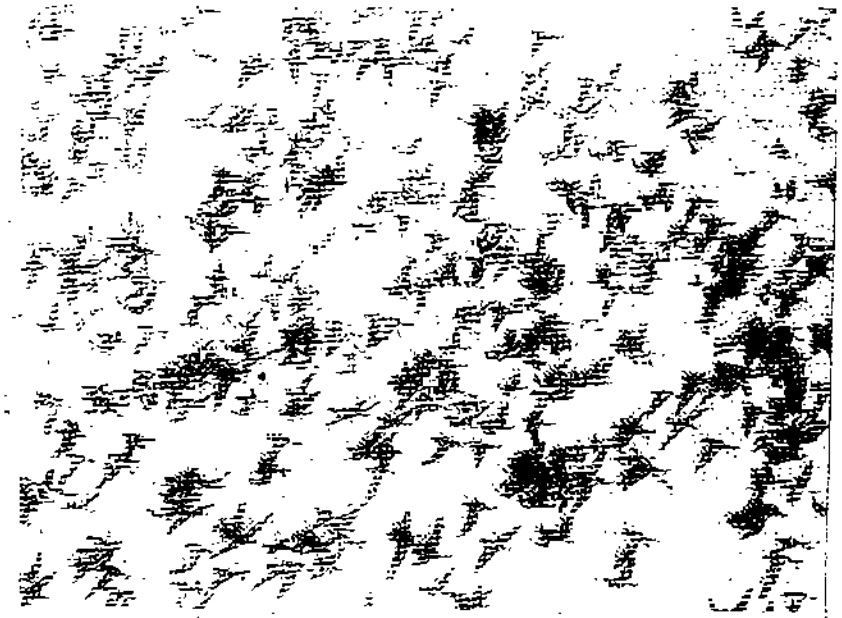


Fig. 13.2 : Migrating geese fill the sky as they travel southwards from their breeding grounds in Canada.

Thus we see that the environment affects behaviour in two main ways. In the immediate sense animals perform behaviour in response to stimuli from the environment while in the long run environment influences gene expression in the development of many behavioural patterns.

Even reflex actions do not develop normally in an unfavorable environment. Newborn chimpanzees were reared in the dark for 40 months and then brought out in light, they showed no eye blink reflex. The reflex appeared only after the chimpanzees had been in the light for about five days. The presence of light (an environmental factor) is necessary for this reflex to develop.

So far we have been discussing the behavioural changes in accordance with changes in environment. Other than these, there are many instances of a permanent relationship between animal behaviour and environment. We all know that certain species of animals are found in particular regions each with a characteristic set of environmental (ecological) conditions. Penguins are found only in Antarctica and associated islands. Sea gulls live only on sea-shores. Some other species such as tiger and spotted deer are widely distributed in the Indian subcontinent but are found only in forested habitats. When a species lives exclusively in a particular environment, a preference is indicated. One of the several reasons for this preference is behavioural compatibility of the concerned social organisation. Group composition, sex ratio all are determined by ecological factors such as forest cover, availability of water, food dispersion, food. You can, therefore, understand how behaviour is related to environment.

Many behavioural acts such as eating food or drinking water are performed basically in response to the stimuli arising inside the body of the concerned animal, nevertheless the basic and the most important function of behaviour is well-being of the individual and continued existence of the species in a given environment. Thus it can be concluded that survival of animals in changing environments is dependant to a great extent upon the flexibility of their behaviour. Life will be in jeopardy if animals did not appropriately respond to environmental stimuli.

An animal may be capable of performing several behavioural acts but each of these acts should be performed at proper time and in a particular environmental situation. A deer can move in and out of a cover or shelter and can graze on grass. But when should it graze, when should it retreat into the cover or shelter depends upon the environmental circumstances. If the deer continues to graze in the open when it is too cold or too hot or when a predator comes in view, it will jeopardize its well-being or even survival. Conversely, if the deer does not come out of shelter or cover to graze even when it is comfortable and safe in the open, it will starve. Atmospheric temperature in this example is an abiotic factor affecting behaviour. Grazing on the other hand is a response to an internal stimulus (feeling of hunger). It is interesting to note that the deer suppresses its response to the internal stimulus when biotic or abiotic factors of environment assume overriding importance. This explains the strong ecological basis of animal behaviour.

Behaviour is the composite and ultimate product of interaction between all such factors, processes and mechanisms just like the collective actions of different parts of a machine. None of these should be viewed in isolation of the others for that will be a misleading over-simplification. It is only for the sake of convenience that we describe each basis separately and not because these are completely independent of others. In the next unit you will learn about innate behaviour and how behavior is shaped through learning and experiences.

13.4 SUMMARY

In this unit you have learnt that:

- Animal behaviour attracted the attention of humans very early in history and still continues to be an interesting field of biology.
- It is important and profitable on many considerations-to study animal behaviour.
- Defining behaviour is not as easy as many people may think, for it depends on the specific objectives of its study and description. However, we can conclude that whatever an animal does is behaviour.
- The physical capacities of an animal determine its behavioural capacities but behaviour is also influenced by several other factor such as genetic and ecological.
- Behaviour is influenced by inheritance of anatomical and physiological characteristics.
- Since behaviour is a means of adjustment of animals to the environment in which they live, it is necessarily directed by ecological factors.
- Behaviour originates and gets organised by physical capabilities of animals which are inherited and is relevant to the environmental needs and therefore cannot be properly understood without taking into consideration all these interacting factors.
- The basic objective of behaviour for the concerned animal is continued survival and wellbeing in a given environmental situation.

13.5 TERMINAL QUESTIONS

1. Why has animal behaviour attracted the attention of humans since early time?

   ....

   ....

   ....

   ....

   ....

2. Define behaviour in your own words.

   ....

   ....

   ....

   ....

   ....

3. Why does behaviour have to be in accordance with the needs of the environment in which the animal lives?

   ....

   ....

   ....

....

....

4. What is the anatomical and physiological basis of behaviour?

....

....

....

....

....

5. Why is it said that behaviour has a genetic basis?

....

....

....

....

....

13.6 ANSWERS

Self-assessment Questions

1. a) i) Ethology
      ii) Comparative psychology
      iii) Adaptation, environment
   b) i) Satisfying mind's curiosity
      ii) Deriving more benefits from livestock and training of pets
      iii) Conservation of endangered species and wildlife management
      iv) Getting advance warning of natural calamities

Terminal Questions

1. Archaeological excavations have provided enough evidence to indicate that animal behaviour attracted man's attention very early in history. Man's pre-historic ancestors studied animal behaviour probably with the objective of saving themselves from dangerous animals and subsequently to domesticate some animals and to derive benefits from them.
2. Behaviour can be defined in several different ways depending upon the specific objectives of its study and description. However, we can define it as the overt activities of animals. In brief, whatever an animal does is behaviour.
3. The basic objective of behaviour is survival and well-being of animals in their environment. Behaviour will fail to achieve this objective if it is not relevant to the specific needs arising in their environment.
4. Animal behaviour depends to a great extent on their physical capacities – body-size, shape of body parts and physiological characteristics. No animal can do anything which its body design and function do not allow.
5. Behaviour as such can not be inherited from parents. But the anatomical and physiological characteristics which have a profound influence on behaviour are inherited by animals from their parents. Thus behaviour has genetic basis too.

UNIT 14 DEVELOPMENT OF BEHAVIOUR

Structure

14.1 INTRODUCTION

In the previous unit you were introduced to the study of animal behaviour. You learnt the definition of behaviour and the importance of its study and how anatomical and physiological attributes of an animal determine its capacity for behaviour.

Research in animal behaviour branched off in several directions. You learnt in the previous unit that some biologists considered behaviour to be genetically determined. Others argued that all behaviour can only be studied in the natural environment while still others strongly advocated that only controlled laboratory conditions can yield authentic results about behaviour. But what causes a particular pattern of behaviour to develop?

You would have heard the repetitive call of the koel as summer approaches and may have wondered why does the koel sing? Do all koels 'know' what they are supposed to sing or does each one learn something from the environment that influences the way it sings? Such questions lead us to study the development of animal behaviour through various approaches.

In this unit we will discuss the role of genes and the environment on the development of behaviour further. You will study that different species of animals have different capacities for behaviour. You will learn about inherited or innate behaviour and how learning and experience shape an animal's behaviour during its lifetime. In recent years biologists have come to regard behaviour as a part of the total adaptational package of an animal, necessary for its survival, therefore, you will read briefly about the evolution and adaptiveness of behaviour. In the next unit you will learn how behaviour is organised at different levels. You will also learn about social behaviour and the need for communications in animals.

Objectives

After studying this unit you should be able to:

- reason why all animals of a species behave, under similar circumstances, in more or less the same way,
- explain how animals learn to behave from their parents and others of their kind,
- discuss and distinguish between innate and learned behaviours,
- describe the adaptive value of behaviour.

14.2 CAUSES OF BEHAVIOUR

Animal behaviour shows a range of variety as great and bewildering as there are sizes, shapes and colours of animals which took generations to describe and classify. No two species behave in a similar manner. For instance, a bird can be recognised by its call or its song, the way it feeds and the way it builds its nest and such behaviour patterns are fixed for each species. No sparrow can build its nest the way a tailor bird does, nor can the sparrow sing like a "koel". Therefore, we can appreciate that anatomical and physiological difference between different species can elicit the very different patterns of behaviour and this difference gets more pronounced as the species get phylogenetically far removed. Apart from this, members of a species also differ from each other in their behaviour.

The enormous variety of behaviour repertoires found in animals that we encounter even in our day to day life makes us wonder why does an animal behave the way it does? Most of you at some time or the other would have seen a house lizard catch an insect on a hot summer night. The lizard approaches the insect slowly and suddenly snaps at the insect and holds it in its mouth. How and why does the lizard do this?

The question **how may** be answered as-the lizard saw the insect, it was hungry, a nerve signal went to the central nervous system which in turn activated the muscles of the leg to move the lizard closer to the insect and the muscles of mouth to catch the insect. The **how** questions are related to the immediate factors and processes that triggered the observed behaviour. These are the **proximate** causes. Proximate causes of a behaviour are observable, immediate and structural (anatomical and physiological), that is, how the structures within the animal operate enabling the animal to behave in certain way.

The answer to the **why** question is that the behaviour took place as it was advantageous or selected during the course of evolution. This is the **ultimate** cause, which is long term, genetic, ecological and evolutionary and leads to better survival and reproduction. The distinction between proximate and ultimate factors can be applied to virtually all behaviour.

The study of the causes of behaviour is therefore, a three fold task. How does the machinery for behaviour work? How does it develop during the individuals life time and how the animals have evolved their machinery for behaviour.

Earlier all animal behaviour traits were classified into either instinctive or learned. These categories were created to acknowledge the differences in the proximate causes of various behaviours. Instincts were claimed to be genetically controlled and learned behaviour was believed to be entirely dependent on experiences or the environment. However, as behavioural science has developed we find that it is difficult to separate the two categories and influence of heredity and environment interact to produce a set of behaviour.

SAQ 1

a) Fill in the blanks:

i) Behaviour has structural and functional basis, and it is important to distinguish between Immediate or .... and the longer-ranging .... causes of a particular behaviour.

ii) Proximate factors in behaviour are brought about by .... and .... systems.

iii) Ultimate factors in behaviour are genetic and ....

b) Explain the two terms instinctive and learned behaviours.

14.3 INNATE BEHAVIOUR

One of the many misconceptions about animal behaviour is that some mysterious source of wisdom directs the animals to behave. There are indeed many instances when animals behave as if they were born with the appropriate responses. Such cases of behaviour are designated as instinctive or innate behaviour. The word 'innate' is of wide and varied connotation and includes several types of behaviour which have one feature in common i.e., **it is not learnt**. Innate behaviour is produced without any mistakes the first time it is performed. It is a programmed, fixed motor pattern and not modified by the environment. This is rather important because the cost of mistakes is high. An example of innate behaviour makes this point clear, kittiwakes are sea birds that nest on narrow ledges near the sea. As soon as the chicks hatch they stand still, for moving about on a narrow ledge could prove fatal. Whereas, the chicks of herring gulls that are born on flat ground move about after hatching. Innate behaviours appear independent of experiences and are often said to be selected during the course of evolution for their adaptive value and since these behaviours appear automatically without variation, they are also energy saving devices. Let us now discuss different categories of 'innate behaviour'.

i) **Taxes**: You have learnt in LSE-09, Unit-15 about taxes; lower organisms, display a variety of automatic and stereotyped reactions to external stimuli (for instance light, temperature, weak electrical current) which certainly can not be learnt by such simple creatures with a very short life span. These responses called taxes, are in the form of orientation of the organism either away from or towards the stimulus and thus resemble the tropic responses of plants. Taxes are regarded as the properties of the organism's inherited receptors and neural connections. Taxes help the lower organisms adjust to their environment.

ii) **Reflexes**: Another category of innate behaviour similar to taxes, are reflexes which are also the function of inherited neural mechanisms. In fact, in many respects it is difficult to make a clear-cut distinction between taxes and reflexes. However, taxes involve orientation of the whole body of the organism while reflexes are responses of only a part of the body like the flexion of a limb in response to a painful blow or the blinking of the eyelids in response to a flash of light. Reflexes in lower organisms are adaptive in function and are relatively invariable but are progressively variable in higher organisms. For instance people living in urban environment have subdued reflexes to various types of sights and noises.

iii) **Instinct**: This is perhaps the most complex of all categories of innate behaviour and also the most difficult to explain. We can define an instinct as a behaviour that appears fully functional from the first time it is performed even though the organism may have had no experience with the cues to which it reacts.

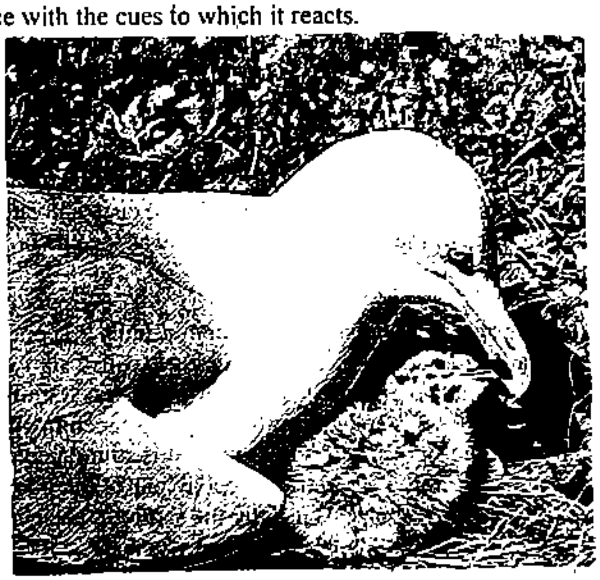


Fig. 14.1: Begging behaviour in chick of herring gull. Pecking by the chick instinctively at the red spot on the herring gull's beak induces it to regurgitate food.

Typically such behaviours are mechanically triggered by a simple cue or a stimulus. A well-cited example is of the garter snake. Experiments showed that a new born garter snake from coastal areas if presented with a slug, darts out its tongue to get the chemical scent. If presented with a cotton swab dipped in slug extract, a similar response is elicited. The snake detects and captures food in this way in nature and the newborn knows what to do without having ever seen another snake capturing food. Chicks of herring gulls instinctively peck at any stick with a red spot on it, as the red patch on the beak is the sign that induces it to peck which elicits a feeding response in the parent bird.

Instinctive behaviour seems to be triggered by rather limited environmental cues. Male stickleback fish in reproductive condition have red bellies and they guard their eggs in the nest. Therefore, if any thing red is placed near their nest, males will attack it aggressively because in breeding condition they recognise and attack other males that also have red bellies (Fig. 14.2).

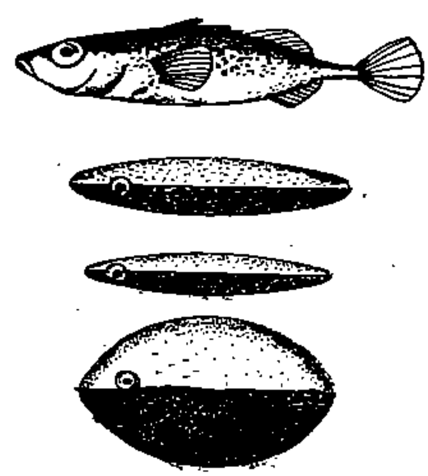


Fig. 14.2: In an experiment the carefully made model of the stickleback (a) does not triggers an attack by the breedin males, while the crudely made models having red bellies are attacked all the time.

A very interesting experiment that popularised the concept of instinct was performed by the two pioneers of ethology, Conrad Lorenz and Niko Tinbergen. They observed that while incubating the eggs a female greylag goose will pull back any egg that has rolled out of the nest, under her neck by extending her bill over it and bending her neck (Fig. 14.3). If the egg is removed away from the goose during her act of retrieval she still completes the act. In an experiment if the egg was replaced by a rounded stone or a larger egg than her own it was still retrieved.

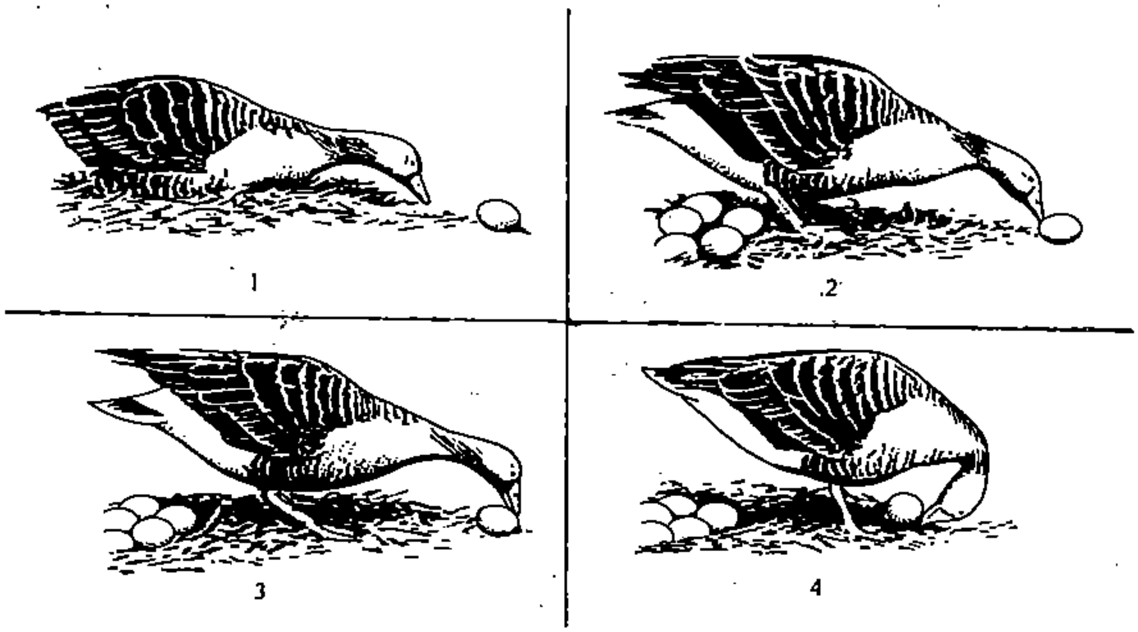


Fig. 14.3: A greylag goose will roll her egg back to her nest and will continue with the FAP even if the egg is removed midway through the process. (after Lorenz and Tinbergen 1938. Zeit Tierpsychol 2:1-29)

Interestingly if the egg is removed during the retrieval act the goose still continued the chin tucking movements. Ethologists call this kind of innate stereotyped behaviour as a **fixed action pattern** (FAP) which is played out to completion, once activated by a simple sensory cue. The presence of the egg outside the nest was the cue or the trigger that released the egg retrieval behaviour.

This stimulus is termed as the **releaser** and since the animal usually responds to some aspect of the releaser (colour, shape, sound etc.) the stimulus is called **sign stimulus**. The hypothetical neural mechanism that receives sensory input from sign stimulus detectors to make the decision to activate the FAP is called **innate releasing mechanism**. FAPs start and stop under the influence of the sign stimulus but unless it is stimulated to stop, the FAP completes its course automatically as the egg retrieval behaviour of the goose shows. There are hundreds of sign stimuli and the response is usually the same for each case for a species. Though a sign stimulus does not invariably provoke its FAP, a lot depends on the animals physiological condition and nervous system. Thus only during the breeding season will the male sticklebacks attack other fish with red bellies. A stimulus may be filtered out by the nervous system. For instance if the animal is hungry food will stimulate feeding behaviour but if the animal sees a predator the food stimulus will become ineffective. Generally stimuli that elicit escape behaviour take precedence over stimuli for food.

Ethologists explain instinctive behaviour as the outcome of complex interactions of internal conditions and external influences. Many aspects of reproductive behaviour in animals, attraction towards an individual of the opposite sex, courtship displays and movements of body parts associated with the act of copulation, are regarded as instinctive behaviour. Reproductive behaviour depends to a great extent on the presence of sex hormones. There will be no response if the level of sex-hormones in the blood is very low. But with the increase in sex-hormones level (this can also be done experimentally) courtship displays and actions associated with copulation start even with minimum of stimulation (environmental factor) such as a passive mate.

Sometimes when the sex-hormone level rises beyond certain limits, the animal gets aroused even at the sight of an individual of the same sex or of a different species or even inanimate dummy of the mate. This indicates the relative roles of internal and external ctors in the origin and development of instinctive behaviour. It also shows that relative effectiveness of one set of factors may be compensated for by the other set of factors. ote that in the above example, increasing level of sex hormone (internal factor) minates to a great extent the need of stimulation (external factor).

ie term 'instinct' had been coined to designate a class or catagory of behaviour which is thought to develop without learning. But with the passage of time and a much better derstanding of various dimensions of behaviour development, the meaning of instinct s undergone considerable change. Present day ethologists generally agree that clear stinction between 'instinctive' and 'learnt' behaviour is neither feasible nor necessary. conclusive test to see if instinctive behaviour can develop without any influence of rning or other external factors seems impossible. Instinctive behaviour is conceived as outcome of complex interactions between internal (inherited) and external (learning, perience) factors.

AQ 2

Indicate whether the given statements are true or false.

i) Taxes involve the orientation of only a part of the body towards a stimulus.
ii) A behaviour can be considered instinctive if it appears fully functional the first time it is elicited.
iii) Some instinctive behaviours can be modified or become more efficient with practice.
iv) Reflexes are not part of innate behaviour but genetically influenced.

Shoving of the eggs of the host out of the nest by the hatchling cuckoo is an example of learned or innate behaviour?

1.4 LEARNING AND EXPERIENCES

the earlier section we concluded that the instinct concept can help explain certain kinds behaviour in animals that appears fully formed even if they are denied all opportunities earn. Behaviour is different from the functioning of machines which work in a fixed l predetermined patterns. A machine is regarded as defective if its functioning varies n slightly from what it has been designed for. It needs repair if its functioning omes inconsistent. Animal behaviour by contrast is not a passive mechanical activity. imals respond innately to certain stimuli but also store information about the various nnections between experience and consequences of their action.

s information storage results in learning, which is the adaptive modification in aviour in response to specific experiences during the individuals lifetime. For instance initial begging for food in a chick is an innate response but later it learns where and en and what kind of food it can get most easily.

animals can alter their behaviour to the extent their inherited capacities (anatomy and siology) permit. But why do animals have to modify their behaviour? Recall reading Unit 13 that the basic objective of behaviour is survival and well-being of the cerned animal. The importance of learning varies from one species to another. For ance a tapeworm is seldom considered clever for it has no need to be so. It lives in an ironment that is conducive to its well being. Its food is easily available and as for ing offspring it has simply to produce thousands of eggs. In contrast monkeys live in nstantly changing and often dangerous environment. They must learn to cope with a iety of complex situations. Unlike tape-worms their life span is long and that gives n enough time to mature and accumulate information.

ng deeper into the mechanisms of learning and behaviour modifications we can gorise the various types of learning.

4.1 Associative Learning

volves the capacity to make connections between a new stimulus and a familiar ulus. One kind of associative learning is **classical conditioning of reflexes**.

Conditioned reflexes are behaviour patterns shown when an animal has learnt to associate a new stimulus with a stimulus that normally elicits a reflex. This was shown by the Russian Physiologist Ivan Pavlov in his classical experiments on conditioning (Fig. 14.4) Pavlov showed that if a hungry dog is shown food, as a reflex reaction it salivates. He then demonstrated that if a bell is rung or a light is shown to the dog just before it was given food, soon the dog would begin to salivate at the sound of the bell or the sight of the light without the stimulus of food. The dog learns to respond to the new stimulus of the bell or light and associates it with food.

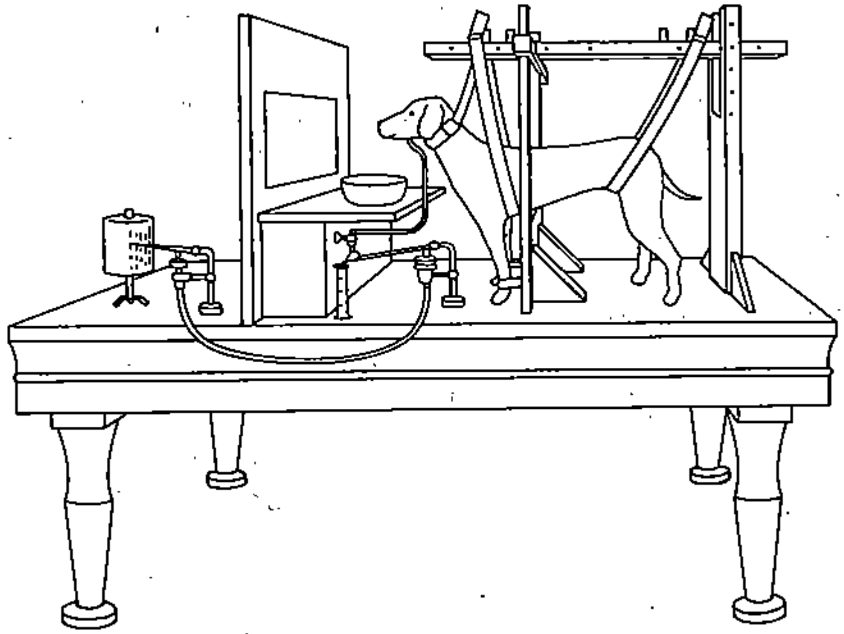


Fig. 14.4: Arrangements for Pavlov's classical experiment on conditioning of reflexes. The dog is restrained on a stand facing a panel, under experimental conditions, well insulated from external disturbances. A tube running from a fistula in its cheek collects the saliva as it is secreted. This drips on a hinged plate which records the intensity and duration of the secretion

B.F. Skinner an American Psychologis devoted his life to the study of instrumental or operant conditioning. The famous Skinner box called after him is basically a problem box in which an animal (in Skinner's experiments a rat) learns by trial and error that pressing a bar in the box releases a food pellet. After a few trials the rat pressed the bar repeatedly and quickly. Skinner believed that on could condition virtually any response and these techniques have been used t regulate internal activities, such as heart rate or brain electrical activity which were earlier thought to be entirely unconsciously regulated.

Pavlov called the food as unconditioned stimulus and salivation is its unconditioned response. The bell is the conditioned stimulus and the salivation in response to the bell or light becomes the conditioned response. A similar conditioned response can be formed to a negative stimulus or punishment in a similar manner. Pavlovian or classical conditioning is very widely observed in animals and it pervades every aspect of normal life in higher animals including humans.

Another form of associative learning is **instrumental conditioning** or learning by **trial and error** where a **reinforcing stimulus** can be either a reward or a punishment and appears after a particular behaviour is performed by chance. If an animal gets a reward for performing a particular behaviour it soon learns that behaviour (Fig. 14.5). Similarly a punishment would deter it from performing that act. Therefore, the correct response is instrumental in providing access to reward. This type of learning has been known to circus trainers for centuries.

Fig. 14.5: The rat examines a metallic lever in a Skinner box and learns to press it after being rewarded with food which acts as a reinforcer.

14.4.2 Extinction and Habituation

In conditioning the behaviour persists for as long as there is persistent reinforcement. If the reinforcing stimulus is removed the learning behaviour is extinguished. This is called **extinction**. However, if the conditioned stimulus is again paired with a reinforcer there is rapid recovery of the original conditioning. At the same time repeated application of a stimulus often results in a decreased responsiveness. This phenomenon is called **habituation**, a form of non-associative learning. Evidence of habituation has been obtained throughout the animal kingdom from coelenterates to humans. The function of habituation is to discriminate between novel and familiar events and to ensure that the animals behaviour is more or less appropriate to each.

All of us see a crude bamboo cross wearing a worn-out shirt with an inverted earthen pot resembling a human head, standing in the crop fields. This is popularly called a scare-crow and has been used to frighten the pest-birds. When first installed in a season, it is quite effective in keeping the birds away, but gradually loses its effectiveness and the birds are sometimes seen sitting on the device itself! Domestic cattle in the villages get panicky at the sight of a moving motor vehicle but those living in towns do not bother about so many vehicles on the roads.

There can be many such examples to prove that repeated exposure to the same situation or repeated stimulation of a particular type leads to a change in the behaviour of the concerned animal.

Extinction differs from habituation as it occurs in relation to previously learned responses whereas, habituation occurs with innate response that have not occurred through any processes of conditioning.

SAQ 3

i) Define 'learning' in simple terms as briefly as you can

....

....

....

....

....

....

....

....

ii) A bird learns to avoid the black and orange caterpillar of the cinnabar moth after one or two times because of its evil taste. What kind of learning is this?

....

....

....

....

....

....

....

....

14.4.3 Latent and Insight Learning

Latent learning refers to an ability to store information about features of the environment which can be used later in guiding the animal through its habitat. This occurs without any

Wolfgang Kohler was interned on the Island of Tenerife between 1913 and 1917 throughout World War I. He studied chimpanzees at the Anthropoid station there and reported his results in a book. The Mentality of Apes published in 1925.

reward or punishment. Experiments have shown that if a mouse is allowed to roam in a complicated maze (without any reward) prior to the actual experiment it will be able to find its way through it with fewer food reinforced learning trials.

Insight learning is a form of reasoning that draws on the results of past experiences to arrive at a solution to a problem. Insight learning has been adequately determined only some primates and birds. A classic example of insight learning was demonstrated by Wolfgang Kohler experiments with chimpanzees. A bunch of bananas was placed in the cage along with boxes and sticks which if used appropriately, would enable the chimpanzee to reach the bananas.

After appearing to study the situation the animal piled up the boxes to make a stand and reached the bananas (Fig. 14.6).

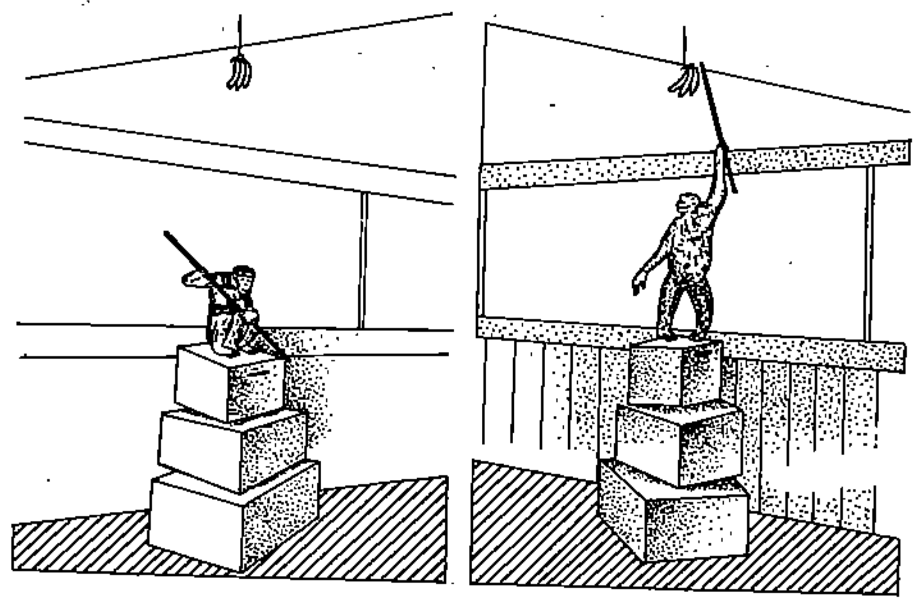


Fig. 14.6: Insight learning shown in captive chimpanzee. The animal could perceive that by climbing up on boxes after piling them one over the other, he could reach the bananas.

14.4.4 Imprinting

We said in Unit 13 that an animal's behaviour like its anatomy and physiology forms during its development through the interactions of its genetic makeup and the environment. In some animals the capacity to learn specific kind of behaviour is pronounced during certain early stages of development. This form of learning is called **imprinting.**

Konrad Lorenz in his famous studies on imprinting showed that goslings (young geese) and ducklings learn to follow their parents and to respond to their signals during a critical period after they hatch. Lorenz found that goslings would follow him as if he was their mother if they saw him rather than their mother during this critical period.

Imprinting has significant long-term consequences. When male goslings or ducklings have matured, they direct their sexual behaviour towards members of whatever species they follow as hatchings. In nature it would obviously be the female of their own species. However, sexually mature birds that had been imprinted on Lorenz directed their courtship behaviour at him.

Imprinting is especially important in many kinds of song birds. If male white crowned sparrows are deafened while very young they will sing disconnected notes but no real song The birds must be able to hear themselves sing in order to learn the songs of their species. Normally they must be exposed to the song of their species at age 3 months though they will not be able to sing till a few months later. A bird that has been isolated after hearing the song at three months age will still sing the song correctly not only the basic song of the species, but also the dilect of the local population whose song it heard (Fig. 14.7). However, this imprinting is specific, for the young birds can learn the song and dilect of their own species not the dilect of other species to which they might be exposed.

Imprinting is thus a kind of learning that takes place during a critical period of time during development and is very closely under genetic constraints.

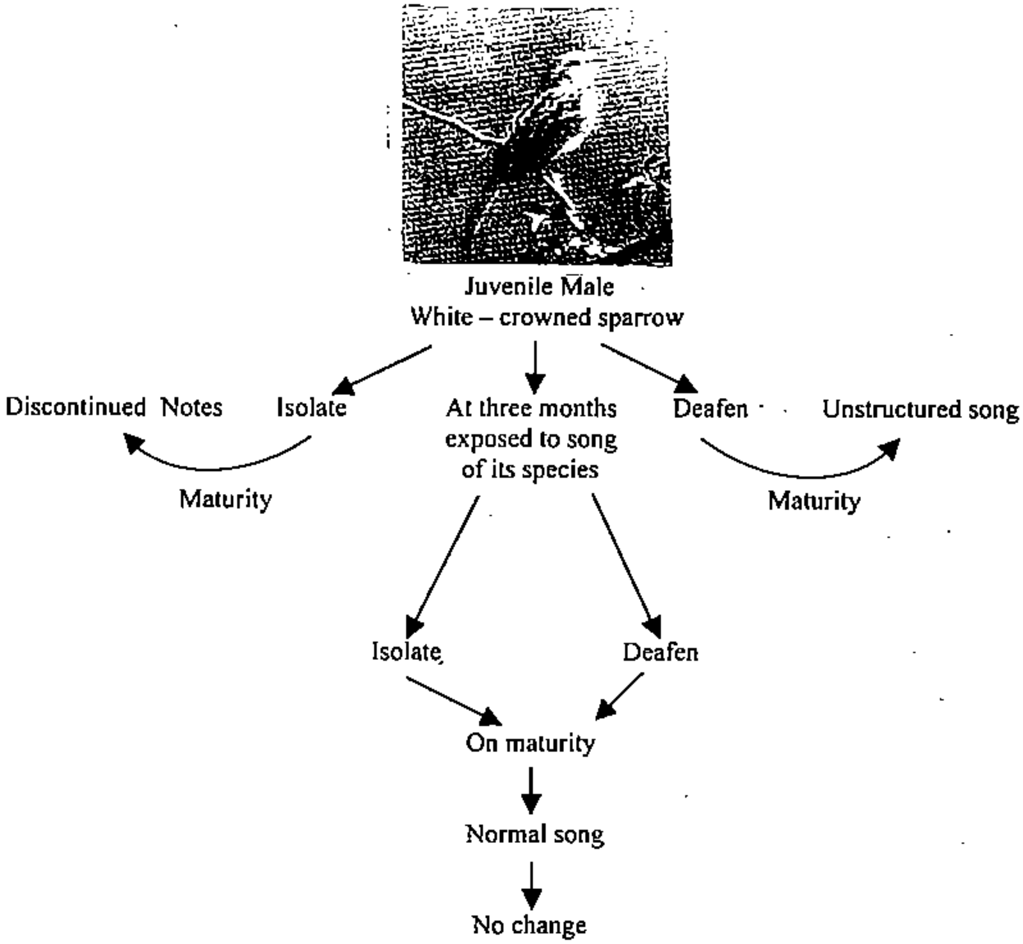


Fig. 14.7: Diagrammatic representation of some results of the work on song development of white-crowned sparrow.

Under natural conditions two important consequenses of imprinting are formation of social attachment to a specific individual – the mother and the eventual recognition of a suitable mate. Imprinting behaviour is also seen in some mammals. Young shrews of a European species hold on to the fur of their mother or sibling forming a line of babies (Fig. 14.8). They become imprinted on the odor of the mother between 5 and 14 days after birth. Before that period baby shrews will form a caravan by even grasping a cloth. However, after day 5 if they are given a substitute mother of another species they will become imprinted on her and even if they are returned to their natural mother after day 15 they will not follow her!

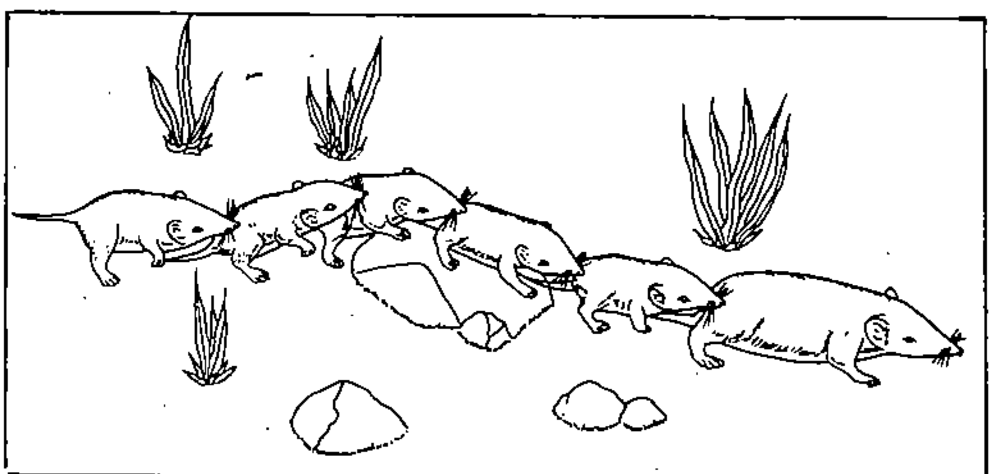


Fig. 14.8: Imprinting in shrews. Young shrews get imprinted on their mother's odor early in life and follow her in a 'caravan'.

SAQ 4

Identify the type of learning that has taken place in the following examples.

a) A lamb follows the keeper who reared it on the bottle even after being weaned and after joining the flock.
b) A chimpanzee uses a stick to rake in a banana from outside its cage.
c) A loud cracker sound disturbs the pet dog but daily low flying planes over the house make no impact.

14.5 EVOLUTION OF BEHAVIOUR

That behaviour can be shaped and modified by evolution in a manner similar to anatomical and physiologica traits, is the subject of central importance in Darwin's Origin of Species. His concepts were further elaborated by the works of Konrad Lorenz, Karl Von Frish and Niko Timbergen for which they received the Nobel prize of 1973 and since then have been carried forward by other ethologists.

Until now we were concerned with the proximate differences between instinctive and learned behaviours. Now let us look at the ultimate or evolutionary basis of behaviours. We find that there is endless variety in the ways animals behave and those that possess suitable structures and behaviour patterns are the ones that survive. The process of natural selection forces all species to adapt themselves to their changing environments and the species keep expanding their range and invading new habitats. This process is endless and species keep on evolving. Evidence that animal structures have evolved has been provided by fossil records and it is often said that behaviour leaves no evidences hence it is difficult to prove that evolution of behaviour has taken place.

But this is only partially true. Fossil records often provide clues to behaviour patterns. For example, the *Archeopteryx* had wings but no keel suggesting that it glided rather than flew.

Another approach to the study of evolution of behaviour is by comparing fossil records with present day species. For example, the role of the head ornaments of dinosaurs can be inferred by comparing the behaviour of deer and certain beetles that possess head ornaments.

There is also a great deal of indirect evidence that supports the evolution of behaviour. Experiments have shown that particular genes or their mutations affect particular bits of behaviour. You have studied in Unit 13 in the subsection Genetic basis of behaviour that cross breeding experiments have linked behaviour to heredity (Refer to the nest building behaviour of crossbred species of lovebirds). Evidently mixing up genes mixed up the behaviour. That natural selection acts on behaviour in the way predicted by evolutionary theory is evidenced by breeding experiments of domestic animals. Selective breeding for behavioural traits has gone on over the centuries. Dogs have been bred for aggressiveness, speed, herding, various kinds of hunting and so forth. Another approach is to see how survival is affected when some kind of behaviour and its effect is eliminated. For if behaviour is a product of natural selection then its diminution should affect the survival and reproductive success. Experiments showed that gulls that removed the egg shells from their nests had a better survival rate because conspicuous egg shells increase the likelihood that the nest would be robbed by foxes.

Inspite of several such examples we find that it is difficult to say as to how a particular behaviour evolved, for behaviour is very flexible. While certain behaviour patterns like display are fixed within a species other aspects of behaviour may be flexible. Apart from this there may be a strong role of learning and experience in the particular behaviour. Animals can because of their behaviour move to different places, choose new foods and modify their environment in several ways. Any such action changes the selective forces acting on them. Let us explain this a bit further.

An animal may eat only blue berries, but one year there is a scarcity of blue berries. In such a situation only those with a behaviour flexible enough to switch to eating say, red berries may be the ones to survive. Over a series of such disasters, those who learn to eat alternate food will be favoured over slow learners till ultimately the survivers will not have to learn to eat red berries but will do so on first encounter as an instinct. Such an example indicates the complex and fascinating interplay between evolution and behaviour.

SAQ 5

a) What do you understand by the term evolution of behaviour? Explain briefly.

....

....

....

....

b) Indicate whether the statements given are true or false.

   i) In animals today we see the combination of structural adaptations and refined behavioural patterns, developed through many generations that enable them to survive.
   ii) Crossbreeding experiments do not prove that behaviour can be changed through natural selection.
   iii) Fossil records are totally lacking for evolution of behaviour, therefore no conclusive evidence for evolution of behaviour exists.

14.6 ADAPTIVENESS OF BEHAVIOUR

As no animal can change its physical characteristics during its life time, change or modification of behaviour is the only means of continued adjustment with the ever changing environment. Behaviour of an individual can vary or change in response to environmental demands only to a certain extent.

Those individuals or groups whose behavioural characteristics are most appropriate for a given environment survive in large percentage and also live longer than others. Such individuals or groups leave more numerous offspring than the less suitable. Thus the population is perpetually dominated by such types who are behaviourally (and physically of course) most in tune with a given environment or in other words the best 'adapted' ones.

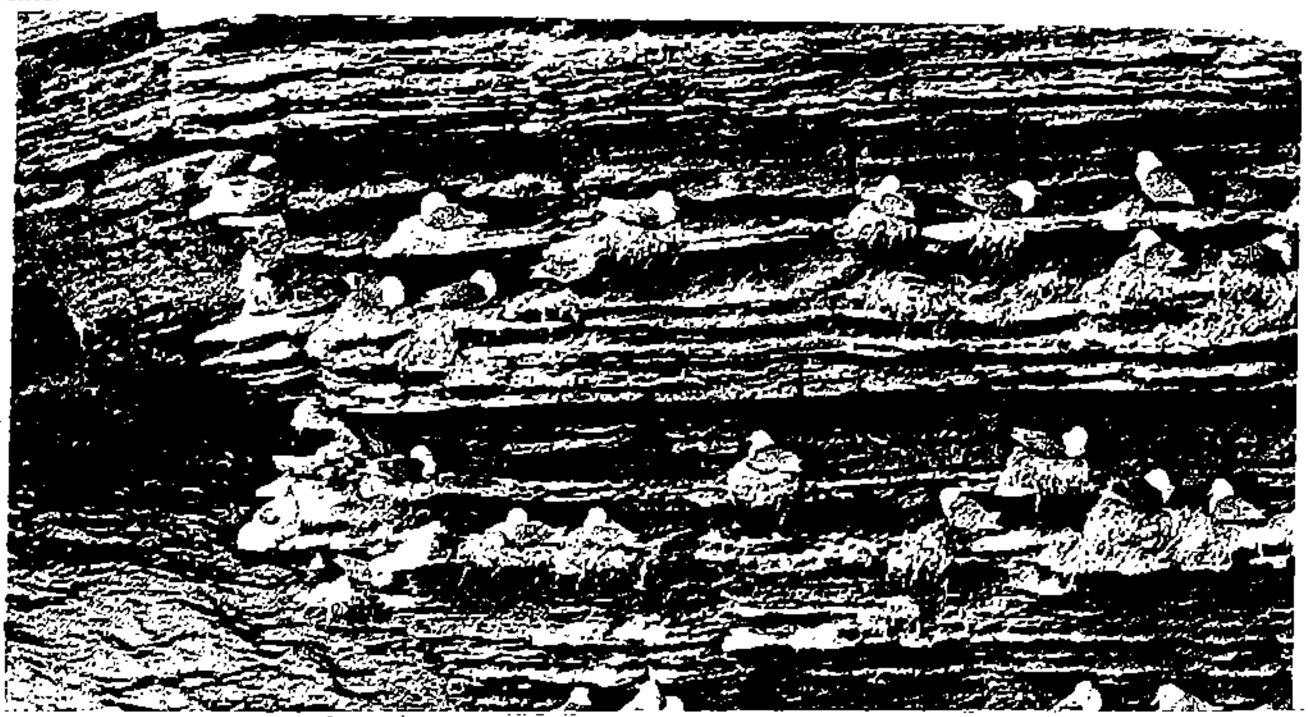


Fig. 14.9 : Cliff nesting habitat of Kittiwake gulls. Kittiwakes have clawed feet that help them to cling to the narrowest of cliff ledges.

How do we know whether a particular behaviour is adaptive i.e., it increases the fitness of the individual or the species as a whole? Behavioural ecologists or adaptationists use several methods to explain this by additional observations by experiments or comparing data from related species that occupy different habitats. A classic example using the comparative approach was a study of nesting habits of Kittiwakes (*Rissa tridactyla*) that live on cliff ledges and those of ground nesting gulls. As a result of predator pressure, Kittiwakes retain some of the features of ground-nesting gulls and seem to have lost many of the antipredator adaptations. For example, they fail to camouflage the nest, they rarely give alarm calls and they do not mob predators (ground gulls attack any predator that approaches their nests collectively, a behaviour known as mobbing). In fact Kittiwakes have special adaptations for cliff-nesting (Fig. 14.9) thus, comparison of closely related species living in different habitats can often reveal those aspects of behaviour which are particularly important in adapting the animal to its environment. You will study adaptive behaviour in more detail in the last unit (Unit-16) of this block.

SAQ 6

Why is behavioural adaptation the only means of continued adjustment with the ever changing environment?

....

....

....

....

14.7 SUMMARY

In this unit you have learnt that:

- Basic questions about behaviour can be put in two categories. **How** genetic, developmental and physiological mechanisms cause an individual to behave in particular ways, and **why** do animals behave in a particular way through out evolution.
- As a consequence of differences in anatomical and physiological characteristics, species have differential capacities for behaviour.
- If a behavioural pattern develops in an animal apparently without learning (either from others or by trial and error) it is designated as 'innate'. But it should be noted that behaviour neither develops exclusively within the animal nor exclusively under the influence external environmental factors.
- Innate behaviour in simplest organisms (protozoa, coelenterata etc.) develops as 'taxes' while 'reflexes' are present in a wide variety of organisms both lower and higher. 'Instinctive' behaviour is also observed in diverse groups of animals from honey bees to birds and mammals.
- Learning leads to appropriate alterations in behaviour to the extent anatomical and physiological characteristics permit (capacity). This alteration helps animals keep in tune with the ever-changing environment.
- As anatomical and physiological changes in accordance with environmental changes can not take place during the life time of individuals, alteration of behaviour is the only means of adaptation of individuals to changing environment.

14.8 TERMINAL QUESTIONS

1. Give two examples of FAPs?

....

....

....

2. Explain what is meant by the term 'innate behaviour'.

....

....

....

....

3. Differentiate between 'taxes' and 'reflexes'.

....

....

....

4. Define the term 'instinct' and explain how instinctive behaviour develops.

....

....

....

....

5. What is the ecological advantage of an animal's ability to slightly alter its behaviour through learning?

....

....

6. Can animals maintain conformity with the changing environment in which they live, without being able to alter their behaviour?

....

....

....

7. What do you understand by 'adaptiveness of behaviour'?

....

....

....

8. Summarise as briefly as you can, the phenomenon of 'evolution of behaviour'.

....

....

....

14.9 ANSWERS

Self-assessment Questions

1. a) i) proximate, ultimate.
   ii) anatomical, physiological.
   iii) ecological.
   b) Instinctive behaviour is sterotyped, genetically programmed behaviour, learning may or may not be involved. While learnt behaviour is behaviour that is modified by experience.
2. a) i) F, ii) T, iii) T, iv) F
   b) Innate Behaviour
3. i) Storage, somewhere in the individual's nervous system (brain in case of higher animals) of all observations and experiences, which may lead to alteration of behaviour in the best interest of the concerned animals, is called learning.
   ii) conditioned learning.
4. a) imprinting
   b) insight
   c) habituation
5. a) Gradual changes in behaviour, brought about by natural selection, generation after generation, are called evolution of behaviour.
   b) i) T, ii) F, iii) F.
6. Because anatomical and physiological characters of a species do not change but the behaviour can be modified gradually to suit the changing environment.

Terminal Questions

1. i) Yawning in humans. No matter who is yawning they all last for about 6 seconds and are different to stop midway and are infectious. Yawing releases yawns in other people if they see or even hear a yawn!
   ii) Food begging behaviour in baby gulls is a FAP that is released by seeing the red dot at the end of the beak of the parent herring gull.
2. When behaviour appears to originate and develop independant of learning, it is designated as 'innate'.
3. A clear cut distinction between 'taxes' and 'reflexes' is very difficult if not impossible. However, taxes usually involve orientation of the whole body of an organism while reflexes are responses of only a part of the body.
4. The term 'instinct' is used for a category of behaviour which equips the animal with ready made adaptive responses, without the direct involvement of learning. Instincts are regarded as the outcome of complex interactions of internal conditions and external influences which have become a behavioural characteristic of a species.
5. Learning abilities provide the animal an opportunity for making appropriate alternations in its behaviour during its life time.
6. No, animals will not be able to remain in tune with a regularly changing environment if they do not alter their behaviour accordingly.
7. Establishment of appropriate behavioural responses in the population of a species dwelling in a particular environment is the adaptiveness of behaviour.
8. The regular process of adaptive changes in the behaviour of a species brought about by the process of natural selection is evolution of behaviour.

UNIT 15 ORGANISATION OF BEHAVIOUR

Structure

15.1 INTRODUCTION

In the earlier two units on behaviour you learnt that animal behaviour can be studied using different approaches. Ethologists focus on the mechanisms of behaviour (the proximate causes) as well as on the function and evolution of behaviour (ultimate causes). You are aware that the development of a behaviour pattern depends on an interaction between the organism and its environment and the response or behaviour of the animal to any external or internal stimuli depends on its anatomical and physiological ability.

Most of the behaviour performed by animals is complex. Scientists that study behaviour often look for simple units or patterns of behaviour that they hope will reveal the essential features of the more complex activities. For example, social behaviour or courtship and mating behaviour are the ultimate outcome of many smaller behaviour acts combined together and organised in a systemic way.

In this unit you will learn how different behaviour are organised at different level, from moment to moment, over the course of the day, over weeks or a breeding season or the whole year. We will briefly discuss biological rhythms, and migratory behaviour in animals. Migratory behaviour is an example of spatial organisation of behaviour.

Some animals have very little contact with members of their own kind but in some species the integration and communication with others is apparent. We will discuss the various means of communication and the organisation of animal societies through cooperative interaction of the members of the same species. In this unit our emphasis is still on how an animal behaves as it does. In the next unit on adaptive behaviour we focus more on why an animal behaves as it does.

Objectives

After studying this unit you will be able to:

- define different levels at which behaviour is organised,
- describe the short term and long term mechanisms for organising behaviour in vertebrates,
- give examples of biological rhythms and clock in vertebrates,
- explain the migratory behaviour of certain species, and
- explain the means of communication and social organisation in vertebrates.

15.2 ORGANISING MECHANISMS

We can observe animal behaviour at different levels. For instance, when we study social behaviour or courtship and mating behaviour, we observe behaviour at the level of population of a species. To understand the behaviour of a population one would have to observe small groups i.e. courtship behaviour of a group in that species. This group behaviour of course is made up of the behaviour of individuals.

We already know that much of what animals do can be analysed in terms of specific short acts that put together form behaviour patterns that are often species specific and are performed in response to stimuli received from the internal and external environment. Each short act of a behaviour pattern is organised by different components which are:

1) anatomical
2) neurological
3) physiological

Thus if we draw a flow chart to see how a particular behaviour is organised it will look something like the following:

Population
↑
Group
↑
Individuals
↑
Units
↑
Patterns
↑
Acts
↑
Components
(anatomical, neurological, physiological)

15.2.1 Neuronal Command Centres

An animal is constantly receiving stimuli or cues from the environment. If it were to respond to all of them there would be no behaviour only chaos. Some stimuli have to be suppressed so that the individual is able to carry out an act in complete form without interference from other competing behaviour. For instance, escape pattern of behaviour takes precedence over all possible acts. The neural activity in the act of escape suppresses all other activity.

The adaptive significance of filtering mechanisms for stimuli is easy to understand but how is the nervous system organised so that conflicts in responses are avoided? A major hypothesis to explain the organisation of this behaviour is that animal nervous system is endowed with **neuronal command centres**. You are familiar with innate releasing mechanisms, and song pattern systems, etc., (refer to previous unit). These are neuronal command centres or units within the nervous system which are responsible for activating a particular response. These various centres are in contact with each other and can inhibit one another. Thus an animal can avoid conflict when carrying out a particular behaviour. The inhibition of competing command centres is the basis of the animal to do one thing at a time in a sequence rather than simultaneously.

15.2.2 Rhythmic Behaviour

The neuronal command centres not only communicate with one another but also receive inputs from a biological clock that helps animals to change their behaviour in relation to the time of the day, month or year. Thus the animal nervous system produces repeated cycles of behaviour. You have learnt in Unit-15 of LSE-09 that activities of animals show biorhythms and an internal clock or internal anticipatory systems have evolved in animals to predict periodic changes in the external environment and prepare for them. These cyclic control mechanisms give rise to daily rhythms, monthly cycles, or annual rhythms. For instance, activities of many marine animals that live along the shore are linked to the cycle of tides; many animals migrate to and from breeding grounds twice a year and several have annual cycles of hibernation. You would recall that biological rhythms may be endogenous i.e. regulated internally by biological clocks capable of detecting passage of time over a 24 hour period or circadian (cira = approximately, diem = day) or over a period of 365 days circannual (cira = approximately, annum = year). These rhythms may also be exogenous i.e. controlled by environmental cues or they may be both, i.e., endo and exogenous clocks interact and are reset by environmental cues.

Circadian Rhythms

The most widespread and well understood of biorhythms is the circadian rhythm, cycles that persist even under constant conditions. Most of the early studies regarding circadian rhythms were done with insects (Refer to Unit 15, LSE-09) and the general picture that emerges is that insect brains contain a major clock mechanism which is usually set or entrained by signals received from the insect eyes or photoreceptors and in turn the clock sends messages to other regions of the brain to drive the various circadian rhythms.

A broadly similar pattern is observed in vertebrates. For example, if the suprachiasmatic nuclei (SCN) (a pair of cell clusters in the hypothalamus that receives inputs from the nerve fibres originating in the retina), in the brain of hamsters and Norway rats is damaged, they lose circadian rhythms in a wide variety of activities such as heart rate, hormone secretion, locomotion and feeding behaviours. If these animals received foetal SCN transplants they recovered their rhythmic activities about 40% of the time. If they received tissue transplants from other parts of the brain they did not get back their rhythmic activities. This suggests that SCN contains a master clock mechanism in these animals. The SCN contains cells that respond to stimulation by optic nerve fibres that give it information about light and darkness. The chemical activity in these cells sends signals to pineal gland which secretes a hormone melatonin in a rhythmic fashion which in turn imposes a corresponding rhythm on the animals physiological activity. The secretions of the pineal depend on the photoperiod the animal has experienced over the last few days. This ability enables the pineal to adapt to seasonal changes in day length, thereby helping the animal to adjust its daily schedule. The endogenous or environment independent clock helps the animal to adjust its behavioural and physiological cycles without having to constantly check the environment. At the same time the environment dependent elements permit animals to fine tune their daily cycles.

Similarly, the pineal gland is thought to play a role in the timing system of rats, birds and lizards. For example a rat will become active at the right time at night but will adjust to changes in day length as summer changes to winter. The pineal of anole (a small lizard) can be removed and maintained in a container for upto a week. In constant darkness, the isolated pineal gland is still able to secrete the hormone melatonin on a daily cycle and is not affected by temperature differences.

Many of our own physiological processes exhibit circadian rhythms, our body temperature is highest at 4-5 pm and lowest (by almost a degree) between 4-5 am. The secretion of hormones, heart rate, blood pressure, rate of excretion of sodium and potassium; all show circadian peaks and lows.

Circannual Rhythms

A **circannual rhythm** would produce an annual cycle of behavioural events even in the absence of any environment cues correlated with seasonal changes. A definite demonstration of an annual clock was found in golden – mantled ground squirrels of North America. In nature this squirrel spends late fall and winter hibernating in an underground chamber. In an experiment five members of this species were born in captivity and blinded. They were kept in constant darkness throughout their lives under constant temperature and given adequate food. Throughout their lives year after year they entered hibernation at the same time as the squirrels living in the wild.

However, under natural conditions environmental conditions entrain circadian and circannual clocks to produce rhythmic behaviour that matches the environmental conditions such as the time of sunrise and sunset or the onset of rainy season or winter in a given year. The behaviour in all such cases is fine-tuned to environment cues and varies from species to species according to their special needs. You would have noticed that after winter as the temperature rises, lizards come out of hibernation and prepare to breed. If in a particular year the winter is rather short the lizards emerge out of their hibernation earlier too. Experiments on the green anole of Southern United States have revealed that transition from winter hibernation to reproductive activity is highly dependent on environmental temperature. These lizards have temperature receptors that cause the pituitary gland to release gonadotropic hormones that stimulate the growth of gonads. A series of cold days delay the start of reproduction and warmer days end the dormancy period sooner. Therefore, anoles start their reproductive activity when food i.e. insects are plentiful.

Lunar cycles

Daily and annual are not the only behaviour rhythms in animals. There are some species whose biological rhythms reflect the lunar cycle such as 29.5 days of moonlight intensity or the 14.8 day cycle of tides. The grunion, a small pelagic fish that lives off the Pacific coast of United States, mates and lays eggs from April to June at high tide on nights immediately following the night with a full moon or a new moon. At high tide the fish squirm on the beach lay eggs and sperms in the sand and returns to the sea in the next wave. After 15 days when the next tide reaches the beach, the fry are uncovered and swept out to sea.

The behaviour of banner tail kangaroo rat is also temporarily regulated by the phase of the moon. Laboratory experiments suggest that the behaviour is not regulated by an internal clock but by direct monitoring of moonlight as banner tail kangaroo rats forage in complete darkness.

15.2.3 Hormones as Organisers of Behaviour

The environmental cues received by the animals often exert their effect by changing the hormonal state of the animal particularly with respect to its reproductive cycle. Hormones often act as fine tuners of the neural command centres that are stimulated by environmental stimuli to enable the animal to behave differently under different conditions. You would recall that hormones secreted by white crowned sparrow affect the development of gonads which in turn release more hormones that affect the bird's brain and behaviour. Hormones promote reproduction at times when the environment, social and internal physiological conditions are most favourable.

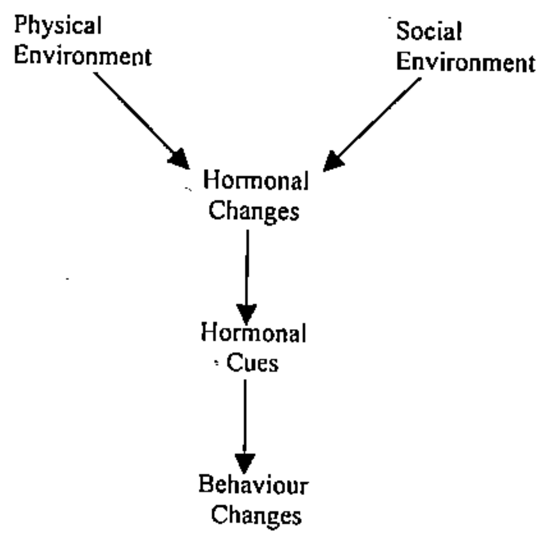


Fig. 15.1: Environmental cues trigger internal hormonal changes necessary to change behaviour.

The precise role played by hormones in affecting behavioural change varies from species to species. For instance, male sexual behaviour in some animals may or may not depend on the testosterone circulating in the blood. Let us take the example of the anole again. The male green anole has rising levels of testosterone when it makes mature sperms, defends its territory and mates with females. On the other hand, when red striped garter snakes emerge out of their hibernation, they emerge enmass and engage in sexual activity. The males are mostly nonaggressive and do not fight with other males for the receptive females. Studies show that these nonaggressive males have almost no circulating testosterone in their blood. Yet they have no trouble in mating. Their mating behaviour depends on temperature signals from the environment which are detected by the pineal gland. Removal of pineal gland before hibernation produces male snakes that are unable to court the following spring. But sperm production does depend on levels of testosterone in males in the fall before hibernation as the sperms are produced in fall and stored internally over the winter in preparation for the spring mating activity.

SAQ 1

i) How do animals avoid reacting to conflicting stimuli reaching at the same time?

....

....

ii) Fill in the blanks:

a) Bats showing daily torpor in extremely unfavourable climate conditions is an example of ....rhythm.

b) A noctural animal that stops hunting and begins to go back to its den at daybreak is showing .... rhythm.

c) Migration of birds causes changes in their body weight, gonad size etc. This is under the influence of .... rhythm.

15.3 MIGRATION

In the earlier section we discussed that the 24 hour periodicity of light and darkness places restrictions on the time at which the animal can exploit the resources in its environment. In adapting to this external periodicity most animals exhibit endogenously timed daily cycles of activity. Similarly lunar cycles restrict the times of foraging in many marine animals. Apart from the daily and monthly rhythms are the seasonal changes causing the annual cycles. Many animals have adapted to the seasonal changes in climate either by changing their behaviour as the seasons chang or by **migrating** regularly between different environments, leaving a particular ar when the season becomes inhospitable.

The regular annual and lunar movements of animals either as individuals or as populations are normally considered as migration. Migrations may be part of exploratory movements or colonisation of new habitats. Exploratory migration is common in young vertebrates and may be responsible for successive colonisation when ecological conditions are favourable.

Periodic migrations occur in a variety of species in response to changes in environmental condition. You all must have heard of the swarms of locusts that descend on crops periodically. Locust *Schistocerca gregaria* live in seasonally arid areas and wherever there is overcrowding the insects may develop into one of three adult types **gregaria** that aggregate into dense swarms and fly into areas of low barometric pressure where they are most likely to encounter rain. Wet conditions stop the migration and the locusts mate and produce eggs. Locust swarms show seasonal cycles but the individuals are not able to complete the circuit as the generation time is too small. Therefore, their movement is not true migration.

Some seasonal migrants initiate their migration on the basis of a circannual rhythm rather than in response to changes in environmental conditions. These are usually **return migrations** in which the animal returns back to a habitat that has been previously visited. This is the most widely recognised type of migration and some of the best observed examples are in birds, bats, salmon, eels, whales, antelopes.

Some migrations involve astonishing feats of endurance and navigation. You all must have heard about the Siberian cranes that fly thousands of miles from Baikal over land and sea to pass the winter in the wetlands of Bharatpur each year. The main migratory route of birds to India runs down the Brahamaputra Valley, Indus Valley and there is evidence that some fly straight over the Himalayas and Hindukush over 9000 meters.

The arctic tern holds the record for the longest migration on the planet. It flies as long as 35,400 kilometres per year from Arctic to Antarctic and back.

Fig. 15.2: Migratory cranes in Keoladeo National Park, Bharatpur.

To make such migratory trips, birds require complex navigational skills. The barn swallow (*Hirundo rustica*) a bird that, even fully grown is only the size of a man's clenched fist, flies an incredible 10,000 kilometer from its breed-grounds in Europe, Asia and North America to spend the winter in the Southern Hemisphere. Let us follow the migratory route of the swallow from England to South Africa.

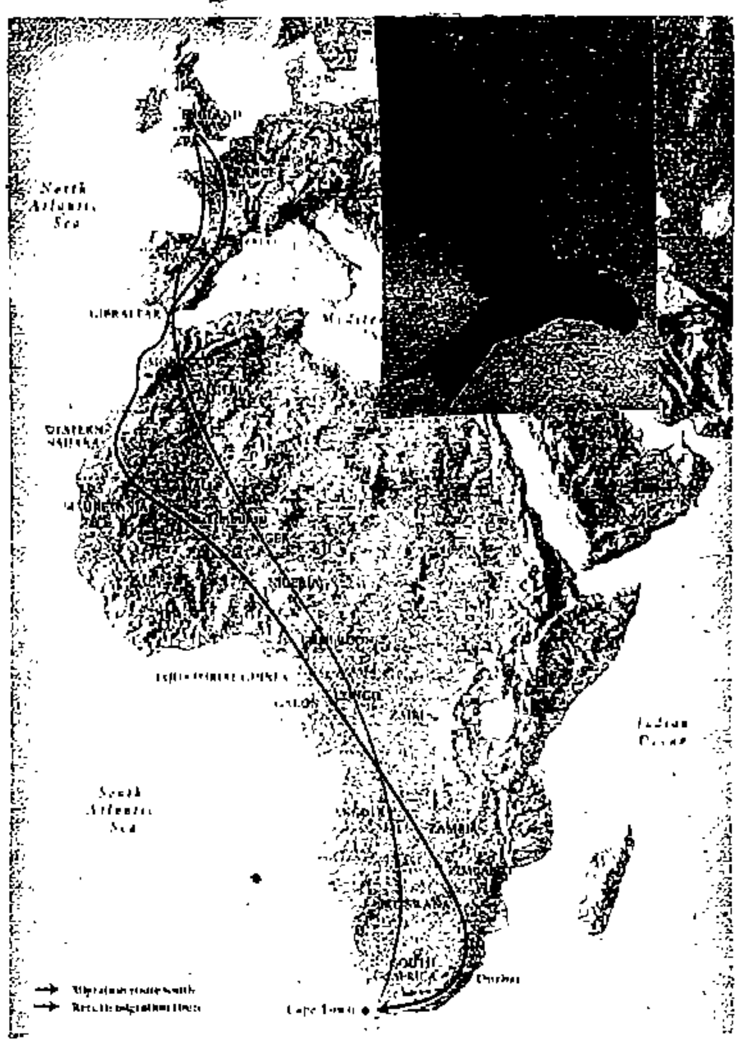


Fig. 15.3: Migratory route of the English barn swallow *Hirundo rustica*. (adapted from Nigel Marvin – Incredible journeys)

In mid-September as the days get shorter the annual calendar within their bodies signals them to prepare for their annual migration. Fig. 15.3 shows their migration South and the return route. The birds use the sun compass to calculate their position. The most gruelling part of their journey is over the Sahara desert. The migrating birds must cross it as swiftly as possible for there is little opportunity to stop and feed here. The end of the journey comes in the southern most tip of Africa (Fig. 15.3) from where the internal clock makes them restless to return in February.

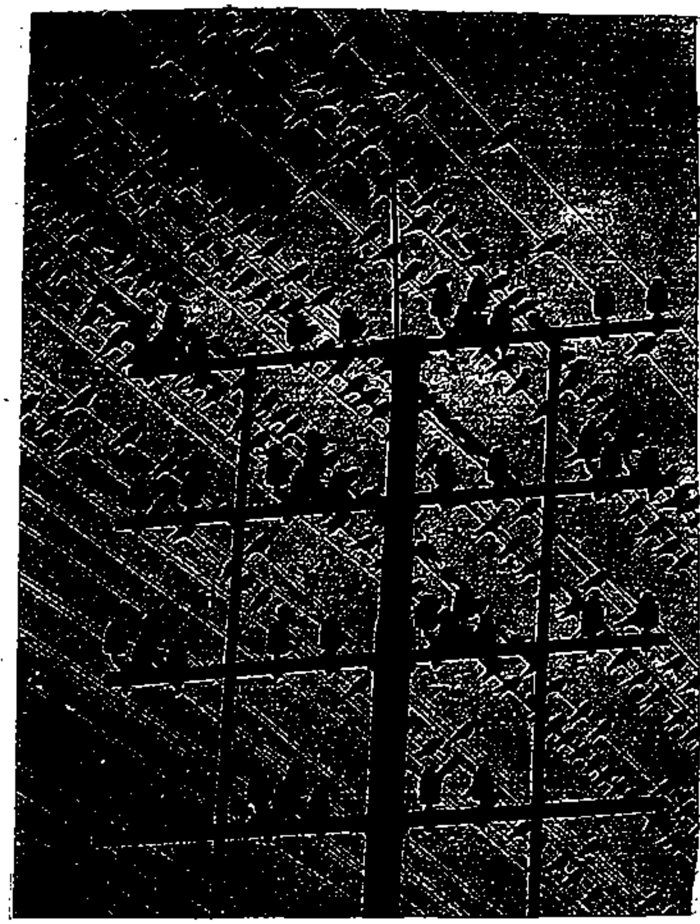


Fig. 15.4: Barn swallows flocking in South Africa before making their return journey.

Long distance migrations also occur in other vertebrate groups. Salmon which spends most of their lives in the sea find the rivers where they were born as they return to spawn, by discriminating the specific olfactory characteristic of that river. Migratory reptiles, especially turtles travel several thousand kilometre to deposit their eggs usually in the same beach sands each year.

The western diamond back rattle snake's migratory movements have been tracked through satellites using data from transmitters, tiny enough to be inserted under the skin of a snake. Scientists have shown that these reptiles navigated to precise destinations, one female was found in the same nest for three summers in succession every autum she travelled 4 km back from the feeding grounds to a favoured site for hibernation where she joined other of her kind in the crevices of rocks.

Whales swim thousands of kilometres to return to the same traditional mating and calving areas. For instance the grey whale (*Eschrichtius robustus*) covers a distance of more than 16,000 km each year. Their journey spans three seas and takes them up and down the whole of the Pacific coast of North America (Fig. 15.5). The breeding grounds are in Mexican water. The calves travel with their mother on their first migrating trip Northwards, tasting the chemical signature of the river systems and estuaries that they pass so that they are able to recognise them. The whales also scan the coast line for visual landmarks and listen to the surf pounding on the shores. The whales use all these basic methods of navigation. The grey whales make their annual migrations because their vulnerable babies need to spend the first few months of their lives in warm sheltered waters. But these waters contain few nutrients and food is scarce. To sustain themselves and eat to grow so huge; they have no choice but to go to the high altitude seas each year where food is plentiful.

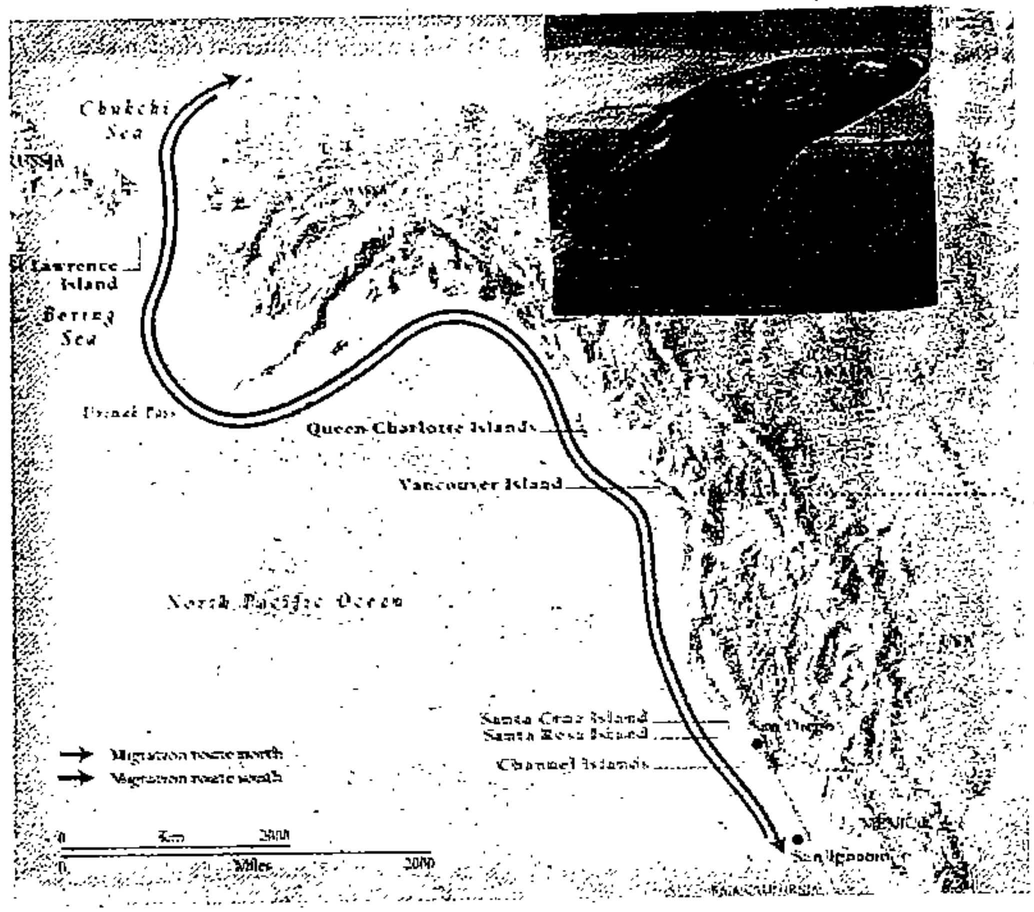


Fig. 15.5: Migratory route of the Grey whale along the coast of North West America. (adapted from Nigel Marvin – Incredible Journeys)

Fresh water eels (*Anguilla*) breed only once in a lifetime. They are wide spread in countries that border the North Atlantic (Europe and North America) and Western Pacific Ocean, from Japan through South East Asia and the Pacific Islands to Australia and New Zealand, then West ward through the Indian Ocean to Madagascar and East Africa. These fresh water eels travel thousands of kilometres to reach their marine breeding grounds and then migrate back to the fresh water river and lakes as elvers. The journey of the European fresh water eels was mapped in the early 1900s and their spawning ground was found in the Sargasso Sea a region of the South West Atlantic in or near the Bermuda triangle. The eggs are shed into the open, deep sea waters where they drift with the current and hatch into flat leaf like larval called **leptocephali** (Fig. 15.6 a). They drift for 1 to 3 years or more, growing slowly into small eels or elvers (Fig. 15.6 d). The young elvers take a year or two to reach American shores and are often three years old by the time they reach European rivers. The movement between freshwater and saltwater involves a special migratory adaptation – a physiological shift in kidney function without which the dramatic change in environment would cause bodily harm. Subsequent findings revealed that all sixteen species of *Anguilla* breed in deep warm water of the sea and all return to the fresh water where they live and mature for upto 15 years before returning back to the sea to spawn and die.

Animal migration remains a mystery still. How do animals know when it is time to migrate? How do they manage to come back to the same place year after year? How do they travel to certain rivers, beaches without mistakes even through they have never seen the place after birth? (Remember the elver that reach the fresh water rivers after hatching in the sea.)

There is evidence that internal factors control not only the onset of migratory activity but also its pattern. Many species have migrating routes characteristic of particular breeding populations. The circannual clock also tells them when to moult, when to begin and stop migrating and when to start breeding. Many migrants develop large appetites at the beginning of the migrating season causing them to increase their body weight and store of fat. This overwhelming desire to eat is induced by the hormones secreted by the pituitary gland. This gland as you know also controls the development of sex glands that produce sex hormones and reproductive cells. In this manner the pituitary guides the animal towards migration and reproduction in interconnected rhythms. Once the internal signal prepares the animal physically for migration, the animal senses external environmental cues and migration begins. In non migrating animals these inner changes do not occur.

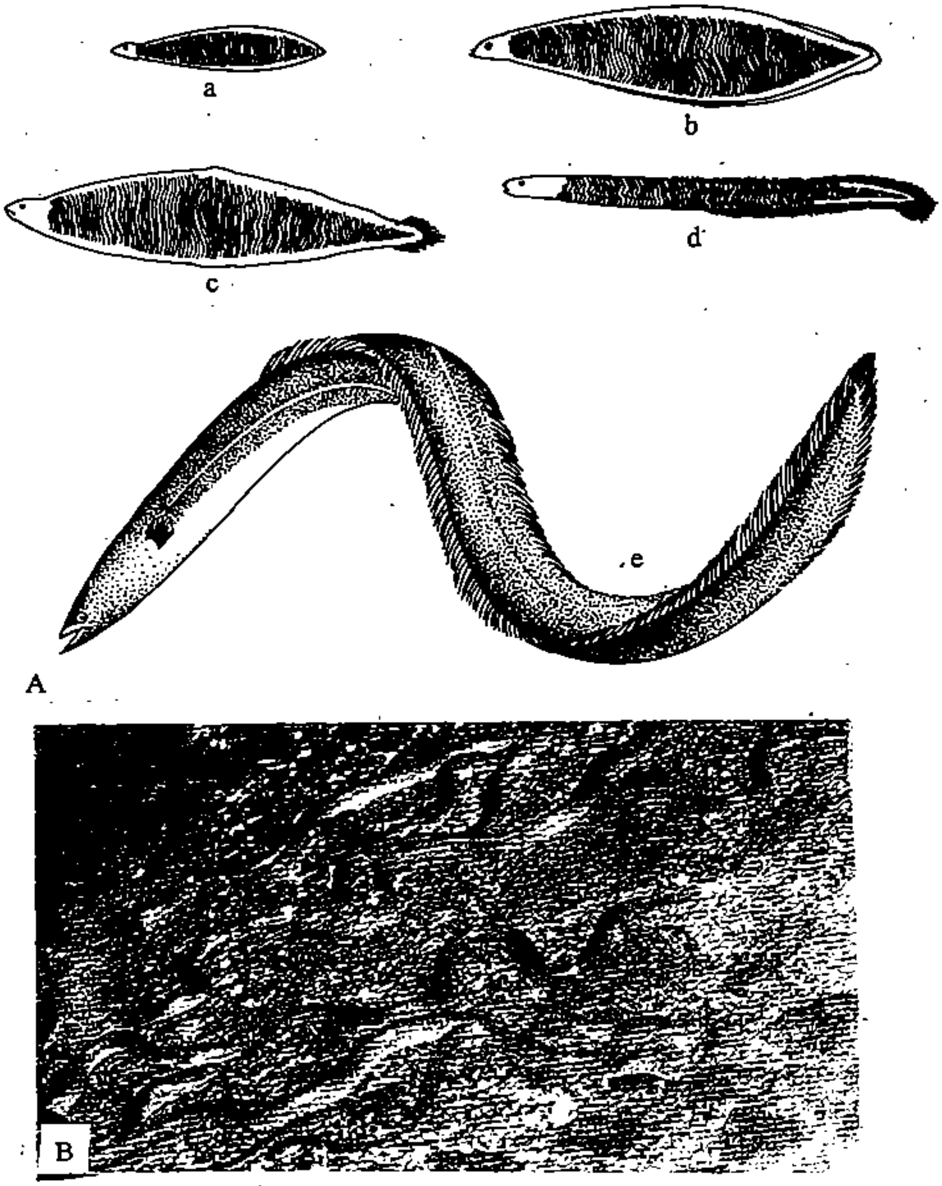


Fig. 15.6 : A) Transformation of the freshwater eel. After hatching in winter or early spring the transparent broad leaf like larvae are called leptocephali (a,b,c). Within 12 months, they develops into 3 inch rounded elvers (d) that resemble adults (e). B) Elvers must surmount obstacles as they travel upstream, often they have to climb concrete dams and to avoid fast flowing water have to wait for nightfall before climbing upstream.

As they begin their migration, animals use a variety of specialised abilities and senses to reach their destination. They rely on external forces such as water and wind currents. For example, elvers emerging from Sargasso sea ride on water currents to reach the mouths of rivers in North America and Europe.

Some animals rely on familiar land mark, such as coast lines, mountain ranges, river valleys to follow a specific route. Mature salmon depend on their olfactory senses and memories the odors of their specific river when they migrate to the sea. They use their memory to track the distinctive odor upstream when they return to the river.

Migratory animals combine their sense of time with cues from the sun to determine their exact location and direction. But some animals that migrate at night use the position of stars to provide orientation. Birds are able to discern true north even if only a part of the sky is visible. These methods of orientation and navigation are called sun compass and star compass and closely resemble the technique of celestial navigation used by sailors in ancient times.

Some birds for example pigeon and sparrows are able to find their destination even if they are taken off course. Recently it has been discovered that tiny crystals of magnetite (a magnetic substance) are present in the brains of some animal species. Scientists believe that magnetite helps animals to use the earth's magnetic field as a guide.

Scientists can track large migrating birds or animals by following their route on land. Individuals can be tagged with identifying markers. Both land and marine animals can be outfitted with electronic callers that send signals to researchers enabling them to determine the exact location as well as overall migrating route. Radars and satellites have also been used to track individuals.

For many animals migratory routes are inborn. For other species that usually migrate in groups, like birds, there is a crucial component of learning from older and more experienced individuals. For animals reared in captivity and then released in the wild, learning their species migratory pattern becomes difficult.

The fact that so many unrelated species have convergent behaviours suggests that this behaviour has no single function but has evolved in response to several different ecological pressures. You would have noticed in all the examples described that, a major migratory behaviour pattern involves movement from a feeding area to a protected breeding area which are relatively free of predators. The areas chosen for breeding are usually rich in food resources.

Much remains to be discovered about the mechanisms that organise migration in animals. As a phenomenon, migration uses abilities that we are just beginning to understand and senses that we lack.

SAQ 2

i) Improve the definition given below to include all fundamental aspects of migration. "Migration is the movement of animals from one place to another as seasons change."

....

....

....

....

ii) Indicate whether the following statements are false or true.

a) Birds that migrate at night use only the position of stars to orient themselves.
b) All migrating animals have magnetite crystals in their brain which helps them to find their migratory routes.
c) The grey whale takes a migratory route that covers 16000 km.
d) Migration usually occurs between breeding and feeding areas.
e) During migration the adults usually leave behind the new batch of offspring.

15.4 SOCIAL ORGANISATION

In the preceding section you learnt about migratory behaviour in vertebrates. Let us now examine how groups or members of a species interact with each other to form social organisations. In the broad sense, any interaction resulting from the response of one animal to another of the same species represents social behaviour. Even a rival male fighting another male over the possession of a female is a social interaction.

Virtually all members of a species exist in pairs or groups for at least some part of their lives, for feeding, drinking or for mating, and some animals spend their entire lives as members of a cooperative, interacting group. Their association typically extends beyond the level of mating and taking care of young. Such groups form societies and display simple to complex social organisations.

Social behaviour has evolved independently in many species of animals; and complex social organisation has been found in invertebrates as well as vertebrates. The term socia organisation refers to populations or groups and not to individuals and determines how members of a species interact with each other. In various social insects (Refer to LSE-09, Unit 15) the social organisation is quite rigid and species specific. In many vertebrates, however, it is more flexible and may vary with changing conditions. For instance, in elephants the females may live in the same family unit for 40 to 50 years. The stability of their relationships would allow them to be called a society. On the other hand, organisation within a flock of birds or within a school of fish would not be termed truly social even though they may live together for months.

Before we discuss the behaviour pattern that contribute towards organisation of societies in vertebrates, let us look at the benefits as well as the costs of living together.

15.4.1 Benefit and Costs of Sociality

As early as 1938, observations on different animal groups showed that many animals are able to face adverse environments if they live in groups. School of fish are less vulnerable to predators because large numbers often confuse the predator. There is safety in number, and the detection of predator may be enhanced by having several individuals on alert to warn against any intruders. For instance, meerkats (socially living mongoose) take turns to keep vigil at high look-out-points, while other individuals feed (Fig. 15.7). When a predator is spotted the group can take collective evasive action like scattering in all directions or physically attacking the predator. A flock of birds on seeing a predatory bird usually bunch together. Predators rarely attach an individual in a close group. Colonial nesting birds like gulls, resort to mobbing when a predator like a fox or even humans approach their nesting sites. Thus survival of gulls that nest in large colonies is much better than those that nest alone.

Fig. 15.7: Meerkets often stand on attention to alert the group against a predator in Kalahari desert in Africa.

On the other hand predators too are more successful if they hunt in groups. Lions, hyenas, wolves, cape hunting dogs are examples of predators that hunt together. Some individuals in the group help to drive the prey towards other hidden members, or help in running down the prey to exhaustion. Another advantage may be that scavengers are kept at bay by other members of the groups.

Another advantage is utilisation of food resources found by one individual. Also living in groups provides protection against harsh weather conditions, as can be seen in penguins that huddle together to incubate their eggs and provide a fairly decent shelter from the cold also their young are reared communally in crèches (Fig. 15.8).

Fig. 15.8: King Penguin chicks in their creche. Living together provides greater protection.

Rearing of young in a group provides greater protection and safety, at the same time the potential for learning and transmitting useful information is another advantage.

Observations on a semi natural colony of Japanese macaque monkeys in Koshima Islands revealed that when they were provided with potatoes caked with mud, they usually rubbed off the mud before eating it. However, it was noted that one day one of the females washed the potato in the nearby sea before eating (Fig. 15.9). Soon the other females began to copy her and this behaviour was learnt by their offspring and soon became a part of the group's habit.

While group living confers some clear advantages, at the same time there are some undoubted disadvantages. There may be competition for resources, increased risk for transmission of parasites and diseases, greater risk of cannibalism of the young by conspecifics and interference in mating. The balance between benefits and costs is a fine one and the behaviour that will be favoured by natural selection will be the one that favours the reproductive interests of individuals in the long run.

Fig 15.9: Japanese Macaques. One monkey may discover a new activity and teach it to its young finally the whole social group may copy it.

15.4.2 Types of Social Behaviour Patterns

We have said earlier that societies of animals vary greatly in their structure, organisation, complexities and types of interactions. You would recall the complex organisation of insect societies from Unit 15, LSE-09. These insects are termed eusocial because of the division into castes such as soldiers, workers, reproductive individuals which are morphologically different from each other. In contrast social organisation in vertebrates is not so rigid though there is an example of a eusocial vertebrate which we will discuss later. Most vertebrate societies also contain genetically related individuals, but unlike insect societies all members are capable of reproduction and competition in reproduction is one of the main principles in determining the social system. Usually a typical vertebrate society would consist of genetically related females and their offspring plus unrelated males that come and join the group.

In a society of animals certain behaviour patterns are important for organising and maintaining the social organisation and for spacing individuals in the group. Let us discuss some of these behaviour patterns:

1. Territoriality and Dominance Hierarchy

Social organisation requires cooperation amongst animals of the same species but at the same time there is competition amongst them because of limited resources like, food water, mates or shelter.

Much of what animals do to resolve their competition is called aggression. Aggression may be defined as offensive physical action, or threat, to force others to give up what they have or might attain. Many ethologists consider aggression as a part of a wider behaviour known as **agonistic behaviour** referring to any activity related to fighting whether it is aggression or defence or submission or retreat. Most aggressive behaviour is in the form of threat displays and rarely does it harm or prove fatal for the members of the same species. The symbolic ritualistic displays of agnostic behaviour are mutually understood. For example, rival male poisonous snakes engage in stylised fights where they butt each other by their heads so that the other is tired and eventually recedes. They never bite each other. The loser usually submits to the winner who becomes dominant. Thus agonistic behaviour is important for maintaining social order, especially establishment of **dominance hierarchies** and maintenance of **territories**.

Territories are marked and defended in social organisation because they contain food resources, sites for attracting mates and rearing young. They are also locations that provide shelter. Of all the classes of vertebrates, birds are the most conspicuously territorial. Most male songbirds as you would recall, establish their territories in early spring and defend them vigorously. Many mammals have **home ranges** rather than territories. It is not an exclusively defended area but is the total area covered by the mammal in its activities. Home ranges of individuals of the same species may overlap and may shift with seasons.

As said earlier some sort of dominance between individuals of a social organisation is established due to agonistic behaviour and is known as dominance hierarchy. Due to this a group of animals can coexist despite competition. The group is organised in such a way that some members of the group have greater access to resources such as food and mates than other do. Those animals at the top of the hierarchy have the first choice of resources and those at the bottom may do without, if resources are scarce. Once a hierarchy is in place coexistence is possible with occasional fights if any member tries to move up the ladder. Dominance hierarchy was first noticed and described in chicken societies. It was seen that when chicken are placed in a pen, they initially fight till a linear hierarchy of dominance is established among them. Higher ranking chick are the first to eat and may peck the lower order chicks if they disturbed the feeding order. This is known as 'pecking order'. Though dominant individuals gain all rights over food, space, mate etc., the subordinates stay around because staying solitary may be even worse or they may in time become dominants.

2. Sexual Strategy

Different species show considerable variations in their social organisation. One of the fundamental influences on social organisation seen in any species is the **mating system** adopted by the individuals of that species. By mating system we mean the role adopted by the two sexes in reproduction.

You have read in LSE-09, Unit 15 that males produce many sperms and to increase their reproductive success they have to fertilise many eggs. For this they have to adopt sexual strategies, hence the aggressive competition to establish dominance hierarchies and territories.

These sexual strategies result in particular kinds of mating systems which have profound effect on the social organisation of the species. For example, where a male has to gain access to females by defending them against rivals, there is a tendency for the social organisation to be based on a harem. This is helped by females who tend to aggregate as a defence against predators or for feeding opportunities. The harem is a basic feature of the social structure found in antelopes and deer. Here the mating system is **polygynous**. Polygyny is also more common in mammals as females are specialised to take care of the young. But where ever both males and females are required to care for the young, **monogamy** is usually the rule. More than 90 percent of the bird species are monogamous. The mating pair lives together for life on a seasonal or continuous basis. Polygyny occurs in birds where males are not required to care for the young like in pheasants where the young require relatively little parental care. Monogamy is not common in mammals, however, it does occur in some primate species or in jackals where males feed the young through regurgitation.

Another kind of mating system found in birds is based on **polyandry** where the females mate with two or more males, but the male mates with only one female. In such cases the females are more conspicuous, territorial and dominant than the male. The eggs are incubated by the males while the female looks for other mates. Therefore, we see that a rough correlation exists between the type of mating system and the amount of parental care given by the two parents.

3. Altruistic and Cooperative Behaviour

Altruistic behaviour is also important in the organisation of some animal societies, (you would recall the supreme altruistic behaviour exhibited by honeybee societies among invertebrates). In altruism an individual gives up or sacrifices some of its own reproductive potential to benefit another individual. For example, one individual of a group of crows gives an alarm call to warn other individuals of the group of an approaching predator even though the alarm call may attract the predator to the sender of the call.

Why would the animal do such an act? At first it does not make sense, for the altruistic individual lets others survive at its expense and to be successful in the biological sense the animal must produce as many young as it can, thereby, passing its genes to the next generation. Studies revealed that altruistic behaviour is shown towards genetically related individuals and by aiding a relative and its young, genes can be passed on as the altruist shares some genes with the relative. Natural selection will favour genes that promote altruistic behaviour towards genetically related individuals. This form of selection is known as **kin selection** and explains how selection acting on related animals can affect the fitness of an individual. In this way a gene carried by a particular individual may pass to the next generation through a relative. An individual's fitness is, therefore, based on both, the genes it passes on, as well as the common genes passed on by relatives. For kin selection to work, individuals must be able to identify relatives as happens in social insects and a small group of primates.

Though extreme altruism is found in eusocial insects where there is a reproductive adult and numerous sterile workers, there is atleast one mammal that can be termed eusocial too. The naked mole rat that lives in dry areas of South Africa has a termite like social organisation.

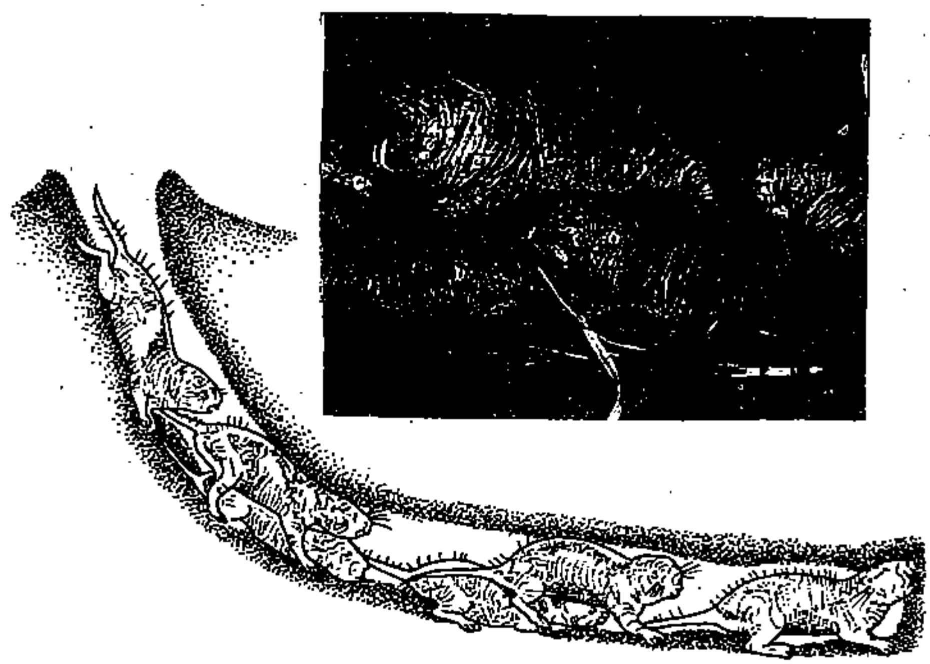


Fig. 15.10: Naked mole rats live underground in colonies of closely related individuals. The workers cooperate to dig tunnels through the hard earth to search for food.

These mole rats build underground tunnels, housing usually only one reproductive female and a caste of workers most of which never breed. They defend their colony and working like a chain gang dig through the hard surface of the earth to look for roots and tubers to feed the rest of the colony (Fig. 15.10). The reproductive female does not participate in looking for food, which is bought to her by the workers. Food is so difficult to find, that a pair of mole rats would find it difficult to survive on their own. By cooperating with the colony and contributing to reproduction of others, the workers get a share of the offspring produced.

Cooperation among animals also shows some form of altruism. Over 200 species of birds show cooperative behaviour. The parents are helped in some way by the other individuals, often by their own young of the previous year. They may help in nest building, territorial defence, feeding and keeping predators away.

Among the big cats, lions are the only ones that show highly cooperatives social organisation. Studies in Serangeti Park in Tanzania showed that a typical lion group consisted of adult lions, lionesses and their cubs. Without exception all lioness were relatives i.e., mothers, daughters, sisters grandmothers, aunts. Most lionesses remain in the pride in which they are born throughout their lives. The few that leave the pride, group together nearby to form a new pride. Cooperation among lionesses in extensive and no dominance hierarchy is present. They hunt together, defend their area together and give birth synchronously. The cubs are pooled together, reared, defended and even suckled communally. The group of males is known as a coalition and these undertake the defence of the pride collectively. The coalition consists of mostly related males but unrelated males may also be present. No clear dominance hierarchy is seen in the coalition. All the related as well as unrelated males cooperate as it is easier to defend and hold the pride together against rival males of other coalitions. Any new coalition that takes over the pride kills all the non-weaned cubs. Therefore, it is in the interest of both the males and females to cooperate so that the cubs grow to sub-adulthood and not get killed by infanticidal replacement males.

Many social organisations in animals seem to change with seasons. For instance outside the breeding seasons, red deer males and females live apart. Males live in loose herds in which dominance hierarchy is well marked. Females live in herds containing young animals of both sexes. As the breeding season approaches the males become aggressive and finally the male herd breaks up with adult males displaying individually, roaring to attract females. They then defend their group of females. After the breeding season both sexes return to their respective herds for the winter.

In many species social behaviour does not change throughout the year as in the case of lions. Generally, those species that cooperate to hunt for prey and to defend themselves stay together throughout the year. Wolves and African wild dogs, hunt in packs and maintain very stable social structures.

Fig. 15.11 : African wild dogs are highly social animals.

African wild dogs (Fig. 15.11) have a complex and unique social structure. They hunt in packs of males and females leaving behind the young, and the old individuals. After making a kill they devour their prey in minutes. Some of the food they eat is regurgitated back for the young, old and infirm individuals in their lair. Many primates also retain a stable social structure, characterised by great complexity and subtlety of relationships. In the next subsection we shall consider the social organisation of primates.

15.4.3 Primate Social Organisation

Primates live in a wide variety of habitats and it is evident from their very early history that the majority of primates were social animals. They have a wide range of types of social organisation.

Many prosimain species like lemurs, loris and tarsier have widely dispersed food supply and they are usually solitary in their way of life, coming in contact only during the time of courtship and mating. Since these species are solitary they are shy, inhabit thick forests and remain hidden in the foliage.

Monogamous adult pairs of primates live with their recent offsprings. Examples are island langurs, silvery marmoset, gibbon, red bellied lemur, night monkeys etc. Nowhere among the social primates are females accorded more permanently privileged positions than among the monogamous species. There are 37 species, most of them endangered and rare. They inhabit tropical rain forests. Gibbons are found in South-East Asia, their groups include 4-8 individuals consisting of an adult male and adult female and upto 4 young ones. Male – female bonding is lifelong and permanent. In such groups usually there is not much difference in the body size of male and female. They are small sized and feed on high protein diet viz. insects, new leaves and ripe fruit. All monogamous groups have definite territory which is defended actively. Parental investment is equal, the female feeds the young and the male carries the young ones on their back (Fig. 15.12). Their anti-predatory device is concealment.

Fig. 15.12: Marmoset is a monogamous primate and usually bears twins. Male carrying twins on its back.

Single male groups with many bonded females and young ones are found in hanuman langurs, red howler monkeys, red tail monkeys, blue monkey. Typically they live in groups of 20 to 100 individuals. There would be just one adult fully grown male designated the 'resident male'. Rest of the group is formed of adult females, subadult females, male – female juveniles and infants. Growing males either leave the group wilfully or are chased away to form all male groups. The adult male is the coordinator of the group and decides the direction in which the group will move and where it will feed or sleep. The males produce loud resonating calls which is necessary for quick and effective gathering of the group. In hanuman langurs it is the adult male that usually defends the territory and herds the females (the harem) away from intruding males. In such groups the males are much larger than the females and male parental care is almost nil. But changing of the overlord or dominant male is of common occurrence, when another male from the all male group chases the resident male and takes over the harem.

Primates with more stable food supply tend to form **multi male groups** with many females and offspring. Examples are rhesus, gorilla, baboon, spider monkey, bearded saki, squirrel monkey etc. Typically there are 3-8 adult males in a group each of which has 5-7 bonded females who remain with their infants. In this way there are many small units living together forming a larger unit or group.

For examples, the mountain gorillas (*Gorilla gorilla beringei*) have a small home range and feed on leaves and stems of forest plants. They live in small groups each led by a 'silverback' or the dominant male (Fig. 15.13). The males have a clear dominance hierarchy, the most dominant called alfa, then beta, gamma and so on. Dominance consists of possession of right of way on a narrow path or a resting place or feeding site. Surprisingly and most unlike other primates the dominant male in gorillas is not aggressive and all other males also have access to receptive females. There is no conflict in mating. These groups are **'age-graded'** i.e. 'The silverback' is the oldest and all other males are younger and graded age wise.

Fig. 15.13: 'Silverback' is the leader of the gorilla group.

The rhesus monkey is widely distributed in India. It lives in large multi-male bisexual groups. The males have a dominance hierarchy and the females acquire their dominance from the males they have been affiliated to. For example, if alfa is the most dominant male his bonded females will enjoy a high place in dominance hierarchy among females and the rest of the group members, even their infants acquire that dominance! The dominant males are recognised by their confident stride with their tail turned up (Fig. 15.14). The subdominant male will walk carefully with his tail tucked in between the hind limbs. If the alfa leaves the groups for a short while. The beta male raises its tail and as soon as the alfa male returns the tail is lowered again. The rhesus groups do not split easily though each day they break into small family groups for foraging. All family units remain in vicinity and unite at the time of danger, for day resting and every evening for roosting.

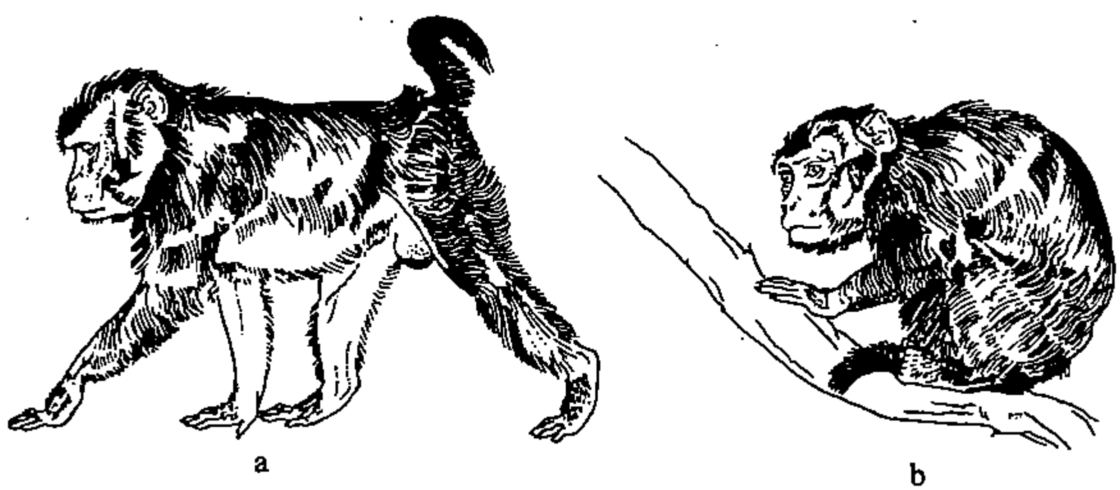


Fig. 15.14: Typical body postures of (a) dominant rhesus male, (b) subordinate male.

The savannah-living baboons usually live in troops made of a number of males and females. The dominant malès have special privileges like access to food water and females. They cooperate in maintaining their social position against rivals and in protecting the mothers and infants from other members of the troop. The dominant males also cooperate in defence against predators. Rich habitats tend to attract more predators and male-male cooperation has considerable advantages in these circumstances (Fig. 15.15).

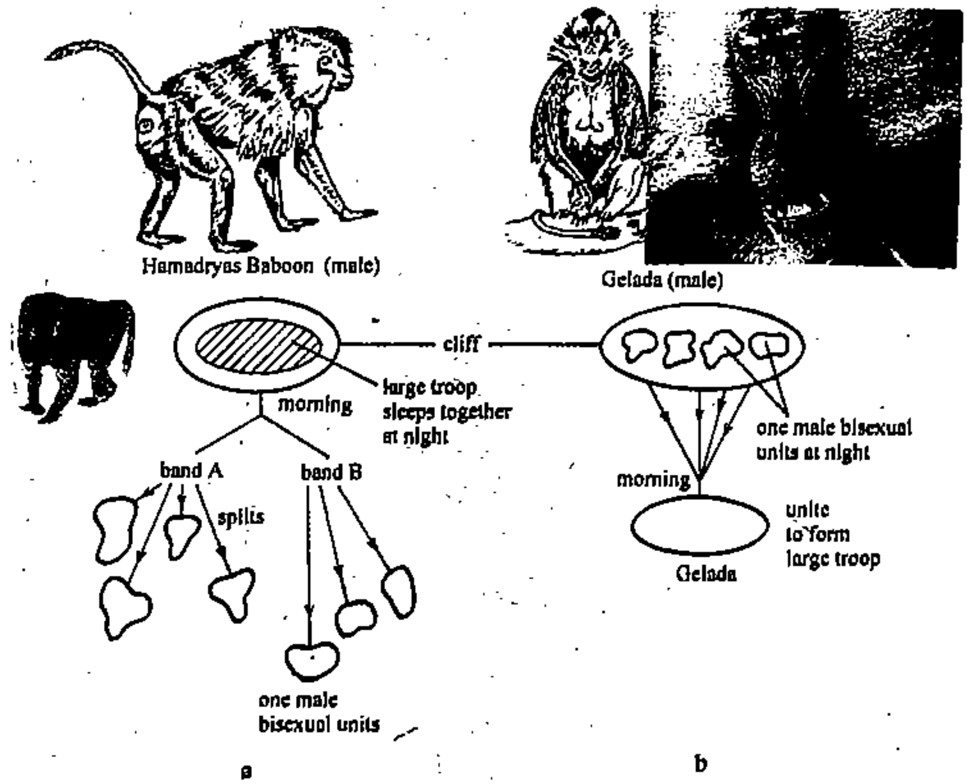


Fig. 15.15: Multi male bisexual groups: a) Hamadryads baboons that live in Somalia and Ethiopia. The troops sleep together on cliffs and separate each day for foraging, b) Gelada baboons found in Northern Ethiopia sleep separately on cliffs in one male family units but unite in the mornings as large troops for foraging.

Pygmy chimpanzees (*Pan paniscus*) found in Democratic Republic of Congo and chimpanzees (*Pan troglodytes*) found in Guniea to Congo and in Uganda and Tanzania form diffused social parties. Their social structure is more variable than other primates. They follow no strict social organisation and may be seen in bands of males, groups of females with or without offspring or form large troops of males and females with young.

Thus we find that apart from any light that may be thrown on the origins of human social life, the primates offer marvellous material for the study of behavioural development.

SAQ 3

i) Give one major difference between insect and vertebrate societies.

....

....

....

....

ii) Fill in the blanks:

a) When a male has to gain access to females by defending them against rivals the social organisation in usually based on ....

b) .... is common in animals where both male and female take care of the young.

c) Where the female mates with two or more males the .... takes care of the young.
d) Langurs have a multi .... and single .... system of social organism.
e) Primates with more stable food sources form .... male groups.

15.5 COMMUNICATION

You would have noted in the preceding section that organisation of social behaviour involves various forms of communication between the individuals of the social organisation. Those animals with more complex societies tend to have more elaborate methods of communicating. Every communication involves action by a communicator and reception by another individual.

Only through communication can one animal influence the behaviour of another. Whereas, human communication is based mainly on sounds, animals use a wide variety of ways to communicate, for instance, through sounds, scents, touch, sight, and movement. In fact any sensory channel may be employed, and in this sense animal communication is by far rich in variety.

Many animals have evolved 'signals'- special behaviour patterns often combined with special structures whose chief function is to send stimuli to another animal, who would respond to that signal. Thus communication would mean a transfer of information. But this is not a complete definition of communication. Let us explain this further. Foraging ants commonly lay a trail of scent that their nest mates pickup and follow to the source of food. There is a small snake *Leptotyphlops* that also detects this scent and follows it to the ant nest where it devours the brood. The scent was laid by the ants to communicate with their nest mates about the food source but we would not say that they communicated with the snake!

We now can elaborate our definition of communication to include that the signaller and receiver are mutually adapted to each other. Therefore, communication occurs through signals that have evolved to the benefit of two animals. The ants communicated the information to their nest mates and one of the disadvantages of such a system was that the snake can make use of this system too.

Communication is not always between members of the same species (intraspecific) only but it also occurs between members of different species (interspecific). The rattle snake's rattling is a signal that communicates danger to other species. A skunk communicates to potential predators by presenting its hind quarters and raising its tail.

The diversity of ways animals use to communicate with each other make us wonder why animals use such different signals. One obvious reason is the difference in environments in which they live. Air and water need different modes of signals. For examples animals travelling in dense forests where they cannot see each other easily, would find sound signals more useful. Another very important reason will be the sensory capacity of the animal receiving the signal. For instance, animals that rely on vision for finding their way and detecting prey will also tend to communicate through visual signals and so on.

Let us now consider the various sensory modes and the biological advantages they bring for the animals for life in particular habitats.

15.5.1 Visual Signals

Visual signals usually operate, only at relatively short range and are usually found in animals living in the open. Many of the elaborately coloured plumes and tufts adorning the more brilliant birds, are used as courtship displays (Fig. 15.16).

Among bony fishes, there are many brilliantly coloured species. They often change colours on being threatened or during mating which indicates the importance of their colouring. The stickleback male as you would recall from Unit 14 has a red underbelly during the mating season. It also responds with an aggressive attitude on seeing other males with red bellies and also responds to a simple red coloured model in much the same way, showing the importance of these colour signals.

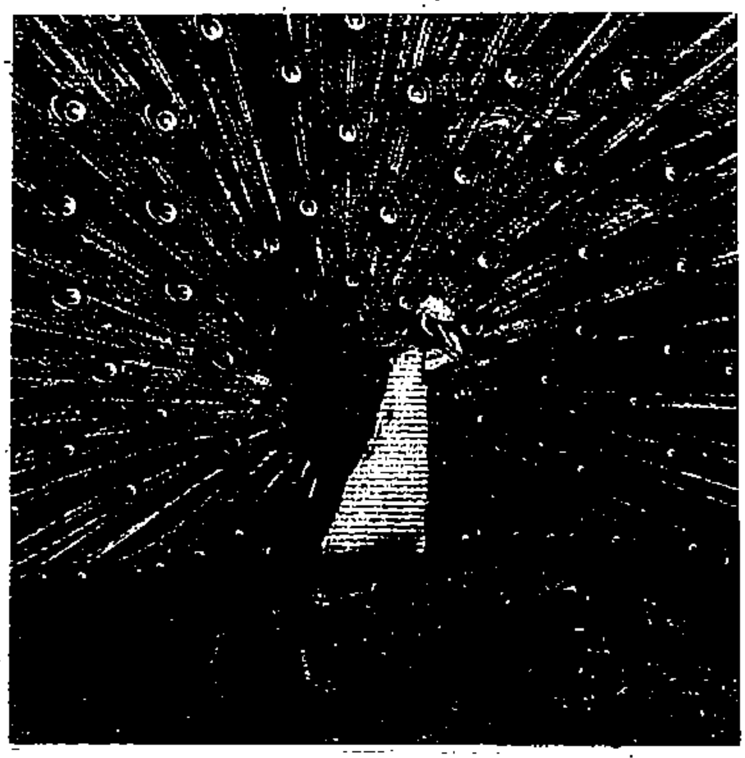


Fig. 15.16: The erection and spreading of the splendid train of the peacock is a typical type of visual signal for courtship.

It is obvious that two animals that exchange visual signals must be able to see each other. This also means that they are visible to the predator too, however, the variety of colours, their patterns and different movement that can be made can produce infinite variety of specific signals (Fig. 15.17). In spite of its obvious disadvantage of exposure for the animals using visual signals, it is widespread in the animal kingdom showing its selective advantage during evolution.

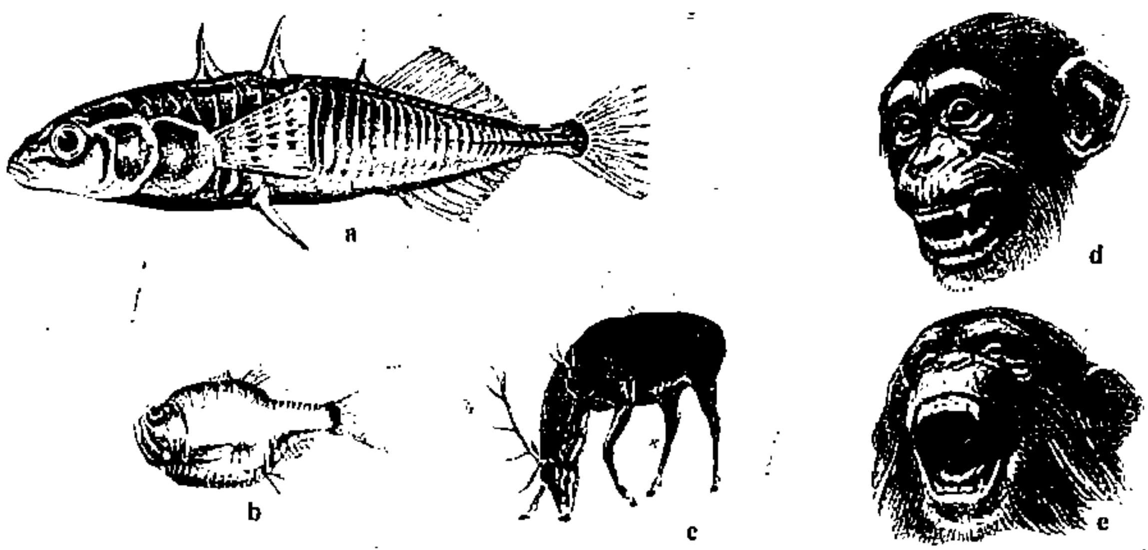


Fig. 15.17 : Visual signals. a) advertisement of species, b) advertisement of territory, c) threat, d) fear, e) sadness.

15.5.2 Acoustic Signals

Sound signals have the advantage that they can travel over considerable distances past and through natural obstacles such as dense vegetation. Long distance signals are therefore, usually calls or specially produced scents. Sound of all frequencies attenuates as it travels but high frequencies attenuate and become scattered by obstacles much more than low frequencies in all types of habitats. For this reason, low frequencies are generally better for communicating over long distances. For example, the male green tree frog produces a call at two frequencies one at low and the other at high frequency. The female at a distance responds to the low frequency call and as it comes nearer the sound gets louder and she responds to both low and high frequency calls.

The territorial song of birds are usually delivered from a high song post, thereby increasing its effective range. The songs also show patterning, which means they are made up of different frequencies and the pattern of the song is made by arranging these notes to form a phrase. Sound spectrogram of bird songs show that they are rarely formed of pure notes but any one moment a number of frequencies are sounding together.

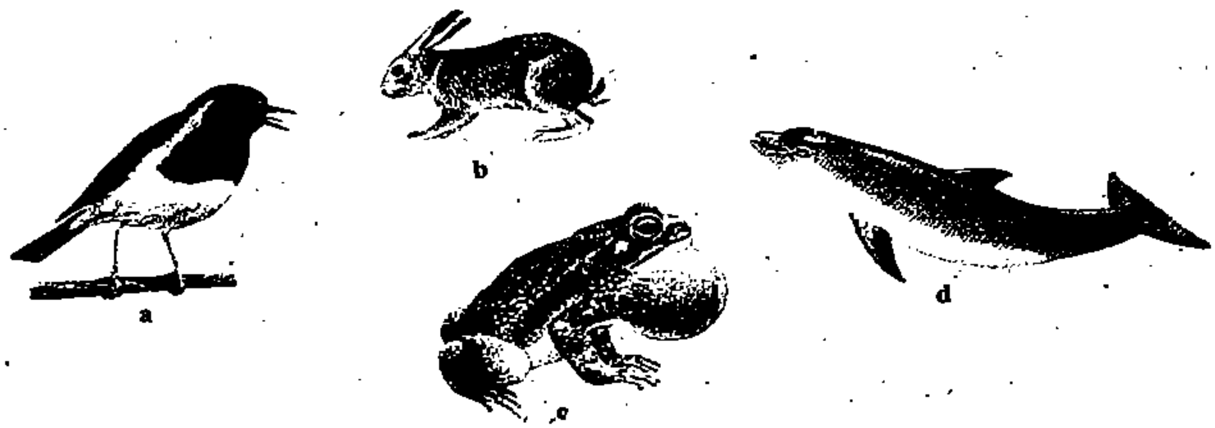


Fig. 15.18: Sound signals. a) demarcation of territory, mating, alarm etc, b) thumping, c) croaking, d) communicating ideas.

The male bird sings his song which advertises his presence, his species and his physiological readiness to mate (Fig. 15.18 a). The song attracts the females and also serves as a threat to other males that try to intrude in his territory. Another type of song makes up the alarm call that warns other birds of various species in the area that a predator is nearby. For example, the alarm call of the mother hen to her chicks for a predator in air is different from the call given if the predator is on land. Alarm calls are also examples of interspecific communication (Fig. 15.18 b).

Acoustic signals are typical means of communication of animals in the canopy of rainforests and among grass roots where the signaller and receiver are generally unable to see each other. Sound travels even further in water because there is less attenuation than in air and so aquatic animals use sound signals extensively for communication (Fig. 15.18 d). The development of the underwater microphone has allowed us to discover the amazing range of sounds produced by fish, and whales. Other humpbacks several hundred kilometres can pick up the 'songs' of hump back whale apart!

The blue whale is the loudest animal on earth! They mostly emit very loud, highly structured repetitive low-frequency rumbling sound, that can travel for many kilometres underwater. These sounds are used for communicating with other blue whales especially to attract and find mates. Th call of the blue whale reaches upto 188 dB. Theoretical calculations by Roger Payne and Douglas Weff (1970) predicted that the loudest sounds might be transmitted across an entire ocean! The blue whale is much louder than a jet which reaches only 170 dB!

15.5.3 Tactile Signals

Touch as a method of information transfer is one of the basic ways of communication. Tactile communications dominate the social interaction of many invertebrates and is also important in many vertebrates particularly mammals, where individuals of the more social species spend a lot of time in physical contact with one another (Fig. 15.19).

Some animals have mechanoreceptors that respond to mechanical disturbances in air or water around them. Fish even when blind can form groups or school, using their lateral line organs to pick up mechanical disturbances made in the water by other fish in the school.

Fig. 15.19: Tail twining communication of dusky titi monkeys

Very few of tactile signals are analysed, but greeting between animals usually involves touch. Giraffes 'neck' when courting, each pressing its neck against the neck of the other. Among primates grooming is an important tactile signal helpful in maintaining primate social organisation (Fig. 15.20). Touch signals are as diverse as the animals that use them but unlike vision or sound they cannot be effective over any distance. The animals must be in contact. Such signals are especially important for group living.

Fig. 15.20 : Rhesus monkey mothers, daughter and young. Grooming is an important part of social organisation.

15.5.4 Chemical Signals

Chemical signals are particularly well developed in insects and mammals. You would recall from LSE-09, Unit-15 about the chemical signals used by insects, ants and honeybees in particular to maintain their social organisation and the female moth in attracting males. Among vertebrates mammals also use chemical communication in the form of pheromones that are used to pass a single, relatively stable message such as breeding condition of a female or the ownership of a territory or alarm (Fig. 15.21). Such a message can persist even in the absence of the signaller. Unlike sound and visual signals it is not possible to produce a pattern with chemical signal like a pattern of a scent, for it is difficult to change the signal quickly.

Fig. 15.21 : Chemical-signals are used in the form of a) alarm substances as in the case of minnows, b) demarcation of territory by scent glands, urination etc.

Chemical structures of scents can be adapted more specifically to their function. Sex pheromones and territory markers need to be persistent and therefore their constituents must be of fairly high molecular weight. A highly persistent odour like that from musk glands or from material left on twigs by antelopes in order to mark territory has a distinct advantage for it is very long lasting but the animal must always be in contact and the receiver must be close by to perceive it. On the other hand scents that need to be dispersed in air are kept for occasional use as for example in courtship, for it is a wasteful process in terms of energy consumption in the animals metabolism. Some animals use their excreta for marking territory. For examples, dogs mark their territories with urine and a hippopotamus uses a fragrant mixture of urine and faeces flicked around by wagging its tail.

15.5.5 What do Animals Communicate?

We have mentioned some of the types of communication in the earlier subsections. The most obvious information communicated is that regarding danger and sexual receptivity. But even these are not just simple communication. Many animals can communicate not just the presence of danger but also the type of danger present! The vervet monkeys use different calls to indicate different sorts of dangers. One alarm call is a series of relatively long tonal units and is given in response to mammalian predators, particularly leopards. Other monkeys hearing this alarm call climb up into a tree. The 'eagle' alarm call consists of short tonal units grouped together and the other monkeys look up and hide in the bushes. A 'snake' alarm call is a series of short widely spaced sounds and on hearing it the others look down on the ground. Tape recorded alarm calls of these three kinds always elicited the same response. This is not exclusive to vervets because other animals also convey information about the type of predator they see.

Chicken can convey the information about the quality of food source. The food calls are produced at a higher rate with highly preferred food. When animals come in conflict, regarding food or mate another category of signalling is seen. They give threat signals to each other before the actual fight starts or there may be no fights at all. This is often the basis of establishment of dominance hierarchies in social organisation seen in vertebrates. A clear example is seen in Red deer stags. In the autumn rutting season they frequently challenge each other to establish ownership over the harem. To begin with there is a roaring match, in which the stags roar giving greater and greater roars per minute. Roaring is exhausting exercise and the stag that can roar the loudest for the longest time period out roars the other stag and conveys that he is physically fitter than the other and probably a better fighter. The other stag may withdraw but if both can roar at the same rate then they proceed to the next step of 'parallel walk' in which they size each others fighting ability. As a result a real fight occurs only amongst those stags that are closely matched in physical fitness and fighting ability.

A great deal of communication takes place during reproductive behaviour in animals. They convey to each other during courtship their species, sex and physiological condition. Lizards have species specific pattern of head bobbing, frogs send out species specific sound signals in a sort of Morse code. Pheromones are also used to identify the right species.

Another interesting type of communication is the type of signal that qualifies other signals that follow. The best example is in play situations seen in carnivores and monkeys. Adult male lions invite cubs to play and the posture adopted then is not seen in any other context (Fig. 15.22).

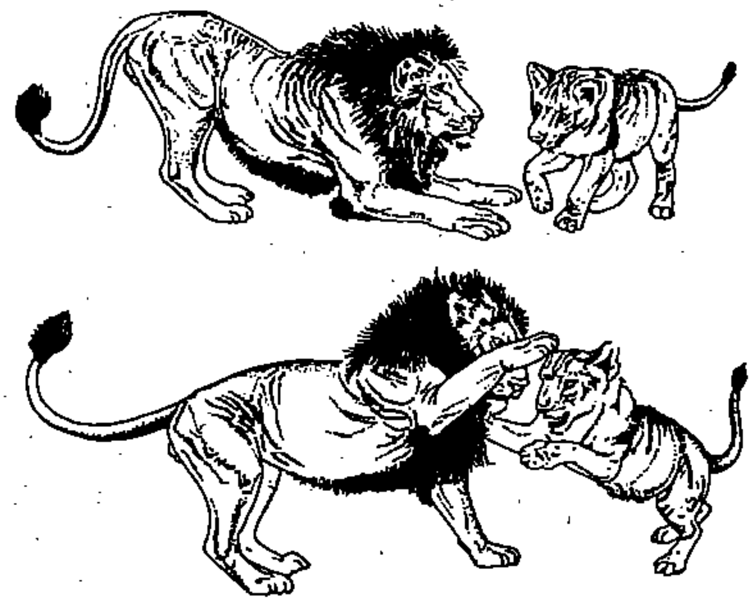


Fig. 15.22 : Communication leading to a play situation in lions. The male's posture with lowered forequarters is seen only as a preliminary to play. He gently cuffs the cub as it joins him to play.

Dogs also adopt a similar posture and may wag their tails during play fights. Monkeys adopt a play face in similar situations. Playful aggression is seen in the behaviour of carnivores and serves as practice of stalking and attacking without the damage of real fights.

The total range of communication for any given species may involve more than one modality. As might be expected, the modalities used by any one species depends on environmental considerations. The proportion of their signals that fall into different sensory modalities are shown in Fig. 15.23.

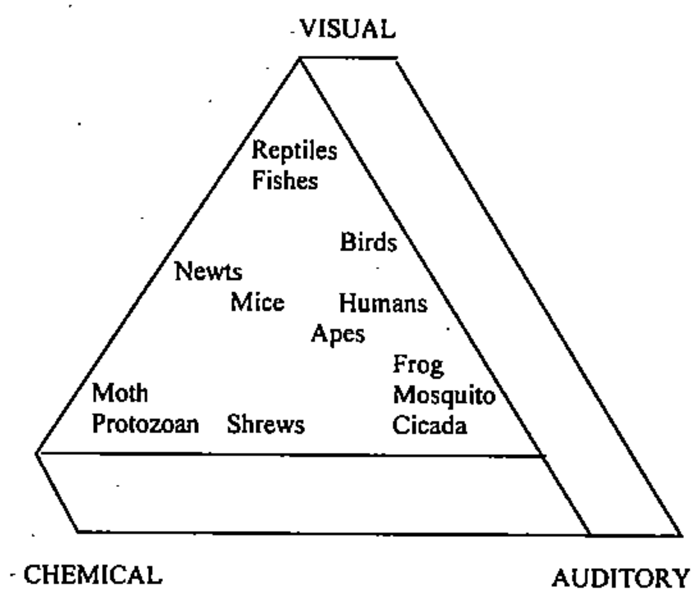


Fig. 15.23: The proportion of type of signals used by animals.

SAQ 4

i) What differences would you expect between communication system of animals that are active at night versus those that are active during the day.

....

....

The emphasis so far in Units 13-15 has been on the various kinds of behaviour. Each of these depends on what we would call the machinery of behaviour i.e. the sense receptors the circuitry of the nervous system and the organisation of muscles in the body. Upto now when we asked the question what causes a specific behaviour we were really asking how the particular behaviour is triggered i.e. due to a visual signal or auditory or a hormonal one.

Let us now in the next unit, examine beyond the immediate causes to find out why an animal behaves in a particular manner i.e. what is the adaptive value of the behaviour in the life of the animal, that has resulted in the behaviour becoming part of the evolutionary heritage of the species.

15.6 SUMMARY

In this unit you have learnt that:

- Behaviour is made up of patterns, acts and components and can be organised and described at different levels.
- Behaviour can be organised by neuronal command centres and inhibition of competing command centres allows the animal to do one thing at a time in a sequence rather than simultaneously.
- The neuronal command centres in the brain receive inputs from a biological clock that helps animals to follow a 24 hour circadian rhythm or yearly circannual rhythm. Many marine animals also follow a tidal, or lunar cycle. These biological rhythms are influenced and reset by environmental cues or endogenous factors.
- Hormones often act as fine tuners of neuronal command centres.
- Many animals have adapted to seasonal changes in climate by migrating regularly between different environments. Animal migrations are often feats of endurance and navigation, which have been explained by using several examples from vertebrate classes. Evidence reveals that migration is controlled by internal factors like circannual clock as well as the external environment.
- A social organisation is an aggregate of individuals of the same species that come together because of mutual benefits. There are of course some disadvantages of group living. Social groups range in complexity.
- Members of the same species often use agonistic behaviour to resolve conflicts over food, mate and other limited resources. Combats tend to be ritualised and usually end with establishment of dominance hierarchies which help to maintain the social organisation.
- One of the fundamental influences on social organisation in many species is the mating system adopted by the individuals. There is a rough correlation between the mating system and parental care given by the two parents in a species.
- Altruistic behaviour and cooperation among individuals are important factors in organisation of more complex and genetically related societies. This concept has been explained using examples from Lions and primates.
- By effective communication one individual influences the activity of others. Animals according to the habitat in which they live have used all sensory channels like visual, auditory, tactile and chemical.
- The most obvious information communicated by animals relates to perception of danger and reproductive activity. Communication signals regarding play behaviour are also an important part of the learning process in carnivores and primates.

15.7 TERMINAL QUESTIONS

1. Select a behaviour in any animal that you have observed. Using the flow chart in section 15.2. Break up that behaviour into its components and suggest at what level of organisation the given behaviour can be studied.

2. How do hormones organise behaviour patterns. Give two examples.

3. Why do animals migrate? Is migration an inbuilt behaviour or is it learnt.

4. Describe what is territorial behaviour and dominance hierarchy. How are these behaviour helpful in organising vertebrate social organisations?

5. Mention two most important benefits and two disadvantages of social life in animals.

....

....

....

....

....

6. Define communication in animals. With the help of an example state how communication helps in social organisation.

....

....

....

....

....

....

....

....

15.8 ANSWER

Self-assessment Questions

1. i) By filtering out stimuli that are not of utmost importance by the various neuronal command centres that remain in contact with each other. During walking if all the limbs of the animal were to move together there would be chaos. When flexor muscles of one limb contract, the flexors of the other limb are inhibited or when the animal starts feeding other behaviours are normally inhibited but if a predator is sighted during feeding, antipredator behaviour takes priority over feeding.
   ii) a) Circadian rhythm
   a) Circadian rhythm
   b) Circannual rhythm
2. i) An instinctive regular two way movement of an animal population along well defined routes linked to seasonal changes.
   ii) a) False, b) False, c) True, d) True, e) False
3. i) In insect societies there is usually only one reproducing female and several fertile males. While in vertebrates, all individuals are capable of reproduction.
   ii) a) harem, b) monogamy, c) male, d) female, male
   e) multi
4. Animals that are nocturnal would rely on auditory and chemical signals more than animals active during the day, who would rely also on visual signals. The habitat would also influence the type of communication used.

Terminal Questions

1. Let us say we select swimming behaviour in ducks for our study. Choose a species. You would have to then choose a particular population of ducks that can be observed. You next choose a group of ducks say 10, for your observation. The unit of behaviour that you may select is swimming. This is made up of several patterns of swimming like dipping in water, diving, flying, landing. Each of these is made up of short acts, for instance, diving is a pattern made of several short acts, diving with head dipped in water first, the length of time spent in diving, or staying under water during the act. Keeping the entire body under water. This act of diving is organised by different components i.e. anatomical (movement of wings, head, body), physiological – movement of muscle and bones, neurological – involvement of nervous system in the act.
2. After castration in stickle backs, complete absence of nest building. Absence of courtship displays in birds on being castrated.
3. Refer to section 15.3. Migration is both inbuilt as well as learnt. Many animals for example, eels, migrate from the sea to the rivers without any help or involvement of

learning while salmons, memorise the odours of their native rivers and migrate back to them.

4. Refer to section 15.4. Territorial behaviour defines the area in which the animal lives feeds and reproduces. It helps in keeping rivals away as well as securing a suitable mate. Dominance hierarchies maintain the integrity of social organisation so that individuals can live in groups peacefully without conflict and food, mate and other limited resources are managed better.

5. a) Benefits
   1) Groups offer protection against predation
   2) Rearing of young ones is shared

   b) Costs
   1) Spread of disease
   2) intraspecific conflict for food and other resources

6. Refer to section 15.5.

UNIT 16 ADAPTIVE BEHAVIOUR

Structure

16.1 INTRODUCTION

In the earlier two units we attempted to answer the proximate question. How do animals behave in different ways in terms of genetic hormonal, neuronal and expenential differences among individuals. In this unit we seek ultimate answers i.e. the adaptive value of a particular behaviour.

Adaptation is a fact of nature. Organisms are equipped in a variety of ways to survive successfully in their environment. This fitness to live under specific environmental conditions is conferred on organisms through the interaction of variation and Natural Selection. Consequently all heritable adaptive changes are evolutionary changes.

The pressing need for survival in organisms has resulted in the evolution of a variety of strategies for (a) luring the prey for food; (b) attracting the mate for reproduction, and (c) defending oneself from predators. These strategies are related to the habitat of the animal. For example, in the darkness of caves, bats and cave birds navigate and hunt through echolocation. In the abyssmal depths of the sea, fishes emit various patterns of light for the purposes of schooling, navigating and finding conspecific mates and food. Bright colours possessed by some vertebrates warn others of associated toxicity. Mimicry helps to conceal certain vertebrates from the eyes of predators. Locomotion is a characteristic of animals and vertebrates who walk run, swim, fly, climb and crawl for which their feet and body are specially adapted. Thus, apart from general adaptations necessary for day to day survival, there are special adaptations for self defence and defence of the young; for securing food and mate. Some of these special adaptations that help vertebrates to cope better and increase their survival, such as colouration, mimicry, bioluminescence, echolocation and variation in locomotion are outlined in this unit.

Objectives

After studying this unit you should be able to:

- explain the meaning and advantages of colouration and mimicry in animals,

- enumerate the various ways by which animals defend themselves and their young,
- discuss the phenomenon of bioluminiscence and its significance,
- explain echolocation in bats, aquatic mammals and cave birds,
- describe the forms and postures in relation to habitat and mode of locomotion of animals.

16.2 COLOURATION

A plethora of colours adorns the skin of living organisms. Wings and bodies of many birds are brightly coloured. The buttocks and scrotal regions of monkeys and baboons are red or blue. While some organisms are brightly coloured, others are of a subdued hue. Whether bright or dull, colour of the skin is of adaptive advantage.

16.2.1 Source of Colour in Animals

The colour of the animal integument is due to **pigments** or **biochromes** present in cells lying within the skin, below it or in deeper tissues of the body. Pigment containing cells are called **chromatophores**. The pigment may be concentrated in the centre of the chromatophore to produce a particular effect or it may be dispersed to produce another effect. In vertebrates, chromatophores are branched cells and may function under neural or hormonal control (Fig. 16.1).

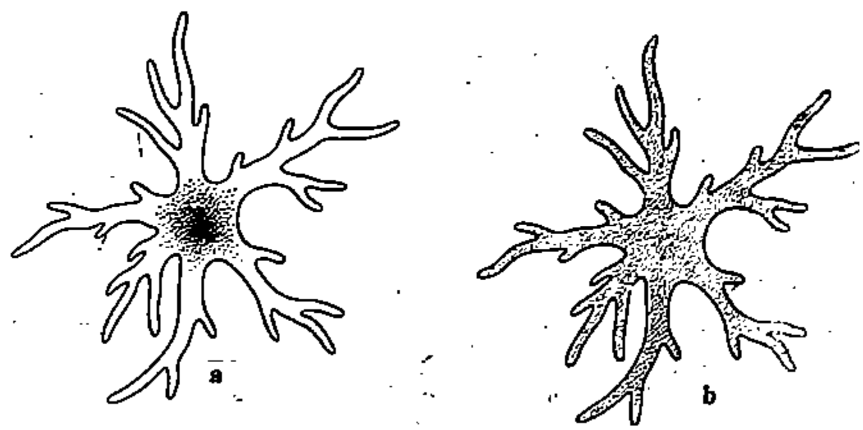


Fig. 16.1: Vertebrate pigment cells are called chromatophores. (a) Chromatophores make the skin light when the pigment is dispersed and (b) dark when pigment is concentrated.

Animal pigments responsible for different colours are:

i) **Melanins** for brown or black colour which are contained in **melanophores** are the most common. Mammals are sober coloured due to the presence of melanin. Coloured patches are seen in mandrills and baboons.
ii) Carotenoids are for yellow and red colour. The yellow pigment containing cells are called **xanthophores** and those containing fat soluble red pigment are called **erythrophores**.
iii) **Pteridines** and **ommochromes** are for yellow colour. Green colour is due to combination of yellow pigment and blue structural colour.

Apart from colour as a result of pigments, colouration in animals may be also due to:

a) **Structural colours** -Colours like the red buttocks of monkeys are due to tyndall scattering by the skin containing melanin. Colours due to reflection of certain wavelengths by surface layer are called structural colours.
b) **Iridiscent colours** - When colours reflected by layers of cells undergo phase interference, they produce shining colours or iridiscent colours.

16.2.2 Colour Perception

Colour perception in animals is due to three different types of cone cells in the retina which perceive respectively red, green and violet colours. From the retina, the impulse reaches the visual centre of the brain. Fish and birds possess good colour vision. Among mammals, primates and some squirrels have good colour vision.

16.2.3 Adaptive Colouration

The major adaptive advantage of colouration is protection from predators. Such colouration assumes the following forms:

i) **Protective colouration or cryptic colouration** helps the animal to blend with its surroundings and escape the predator's eyes.
ii) **Warning or aposematic colouration** warns the predator of aggressive and dangerous behaviour.
iii) **Signal and recognition marks** - Certain vertebrates posses colour patches on the skin which serve as **signal and recognition marks**. Specific colours may also help in attracting or recognising the mate. This is termed **sexual colouration.**

I. PROTECTIVE COLOURATION

Colours and body shape of certain animals help them to hide from the view of enemies through camouflage (Fig. 16.2). Both predators and the prey possess such cryptic colours which protect them from each other's eye.

Fig. 16.2: Protective colouration of animals due to their permanent colours and shapes. (a) Asian horned toad and (b) Australian brown newt and (c) Night jar bird. All of these get concealed among plants as their colouring and body shape blend in with tree branches leaves or forest floors. The animals in this picture are symbolically grouped together. They actually live in different regions of the world and not in the same forest.

Cryptic colouration which renders the animal inconspicuous is of four types.

(i) **Animals may be permanently coloured such that they blend with the surroundings.** Some examples are:

(a) The arctic hare, arctic fox and the polar bear (Fig. 16.3 a) have milk white fur (hair) to blend with the snow covered polar regions. The camel, the gazelle and other desert animals are dull coloured and blend with the colour of sand. The tawny coat colour of the lion (Fig. 16.3 b) blends well with the colour of grasses and the terrain which it inhabits.

Fig. 16.3: Camouflage of animals due to their permanent colour. a) The polar bear's white fur merges perfectly with the ice and snow of the Polar region, b) The African lion's tawny coat blends successfully with dried, yellow grass and brown ground.

(b) Tree frogs and tree snakes are green and can hardly be spotted among the foliage.

(c) Sea birds like gulls and terns are steel grey or blue from above and white below. Their colour harmonises with the sea when viewed from above and with the sky when seen from below.

(d) In certain fishes, the upper surface is dark and the lower surface light coloured. Such a counter shading strategy protects the fish from the predatory bird which watches from above but cannot spot the fish as it blends with the darkness of deep waters. The large predatory fish from below misses it as the light belly blends with daylight (Fig. 16.4).

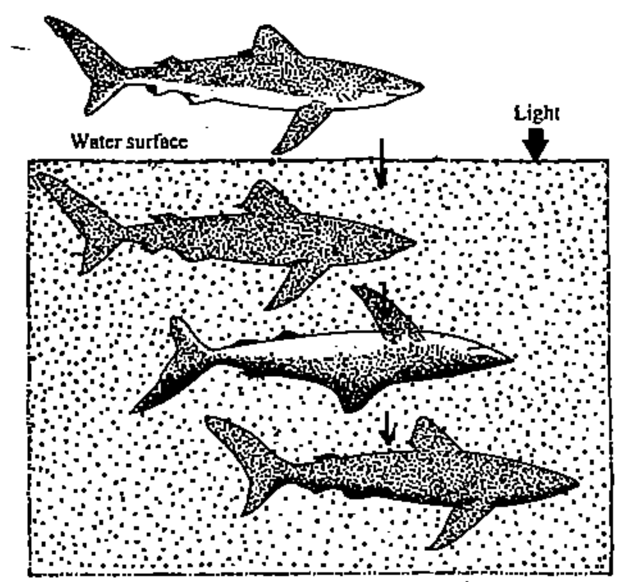


Fig. 16.4: Dark coloured upper surface and light coloured lower surface of a fish.

(ii) **Animals may change their coat colour according to their surroundings by positioning and repositioning the pigment present in the chromatophores.** Examples are:

(a) Among fishes, minnows can change colour with the help of chromatophores. They look light near the sandy and pebbly bank of the lake and dark near the muddy bottom. Under the influence of nerve excitation, the black pigment in the chromatophore cell converts into a spherical central mass. Minute little masses of pigment become invisible to the naked eye and the skin seems light. When the stimulus to the nerve stops, pigment spreads out within chromatophores and skin appears dark.

(b) In amphibians such as *Hyla* the tree frog which is green on foliage and brown on the bark of the tree, the pituitary gland or hypophysis releases a hormone intermedin or melanophore stimulating hormone (MSH). The hormone stimulates the dispersion or concentration of the pigment within chromatophores. (Refer Fig. 16.1)

(c) The garden lizard *Calotes* is green among leaves and brown on twigs and on the ground. Chamaeleon (*Chamaeleo*) is another lizard capable of changing colours to blend with the surroundings (Fig. 16.5).

Fig. 16.5: Protective colouration as seen in Chameleon which changes colour according to surroundings. (a) A leaf frond drops over a basking Chameleon. (b) The Chameleon skin gets warmed by the frond and becomes lighter merging with the foliage.

(iii) **Acquired colouration:** Some animals get camouflaged when they plant upon themselves other material from their surroundings. For example:

(a) Sea dragon of Australian waters, *Phyllopteryx* has leaf like processes which helps it, to covers itself with leaf like fronds which give this fish (a relative of sea horse) a strong resemblance to a piece of sea weed (Fig. 16.6).

(b) The shrimp fish get protected by sheltering among the spines of a sea urchin.

Fig. 16.6: Protective acquired colouration. A leafy sea dragon looks more like a fragment of sea weed than a fish. It is thus well camouflaged among fronds of sea weed.

(iv) **Disruptive colouration**: Jungle animals such as tigers and zebra are striped or banded. Body parts coloured in two different colours break the actual outline of the animal and help it evade recognition by enemies (Fig. 16.7). For example:

(a) The South American anteater *Tachyglossus* has disruptive colouration on head and forelegs. Such a sharp banded pattern of contrasting colours helps to break the outline of the animal (Fig. 16.7 a).

(b) Zebras often move in herds. A predator such as the lion cannot easily pick out the shape of a single animal because of the stripes (Fig. 16.7 b). The zebra gets enough time to escape.

(c) The lizard gecko gets concealed on a tree trunk because of disruptive colours.

(d) The contrasting colour pattern of the bird, night jar (refer again to Fig. 16.2) does not give a coherent shape so that it is able to evade a watchful predator.

II. WARNING OR APOSEMATIC COLOURATION

Bright colours of the body are an ecological strategy. They advertise the poisonous nature to potential predators. The aesthetic value of bright colours of certain animals is nullified by a poisonous bite, a foul smell or a disagreeable taste, so much so that the predator associates bright colours with inedibility (Fig. 16.8).

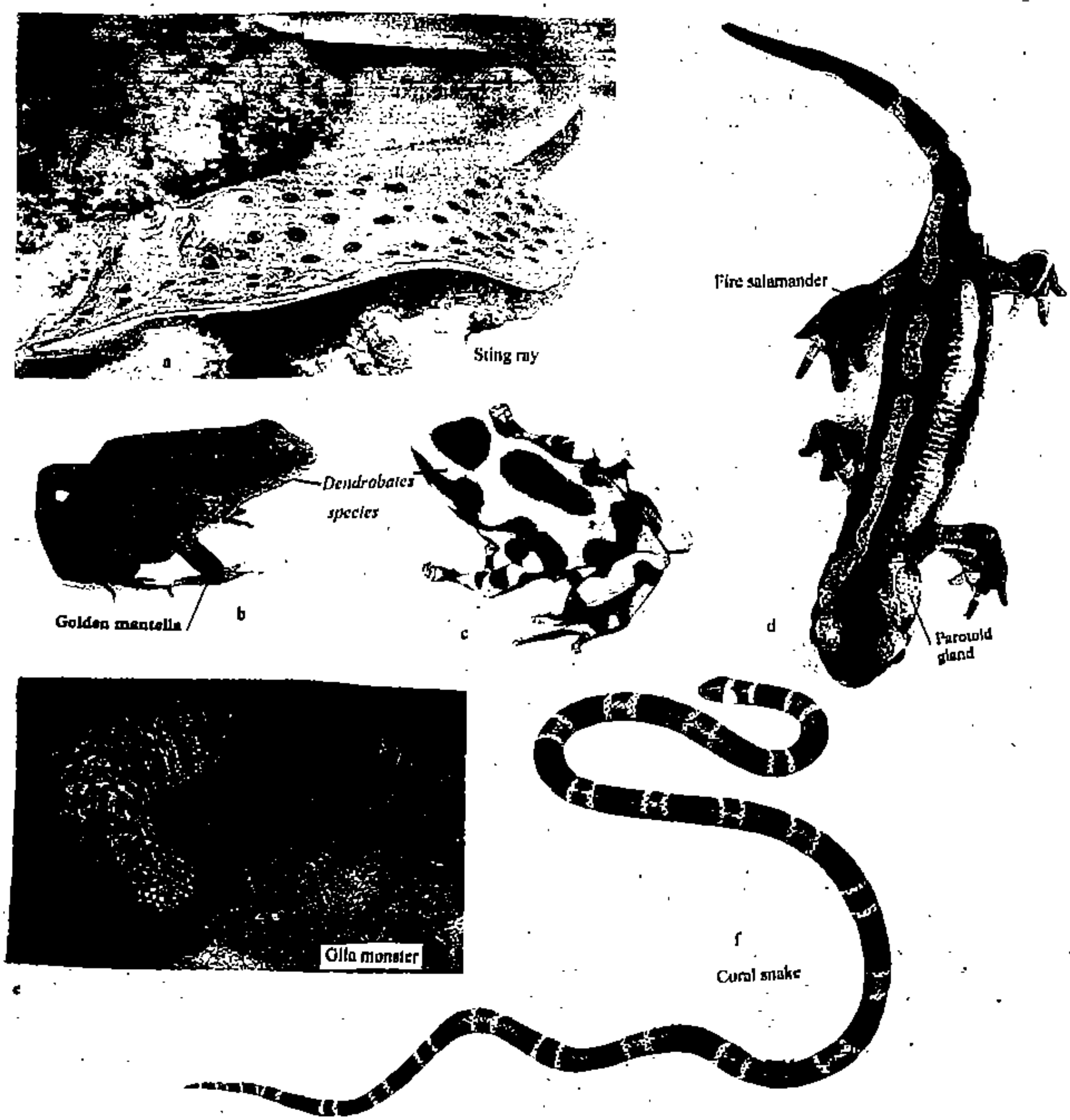


Fig. 16.8: Aposematic colouration. Bright colours of most vertebrates is linked to their poisonous nature and so act as a warning to potential predators. (a) A blue-spotted sting ray capable of giving deadly electric shock. (b) Poison dart frog of South America. (c) Golden mantella frog of Madagascar (Africa) that produces the same kind of poisonous chemical as poison-dart frog. (d) Brightly coloured poisonous fire salamander amphibians. (e) Attractively banded poisonous coral snake (f) Brightly coloured *Heloderma* which is the only poisonous lizard.

(a) Torpedo, the electric ray has bright blue spots which warn the predator of a deadly electric shock. (Fig. 16.8 a)
(b) The brightly coloured skins of amphibians like the deadly poison dart frogs (Fig. 16.8 b) of Central and South America, the poisonous frog of Africa (Fig. 16.8 c) and poisonous salamanders like the yellow and black banded tiger salamander (Ambystoma) as well as the brightly coloured fire salamander (Fig. 16.8 d) warn the predators of their nauseating toxic slimy secretion released by their skin.
(c) *Heloderma* or Gila monster, the only poisonous lizard in the world, is brightly coloured (Fig. 16.8 e).
(d) The coral snake (Fig. 16.8 f), with bright red and black alternating bands and edged with yellow advertise that they possess strong poison.

III. SIGNAL MARKS AND RECOGNITION MARKS

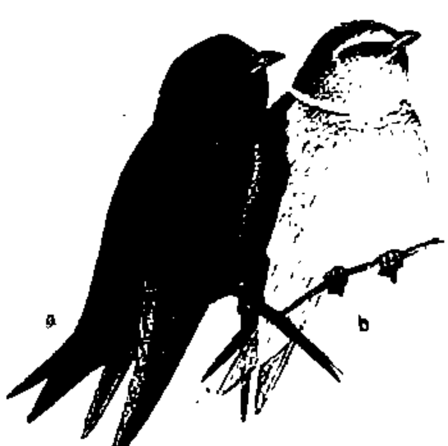
Patches of colour on the body of certain animals, when flashed carry a message for the conspecifics (members of the same species) especially in gregarious forms. Examples are:

(i) Member of white-tailed deer of North America (Fig. 16.9 a) on sensing imminent danger would flash a white patch below the tail to alert the others who make a hasty retreat. Similarly, the Poghorn antelope of North America flashes white hair patches on the rump. (Fig. 16.9 b).

Fig. 16.9: Warning signals of animals (a) the white tailed deer of North America showing its raised tail and rump hair indicating that it senses danger (b) the poghorn antelope of North America which has the most distinct white marking to signal danger.

The cottontail rabbit *Lepus sylvaticus* however uses its white tail like a signal flag. The mother flashes the tail which shines in the dark and the young ones follow her to safety. The red and orange spots on the brook trout *Salvelinus fontinalis* help it to be recognised by conspecific mates.

In the animal world, males are brightly and beautifully coloured while females are drab and dull coloured. The plumage of the male peacock, the red nuptial plumage of the cardinal bird, the male pheasants, the red comb of the cock of domestic fowl the blue plumage of the male of purple martin (Fig. 16.10) are examples of sexual colouration. Among the mammals in various species of deer, and in lions, females are dull compared to males.



16.10: Sexual colouration as seen in purple martin bird (a) male (b) female.

16.3 MIMICRY

You have already learnt that one method to escape from enemies may be through adaptive colouration. A defenceless animal can keep out of harm's way by running away from predators which may not always be a successful method. A number of animals defend themselves by imitating other animals. This is termed 'mimicry'. Mimicry is derived from the Latin word 'mimicus' which means to imitate. Mimicry is thus another defence strategy. **Mimicry is defined as the resemblance in external appearance, shape and colour between organisms belonging to widely separated groups.** The animal which resembles another animal or natural objects amongst which it lives is termed **mimic** and the organism or natural object which is copied is called the **model**. Through mimicry, the mimic either conceals itself from predators or advertises itself as being harmful. In either case it escapes attack by predators.

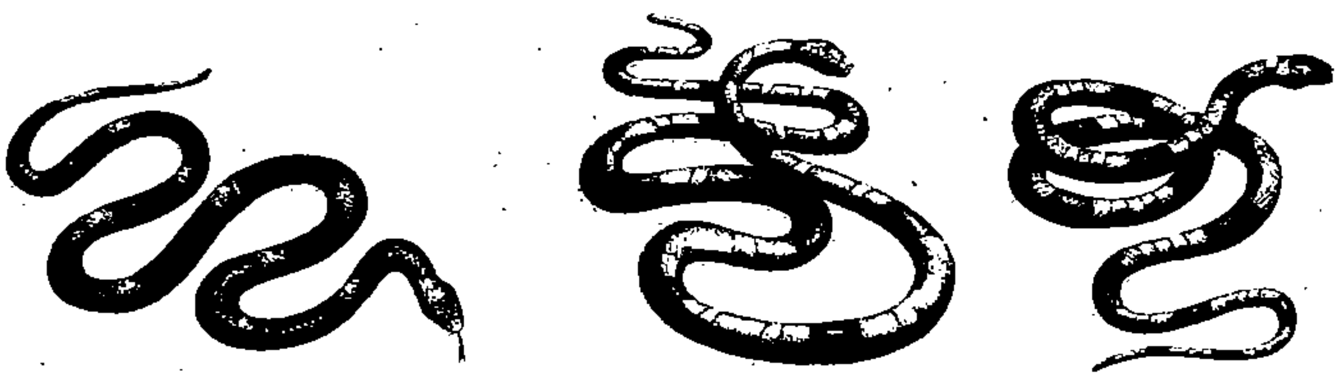
16.3.1 Types of Mimicry

Mimicry is of two kinds:

(i) Batesian mimicry
(ii) Müllerian mimicry

Batesian mimicry

Many unprotected species resemble distasteful species (Fig. 16.11). Both display warning colouration. The mimics, when among a large population of models are avoided by predators. Such a pattern of resemblance is called **batesian mimicry** after the British naturalist H.W. Bates. Batesian mimicry is exhibited by harmless snakes which mimic poisonous snakes. The poisonous snakes of the genus *Elaps* are beautifully coloured with alternating red and black bands. Several harmless colubrid snakes have similar colours and though not exactly identical, the similarity is sufficiently close to fool the predator.



a — Non poisonous king snake which has similar coluring to coral snake

b — lethal coral snake *Micrurus lemniscates*

c — mildly poisonous coral snake *Oxyrhopus trigeminus*

Fig. 16.11: Batesain mimicry exhibited by the (a) non poisonous, harmless king snake which resembles two types of coral snakes (through not related to them) (b) the highly lethal *Micrurus lemiscatus* and (c) the mildly poisonous *Oxyrhopus trigeminus*.

Müllerian Mimicry

This form of mimicry is named after the German biologist, Fritz Müller. Müllerian mimicry is defined as a phenomenon in which two or more unrelated but protected species resemble each other thus achieving a kind of 'group defence'. If animals resembling each other are all poisonous or dangerous, they still gain an advantage by resembling each other as it affords collective protection.

In both Batesian and Müllerian mimicry, mimic and model must not only look alike but also behave or act in a similar fashion if predators are to be deceived. Also mimics have to spend most of their time in the same habitats as their models. Further more they should be greater in number. If they do not fulfill both these conditions the predators would discover that mimics living in a particular area are palatable!

16.3.2 Different Forms of Mimicry

Mimics, the masters of disguise, may:

(a) mimic dead or inanimate living objects (protective mimicry);
(b) mimic harmful species (warning mimicry);
(c) exhibit a particular part of the body in order to resemble or mimic a bait and lure the prey (alluring mimicry);
(d) feign death (conscious mimicry).

Protective mimicry - Examples.

(i) The trumpet fish rests head down among gorgonian seaweed and blends with it, looking just like additional prongs of the seaweed (Fig. 16.12 a). A yellow butterfly fish (Fig. 16.12 b) before a coral is disguised due to its bold pattern that detracts from the shape of its body. Furthermore, its flashy eyespot on the tail helps it escape when the predator attacks the eyespot instead of the true eye. The scorpion fish resembles a barnacle-encrusted rock (Fig. 16.12 c).
(ii) The horned toad of Asia (Fig. 16.2) conceals itself among large leaves and even resembles them in shape.
(iii) The bittern bird, suspicious of an approaching predator stands rigidly among reeds with neck and beak stretched upwards. The yellow ventral side of abdomen with dark vertical stripes is turned towards the enemy. On a calm day when it stands still, it resembles the surrounding reeds. On a windy day the body sways with the reeds.

Predators also mimic and deceive the prey. The zone tailed hawk *Butea* flies among vultures which do not prey on small animals. While flying among vultures, it suddenly pounces on the unsuspecting prey.

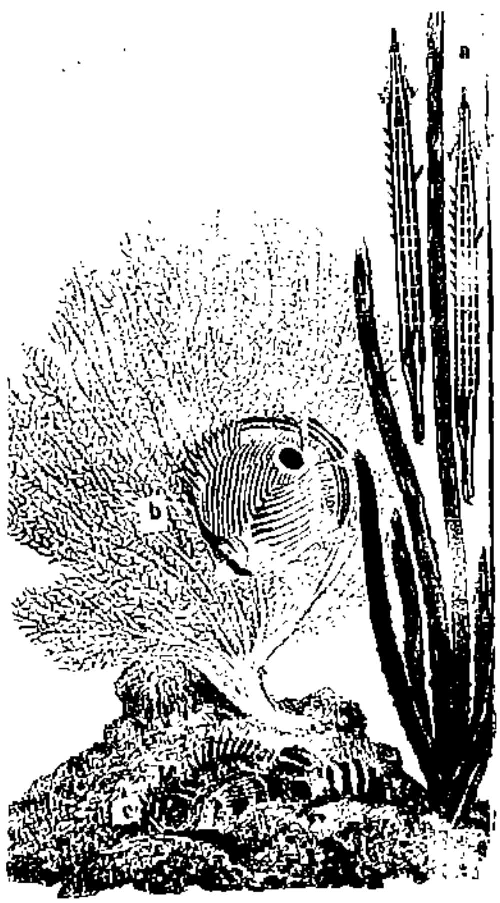


Fig. 16.12: Protective mimicry. (a) File fish head down among gorgonion seaweed. (b) Camouflaged butterfly fish (c) A hoary scorpion fish which blends with the surroundings and whose toxic spines fend off attackers.

Warning mimicry - Examples

(a) The harmless hognose snake *Heterodon* (Fig. 16.13) is not brightly coloured like poisonous snakes but it flattens its head making it triangular and hisses like a

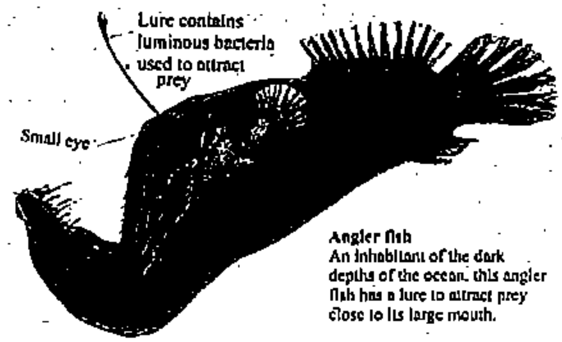
Fig. 16.13: Warning mimicry. The hognose snake in a threatening gesture.

poisonous snake (cobra-like). It may even try to strike and pretend to be dangerous when in reality it is not.

(b) Eye like markings are present on the shell of Burmese soft turtle *Trionyx hurum* and on tail of butterfly fish (Fig. 16.12 b). A predator usually strikes on the head, near the eye. The eyespots on the posterior part of the shell or tail misdirects the predator.

Alluring mimicry - Examples

The deep-sea anglerfish has a modified first fin ray of the dorsal fin, the illicium. Anglerfish has a fleshy cutaneous appendage which is tossed like a bait for luring the fish on which it preys (Fig. 16.14). The American horn frog *Ceratophrys* sits still and moves one finger of the hand to which small frogs and other animals get attracted. *Ceratophrys* promptly preys on them.



16.14: Alluring mimicry. Angler fish is an inhabitant of the dark depths of ocean. This angler fish has a lure to attract prey close to its large mouth.

Conscious mimicry - Examples

When danger approaches, certain animals particularly by certain snakes and opossums (Fig. 16.15 a and b) feign death. The american Opossum, *Didelphis* becomes unconscious and seems as though it is dead. Hard beetles drop as though dead and resemble pebbles when they encounter danger from enemies.

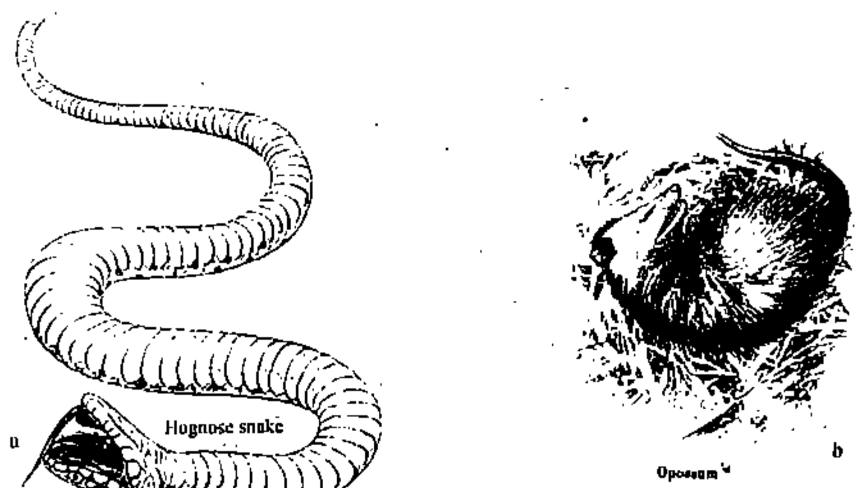


Fig. 16.15: Conscious mimicry. (a) The hognose snake feigns death when threatened. It rolls on its back, hangs opens it mouth and emits a smell similar to decaying flesh (b) The opossum appearing dead.

SAQ 1

1. Fill in the blanks with appropriate words:

   i) The pigment containing cells in the skin are called ....

   ii) The pigment .... is responsible for brown or black colour in vertebrates.

   iii) The protective mechanism whereby animals use other objects to disguise themselves is termed as .... colouration.

iv) Protective or .... colouration helps the animal to blend with its surroundings in order escape the predators eye.

v) .... is defined as the resemblence in external appearance, shape and colour between organisms belonging to widely separated groups.

vi) The type of mimicry in which an unprotected mimic resembles a dangerous model is termed as .... mimicry.

vii) In .... mimicry an animal uses its body part to resemble a bait so that it can catch its prey.

16.4 BIOLUMINESCENCE

A variety of animals shine by their own light. The light produced is by chemical reactions catalysed by an enzyme. The reasons for the production of light vary in different groups of animals.

Light production by organisms is termed **Biological Luminescence** or **Bioluminescence.** In vertebrates no self luminous forms are found among amphibians, reptiles, birds and mammals. However, a variety of fishes, especially deep sea dwellers, are bioluminescent.

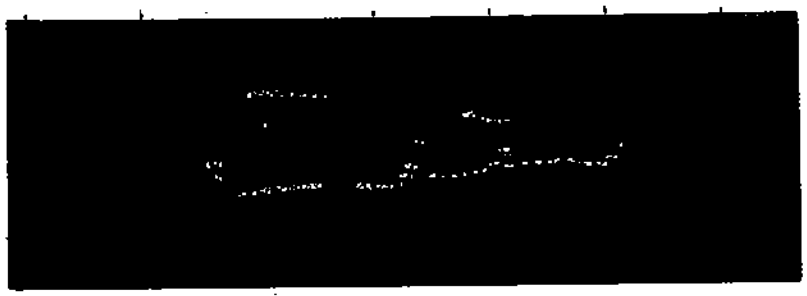
In the ocean depths, only the faintest rays of light reach and it becomes essential for the different kinds of fishes to recognise members of their own species. Patterns of tiny lights are distributed over the body. These lights or **photophores** are flashed continuously or at intervals and act as recognition signals.

About 95% of deep sea fishes possess light organs or photophores. Light patterns are the same in the members of a particular species. The light flashes, however, are different in the male and female of a species.

The lantern fish, *Diaphus*, and the hatchet fish, *Argyropelecus* along with their patterns of light flashed by them are shown in Fig. 16.16 a and 16.16 b.

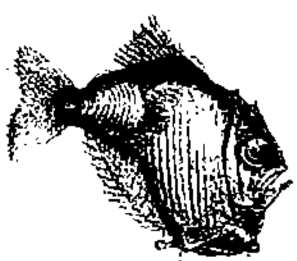
a

a i The lantern fish *(Diaphus)* has luminous organs along its belly.



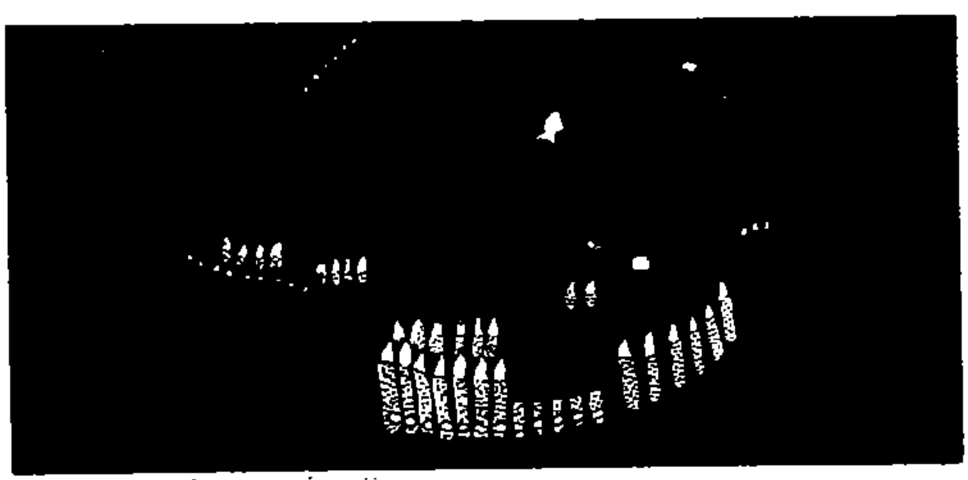
a ii Pattern of light organs of lantern fish as seen in the dark

b



bi

Hatchet fish These fish live in the twilight zone of the ocean where a little light filters down from the surface. They have rows of light producing organs on their bellies and tails, which make them harder to see from below against the little light that there is.



bii Pattern of light organs of Hatchet fish as seen in the dark

Fig. 16.16: Bioluminescent fishes.(a) Lantern fish *Diaphus danae* and (a i) pattern of its light organs as seen in the dark. (b) Hatchet fish *Argyropelecus* and (bii) the pattern of light it shows in the dark.

16.4.1 Luminous Organs in Fish

The luminous organs are **glands** situated in different parts of the body in different species of bioluminiscent fish. Some luminous organs are near the eyes, a number of them are arranged in rows along the side of the body or on the under surface (Fig. 16.16 b).

The most highly developed photogenic organs are ones which have glandular cells and also a focusing lens which produces a parallel beam, an iris to control the amount of light, a reflecting layer often of silver guanin crystals and a pigment enclosing the whole organ to prevent light from radiating into body (Fig. 16.17).

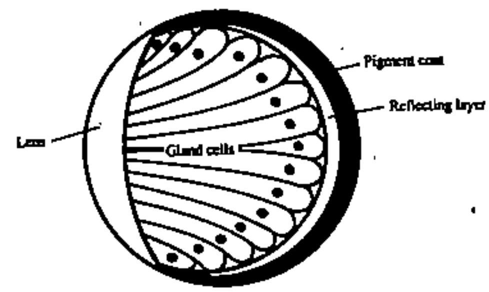


Fig. 16.17: Photogenic organ of bioluminescent fishes.

Basking in others light!

The Indian ocean fish *Photoblepharon* (Fig. 16.18) has symbiotic association with luminescent bacteria. Under each eye, there is a highly vascularised kidney shaped, white spot in which the luminous bacteria grow. Light of the bacteria can be shut off by a fold of skin drawn over the eyespot.

In certain deep sea fish, photogenic organs are large and embedded in pigmented pockets. They can be rotated with muscles, into the pockets or a curtain like membrane can be drawn on the organ like a shutter. The light emitted thus flashes intermittently.

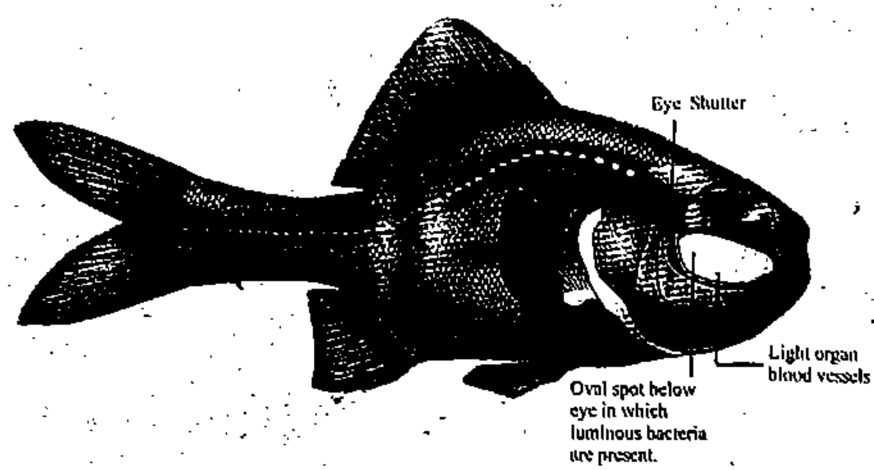


Fig. 16.18: Bioluminescent fish *Photoblepharon*.

In some fish, light organs are on the sides of the head and expel luminous clouds in water to confuse the predator.

16.4.2 Bioluminescent Molecules

Bioluminiscense is due to an enzyme catalysed chemiluminiscence in which the light emitting substrate is oxidised. The oxidation reaction is accompanied by emission of light.

The light emitting chemical is **Luciferin** (Lucifer : light bearer). Luciferin is synthesised in the glandular tissue of the photogenic organ (Fig. 16.17). Luciferin is a protein with more than one thousand amino acids. Approximately, for each molecule of luciferin oxidised, one quantum of light is emitted. The oxidation of luciferin is catalysed by the enzyme **Luciferase**. It also contains more than a thousand amino acids. Luciferin from various luminous organisms has been found to be different. The oxygen required for oxidation of Luciferin comes from the plentiful supply of blood vessels serving the gland.

16.4.3 Mechanism of Bioluminescence

Bioluminescence is an energy requiring **oxidation reaction**. In the presence of oxygen, Luciferin is oxidised by expending ATP. The reaction is catalysed by luciferase and ligh is emitted as a result.

$$LH_2 \text{ (Luciferin)} + ATP + O_2 \xrightarrow{\text{Luciferase}} L = O \text{ (Oxidised Luciferin)} + AMP + P_i + H_2O + \text{LIGHT}$$

The light is shut off when the blood supply is shut off by tiny muscles which constrict the blood vessels supplying the gland. When oxygen does not reach the gland, light is extinguished.

Light production is under control of the nervous system. When the stimulus arrives at the luminous gland, Luciferin, ATP and Oxygen are consumed. The products obtained are: oxidised Luciferin, AMP (adenosine monophosphate), inorganic phosphate, and light (Fig. 16.19).

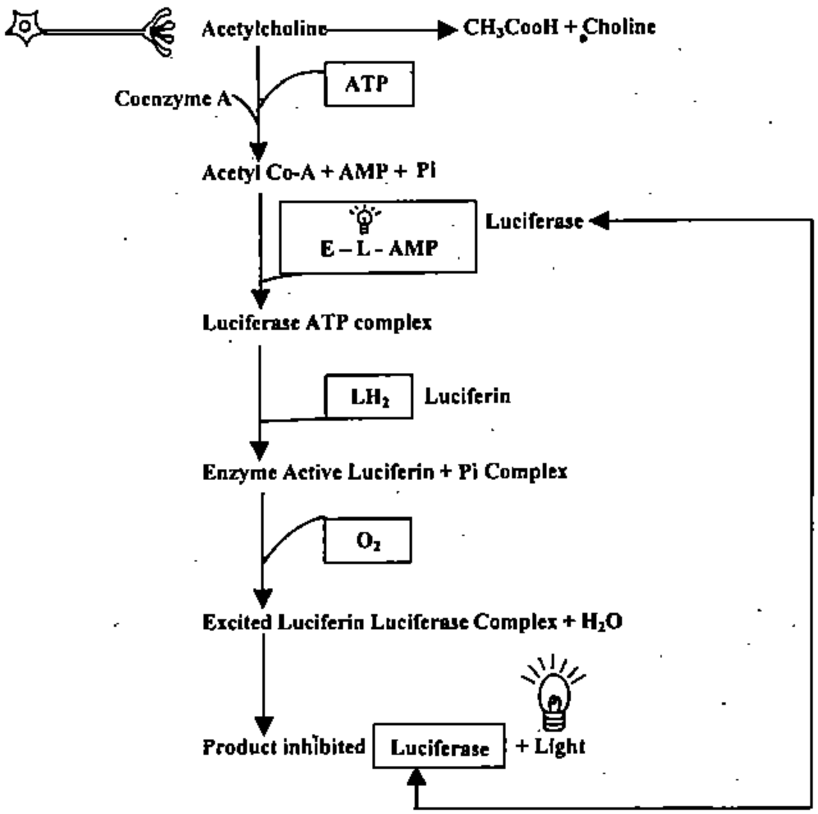


Fig. 16.19 : Mechanism of Bioluminescence.

16.4.4 Colour and Type of Emitted Light

Bioluminescent fish mostly emit blue or blue green light. But few species of fish emit red, pale yellow, yellow-green, orange-purple or blue white light. It is interesting to note that the wave length of light from light organs in a particular species coincides exactly with the wave length readily absorbed by sensory receptors of the eyes of that species. Light emission in fish is probably to recognise conspecifics in the dark. The light which is emitted is **cold light**, whether flashed intermittently or continuously. Light organs are therefore extremely efficient.

16.4.5 Significance of Bioluminescence

Light emission serves various purposes. It may help (i) to keep fish together in the darkness of the deep sea; (ii) to lure and capture prey; (iii) to bring sexes of the same species close to each other for mating; and (iv) to deceive the predator.

Luminescence patterns as recognition signals

The luminous patterns are numerous. Fig. 16.16, as you have seen, shows two types of bioluminious patterns). A double row of tiny lights, evenly spaced or in groups of three, or in a triangular pattern are common. These rows may be below the lateral line or even lower. In viper fish, *Chauliodus* luminous organs are in the mouth. In some they are near the tail and act as search lights. In some fish, first sudden flashes are emitted. A conspecific, close by may respond and then there is full display by both fish as a symbol of recognition. Some fish turn on lights at specific intervals. Such a recognition signal pattern is constant for all members of a species and different in even closely related species. Intraspecific recognition signals are for mating or schooling in dark waters.

Predation and prey capture

Light may be employed to lure positively phototactic (movement towards light) food organisms. In deep sea angler fish, a luminous organ hangs like a glowing bulb from the tip of the elongated first fin ray of dorsal fin. It acts like a fishing rod and is trailed in front of the mouth. Smaller fish, the prey, are attracted to this light and go straight into the mouth of angler fish. (Refer again to Fig. 16.14)

Reproduction

There are specific light emission patterns which differ in the two sexes of a particular species. These flashing patterns in the dark depth of the sea are perceived as recognition symbols by potential mates belonging to the same species.

Escape from enemies

Most marine light emitters give out blue light to blend with the colour of sea water. By faintly illuminating lower surface of the body, luminous organs present beneath the abdomen may help to merge the outline of the certain fishes.

Some fish use luminous clouds for escape from predators.

Lighting up

Luminous organs near eyes and jaws and on the sides of the belly of certain fishes are used as lamps to light up surrounding water in front and beneath the fish, in order to assist it in swimming and navigating rather than groping in dark waters.

SAQ 2

i) Define bioluminescence.

....

....

....

....

ii) Name the light emitting chemical and the enzyme which catalyses its oxidation.

....

....

....

....

iii) What is the chemical nature of the luminous substance?

....

....

....

....

iv) Mention the significant advantages of bioluminescence.

....

....

....

....

v) Name the substances consumed for light emission reaction and the products obtained.

....

....

....

....

16.5 DEFENCE IN ANIMALS

The survival instinct is foremost in living organisms. One of the needs for survival is defence from predators and intruders. Animals exhibit a variety of strategies by which they defend (i) themselves (ii) their young ones or eggs and (iii) their territory. Animals also defend themselves from environmental hazards. Temperature regulation in birds and mammals is a means to defend oneself from the vagaries of the weather. Some animals hibernate or aestivate in severe winter or summer. In extreme environments like in the desert, the caves, oceans and deep sea, animals have altered their habits to suit the environment.

The desert animals forage during cooler hours or night and seek protective shelters during the day. Birds migrate to warmer areas during severe winter.

16.5.1 Adaptations for Defence

For defence purposes, animals may either have (i) structural adaptations or (ii) chemical adaptations or (iii) behavioural adaptations. Structural adaptations include integumentary modifications such as claws, hooves, armour etc. Chemical means of defence are secretions of poison glands, stink glands or changing the colour of the skin by positioning chromatophores. Behavioural adaptations are dramatic. Some animals feign death on sighting a predator, some mimic inanimate objects, while some adopt warning postures. Some prey organisms save themselves by running faster than the predator.

The skin of some amphibians is poisonous (Refer again to Fig. 16.8, b, c and d). The skin of frogs like the poison arrow or dart frog and some toads are poisonous to humans (See also Fig. 16.23 which comes later in the unit).

Among the reptiles, only the lizard *Heloderma* (Gila monster of Mexico) is poisonous (Refer again to Fig. 16.8 e). Several snakes (Fig. 16.8 f) secrete venom (poison) for which their salivary glands are modified into poison glands (Fig. 16.20). The poison glands are primarily to stun and benumb the prey. But their secretions also help in defence.

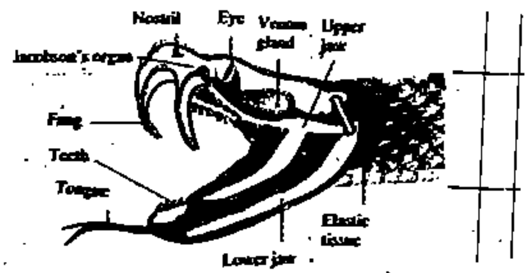


Fig. 16.20: Head of the poisonous rattle snake showing the venom apparatus. The venom gland is a modified salivary gland connected by a duct to the hollow fang.

Warning colouration: You have also learnt in the subsection 16.2.2 about the bright colours of poisonous animals which advertise their poisonous nature to the predators (Fig. 16.8).

Warning mimicry: You have learnt in subsection 16.3.1 about Batesian mimicry in which snakes by means of their shape and colouration, mimic poisonous snakes. The red and orange patches on the body of red backed salamander makes it look like the poisonous eft, as a result it is protected from avian predators.

16.5.2 Various Means of Defence in Animals

(1) **Speedy escape** : The best way to defend oneself is to run away from the clutches of the enemy. Fish use their genius at swimming and ungulates (horse, cow etc.) and kangaroos use their talent for fast running to escape from predators.

The Bolson tortoise, recently discovered in North Mexico makes a one metre long deep and several meters long, burrow in the hard desert soil. It basks at the mouth of the burrow and when a predator comes, quickly dives into the burrow. An aquatic turtle drifts away on a log at the sight of a predator.

(2) **Weaponry** : Antlers and horns (Fig. 16.21 a), teeth (Fig. 16.21 b), claws (16.21 c) and hoofs (Fig. 16.21 d) are used with full force when an animal senses a threat to its life. The canine teeth and sharp claws of carnivores are actually related to their carnivorous feeding habits but may also be used for defence. Hoofs and horns of the ungulates can be weapons of defence when required (Fig. 16.21).

Fig. 16.21: Animals weapons (a) Horn is used by goats and other horned animals to defend themselves and to show off their strengths to opponents (b) teeth is used by the wolf any many other animals to threaten and scare off other animals; (c) claws are used by the cat and other clawed animals for attack and defence (d) Hoofs are used by zebra and similar hoofed animals in order to defend themselves from their enemies.

(3) **Armour** : Scales and scutes cover the body of certain animals such as *Pangolin* (the scaly anteater) and crocodiles, and form a protective armour against attack by predators. The shell of tortoises and turtles also forms an armour against enemies. You have already learnt from Unit 3 that the shell of turtles is made of dermal bones fused to the vertebral column and the ribs. In most turtles a horny layer of epidermal scutes overlies the dermal shell. The shell is hard as a rock. The head and the limbs in a large number of turtles can be retracted into the shell for protection (Fig. 16.22 a). The hard skin of the rhinoceros and the hippopotamus forms their protective armour (Fig. 16.22 b).

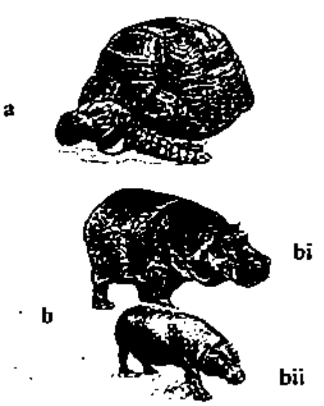


Fig. 16.22: Armours (a) The hard armour of the turtle, (b) the tough hide of the hippopotamus - (b, i) African hippopotamus (b, ii) Pygmy hippopotamus

(4) **Poison glands** : Secretions of mucous glands of some amphibia are irritating or toxic to predators. The poison glands are present on the dorsal surface of the animal (Fig. 16.23) and are exhibited to the predator during defence postures. Some poisonous amphibians also display, as you have studied in subsection 16.2.3, their bright aposematic colouration. (Refer to Fig. 16.8 again)

Toxins of toads, frogs and salamanders of certain families keep the predators away. The name "poison dart frog" for the brightly coloured amphibian is because South American Indians poisoned arrow tips with the toxin of this frog when they went hunting. The toxin is a cutaneous alkaloid batrachotoxin, a neurotoxin causing abnormal heart beats and even heart failure.

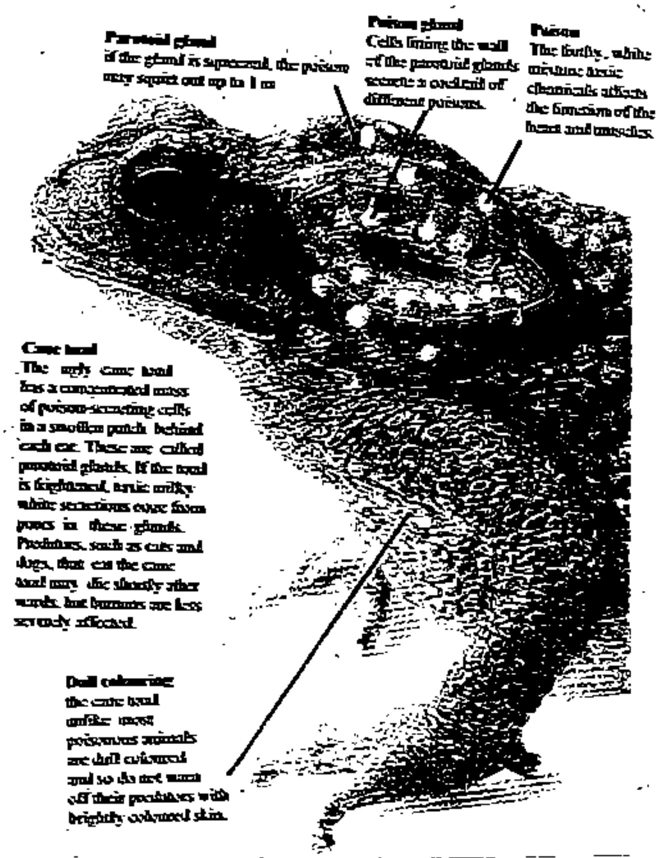


Fig. 16.23: Poisonous defence (a) A poisonous cane toad with a cutaway section of its skin showing its poison glands.

(5) **Stinking secretions** : Striped and spotted skunks (Fig. 16.24) have another efficient defence mechanism. They simply direct the anal glands which produce the stinking secretion straight at their foes.

Fig. 16.24: Stinking secretion. (a) When threatened, a striped skunk raises its tail as a warning. (b) Before spraying, the skunk gives warning by stamping its front feet or hissing and growling. It arches its back and may raise its front paws. (c) If the threat persists the skunk turns its anal glands and ejects two jets of its stinking secretion at the enemy.

The mother Kangaroo does not show autotomy but when exhausted after trying to outrun a predator, it drops the young one from her pouch to distract the predator.

(6) **Autotomy** : One mechanism for avoiding predators is the ability to break off the tail when seized by a predator (Fig. 16.25). You have already briefly read in 3.3.6 of Unit 3 that such a phenomenon of breaking off one's own body part is termed

autotomy. The broken tail moves rapidly and this distracts the attention of a predator, while the lizard escapes to save 'itself'. Caudal (tail) autotomy, as you already know is seen among salamanders and lizards. It is also observed in tuatara (*Sphenodon*), snakes and rodents. The tail is later regenerated.

Fig. 16.25: Lizard running away after dropping its tail which wriggles to and fro in order to distract a cat.

(7) **Threat displays and warning devices** : The cobra when confronted by danger displays its hood by flattening the skin of its neck. The cobra has long movable ribs in this region of its body and on spreading, they spread out the hood with a spectacle mark on it (Fig. 16.26 a). This suddenly makes the cobra which is also venomous look bigger than its size and scares the predator.

The rattle snake shakes the hollow segments at the end of its tail which make a rattling noise and alarms the enemy (Fig. 16.26 b).

Phrynosoma, the frilled lizard has a large frill around its head. This frill is opened up at the sight of the predator making the lizard look frightening (Fig. 16.26 c).

The mandrill baboon opens its large mouth to display sharp teeth in order to ward off its enemies (Fig. 16.26 d).

The deer raises its tail to show a white patch under the tail. The sudden exposure of the white patch alarms the predator (Refer again to Fig. 16.9).

Fig. 16.26: Some vertebrates display a threatening and warning posture when confronted by danger. (a) A cobra snake spreads its hood and hisses loudly to scare off its predator. (b) Rattle snake tries to scare off its enemy by making a rattling sound. (c) *Phrynosoma* expands the frill around its neck and looks very dangerous to the predators. (d) Baboons show their teeth to warn off their enemies.

(8) **Group defence** : Birds and primates act in groups to threaten the predator. A flock of starlings (birds) come together on seeing their predator, the falcon. The tight formation that they make deters the falcon from attacking them.

Audible message by small birds announce impending danger. If the predator is perched on a tree, small birds mob it and utter shrill sounds. If a flying predator approaches them they hide under the cover of the tree and make high pitched drawn out sound as a warning cry.

The arctic musk ox travel in herds. When attacked by a wolf, the adult males form a defensive ring facing outwards towards the enemy and protectively surround the females, the calves and the injured males (Fig 16.27 b).

Fig. 16.27: Group Defence is exhibited in the adult males of arctic musk ox which form a defensive ring against their enemies.

(9) **Mock fights** : Animals attack their enemies as a last resort. Initially for the purpose of defending their young from predator and their mate from another suitor, they make fierce faces, snarling mouths or let out horrific screams. Birds may lift wings as though they are ready to attack. Aggressive frightening postures are adopted as warning messages. You might have experienced a mother cat or dog making threatening sounds while she is feeding her litter.

(10) **Feigning death** : Rabbits and deer can freeze in their tracks to appear as dead to the enemy. An opossum and some snakes (Refer again to Fig. 16.15) can seem completely lifeless to a predator.

16.5.3 Territorial defence

Defending one's territory has a secondary role in defence. Familiarity with one's territory helps to defend oneself and escape from the predator. Animals are gentle creatures and a marked territory is recognised as prohibited. Territories are marked in different ways. Stickleback fish uses pebbles or particular plants. Birds, especially the males, advertise their territories vocally (Fig. 16.28 a). Dogs, foxes, wolves mark their territory with urine.

Antelopes have scent glands which they rub on trees (Fig. 16.28 b). A bison as well as a wild goat tears the bark with horns.

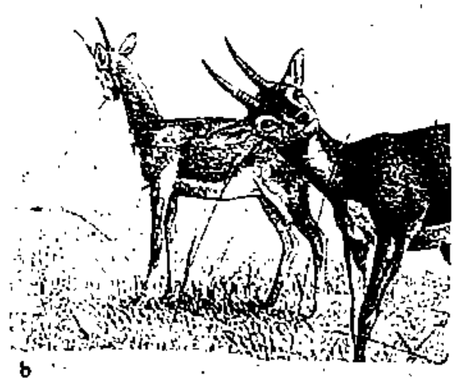


Fig. 16.28: Territorial defence. (a) Male red-winged blackbirds defend their territories by conspicuous display from exposed perches as you can see in this picture. At the time of display the male erect their body feathers, spread their wings and tail and elevate the red feathers on their shoulders. This display is always accompanied by a song and is called a song spread. It warns other males to stay away but it attracts females searching for potential mates. (b) The dwarf antelope called oribi mark their territory systematically. The male first bites off a grass stem to head height and then pushes his scent over the stem, covering it with a sticky black secretion. Territorial marking by oribi is done at times of conflict, stress and mating.

When territories are marked, intruders which may be predators or rival conspecifics, immediately realise that they are trespassing and may face an attack by the territory owner. Territorial lizards such as *Anolis* defend the territory by doing pushups, head bobs and display their gular fan. A male challenges another male by adopting aggressive postures because of which the male intruder flees.

SAQ 3

1. Why is "**poison dart frog**" called so?

   ....

   ....

2. Name five different methods of self defence in animals.

   ....

   ....

   ....

3. In what way do the following save themselves from predators? Answer in one or two words.

   i) an eft
   ii) a lizard
   iii) a rabbit

   ....

   ....

   ....

16.6 ECHOLOCATION

Mammals such as bats (Order Chiroptera), dolphins and whales (Order Cetacea), sea lions and seals (Order Pinnipedia) emit shrill **ultrasonic** cries. Their auditory apparatus (ear) is geared to receive echoes of these cries. The echoes help them to detect objects in their environment and to navigate in the dark. The ability of an animal to detect obstacles and prey from the echoes of its own sounds is termed **echolocation**.

16.6.1 Sonar or Echolocation in Bats

Bats are nocturnal mammals. Many species of bats live in dark caves. While flying in the dark they produce high frequency sounds of greater than 100,000 cycles per second and, therefore, of very short wave length. These sounds reflect back from objects in their path, apprising the bat of the size, shape and distance of the objects (Fig. 16.29). High frequency sounds help to detect tiny flying insects on which the insectivorous bats prey. The bat gets a detailed image of its prey's environment from the echoes of its own cries. Furthermore the flying insect makes faint ultrasound noises which the bat recognises. Bat brains have echodetector nerve cells or neurons which respond more intensely to the second sound (the echo). The echo detector cells inform the bat about the closeness of the obstacle.

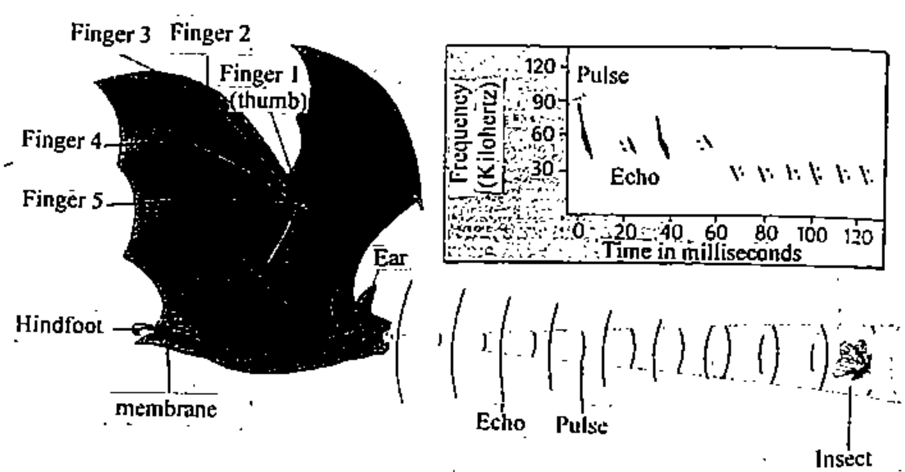


Fig. 16.29: Echolocation by the little brown bat *Myotis lucifugus* of an insect. The bat's mouth directs frequency modulated pulses in a narrow beam. As the bat nears its prey, it emits shorter, lower signals at a faster rate.

16.6.2 Echolocation in Aquatic Mammals

Whales and dolphins produce underwater sounds of frequencies as high as 300,000 cycles per second. Sound travels about four times as rapidly in water as through air. Also the density of mammalian body and of the water is similar. Thus the ear of the aquatic mammals which use ultrasound and echolocation for navigating under water, is remarkably adapted. There is no pinna or external ear but a minute auditory canal is present. The tympanic bone which lodges the cochlea is suspended from the skull by ligaments and surrounded by a cavity filled with air or foam. Sound waves can be transmitted by specially modified auditory ossicles.

Aquatic mammals produce sound through nasal sacs opening into the external nostrils termed **blow holes** (Fig. 16.30 a). From the differences in the intensity of reflected sounds received in each ear, dolphins, porpoises and whales can know the direction of the obstacle (Fig. 16.30 b). They are also capable of modulating sound that they emit.

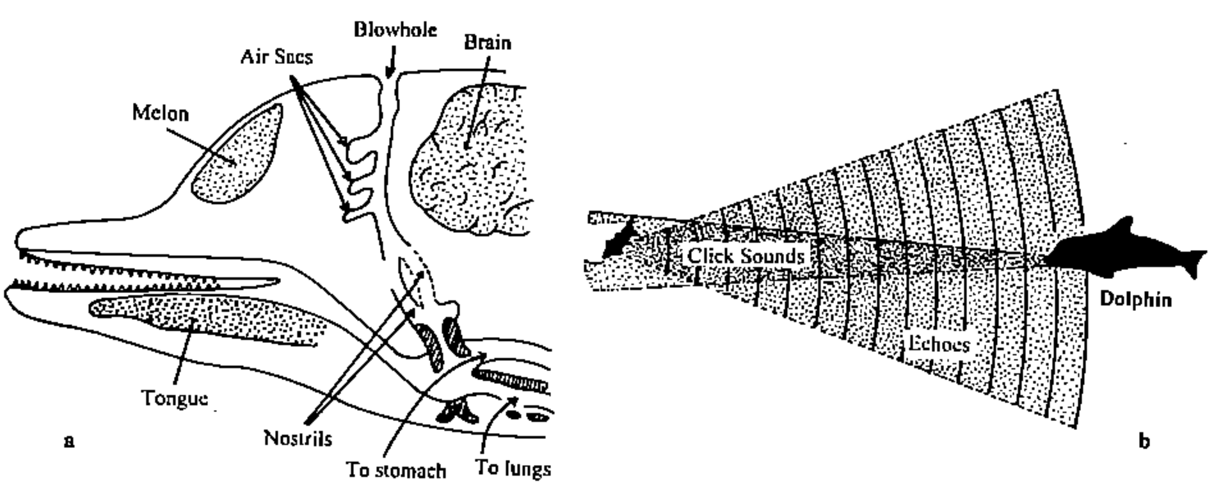


Fig. 16.30: Echolocation in aquatic mammals. (a) Internal structure of whale showing blow hole and its connections. (b) Dolphin transmits patterns of clicks which are reflected from any unseen object. Reflected echoes are picked up by the dolphin. Clicking sounds are produced from the blowhole.

16.6.3 Echolocation in Birds

Cave birds also resort to echolocation for finding their way in darkness. *Collocalia maxima* is a swift which emits clicks of short duration to navigate in the dark caves of Sarawak. The oil bird of South America commonly called guacharo, *Steatornis caripensis*, also uses echolocation to navigate inside the caves. Both these cave-dwelling birds have retinas which are highly specialised for dim light vision and excellent night vision.

SAQ 4

i) Define echolocation.

....

....

....

....

ii) Name the sound producing organ in whales.

....

....

....

....

iii) Name a cave bird which uses echolocation for navigation.

....

....

....

....

16.7 LOCOMOTION IN VERTEBRATES

Movement is characteristic of animals. Animals move to procure food, shelter and mate and to escape from enemies. It is amazing how in accordance with the demands posed by their aquatic, terrestrial and aerial habitats animals have evolved structural and physiological adaptations for locomotion which are quality wise the most efficient and energy wise the most economical.

16.7.1 Basic Locomotion Plans

In vertebrate body, single cells movements displacing the whole body is by means of **skeletal muscles.**

Vertebrates display two kinds of locomotion - (i) **axial** and (ii) **appendicular**.

AXIAL LOCOMOTION

(i) In axial locomotion, propulsion is by flexing the muscles of the body and/or the tail. The muscles of the body are metamerically arranged. This kind of locomotion is usually associated with animals of aquatic habitats eg. fish, aquatic snakes, cetacean mammals. All fish have axial locomotion. With the evolution of tetrapods, the role of axial muscles changed from that of locomotion to that of support.

APPENDICULAR LOCOMOTION

(ii) In appendicular locomotion, the movement of appendages propel the body. This kind of movement is associated with the animals of terrestrial and aerial habitat. The basic structure of appendages (fore and hind limbs) is the same in all tetrapods. Vertebrate appendages may be paired or unpaired (Fig. 16.31). The functional value of unpaired appendage is much less than that of paired appendages.

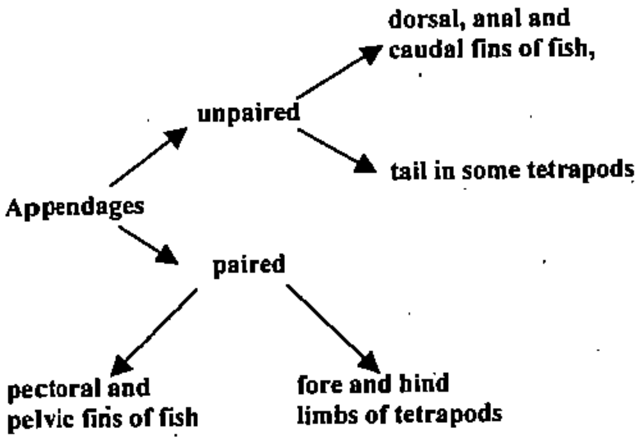


Fig. 16.31: The paired and unpaired appendage plans in vertebrates.

Vertebrates exhibit differences in locomotion which is related to their habitat.

i) **Locomotion in water by aquatic vertebrates** such as fish, amphibians, aquatic birds, whales, dolphins, porpoises (mammalian order Cetacea), seals and walruses (mammalian order Pinnipedia), otter (Order Carnivora).
ii) **Movement in air** is performed by some animals and fliers which are called **volant** animals.
iii) **Locomotion on Land in terrestrial animals** some terrestrial animals walk or run on the ground. They are called **cursorial animals**.
iv) Some other terrestrial vertebrates are adapted to climb trees or other surfaces. They are called **arboreal** or **scansorial** animals.

16.7.2 Locomotion in Water

Aquatic vertebrates swim and dive in water. The ancestors of fish swam in waters so fish are **primary swimmers**. Other aquatic vertebrates evolved from terrestrial ancestors. They are **secondary swimmers** (Fig. 16.32) and probably took to aquatic life because it provided them (a)access to food such as plankton, aquatic plants and aquatic invertebrates (b) an escape route from terrestrial predators and (c) favourable avenues for dispersal and migration. Examples of secondary swimmers are aquatic amphibia and reptiles, penguins, seals, sea lions etc. Fishes are fast swimmers and secondary swimmers are much slower.

Some animals do not exert themselves but use others to hitch a ride. Ectoparasitic fish such as sucker fish (*Echeneis*) and the jawless lamprey (*Petromyzon*) have adaptations for adhering to the back of other fishes.

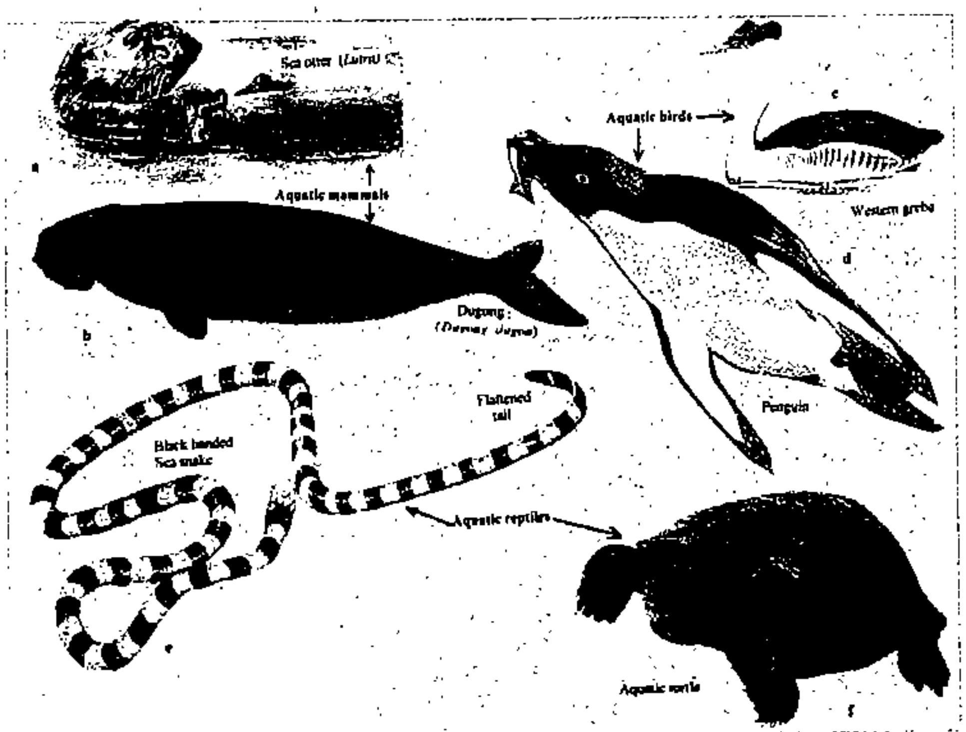


Fig. 16.32: Secondary swimmers (a) Aquatic mammals – sea other and Dugong (b) Aquatic birds – Western Grebe and Penguin (c) Aquatic reptiles – sea snake and aquatic turtle.

Drag is the resistance offered by the medium to the motion of an object. There are different type drags which are interdependent. They are (i) friction drag (ii) pressure drag (iii) wave drag

Adaptations for aquatic locomotion

The relative density of water compared to air of water is much greater. Water is thus a viscous medium which helps to support aquatic vertebrates and provides a medium against which moving animal can thrust while swimming. Aquatic animals thus have to face certain challenges posed by water. The following adaptive features are necessary in primary swimmers for locomotion in water.

1. Reducing drag

The body is streamlined, tapering at both ends so that water readily flows over it and drag is reduced to a minimum. The skin is loose and smooth (e.g. dolphin) and offers least resistance to water. In some fish, the body is covered with scales but mucous glands beneath the surface keep them moistened in order to reduce friction.

2. Propulsion

The body is propelled in water by muscles. Blocks of muscles or myotomes are present on either side of the vertebral column. Myotomes contract and relax alternately on each side of the flexible vertebral column which bends synchronously with the muscles. The direction of wave of contraction is from front to back. In swimming, a wave of muscle contraction starts in the anterior most muscles mass on one side of the body and proceeds backwards, each myotome contracting in turn. Before the first wave of contraction proceeds too far, another wave starts at the anterior end on the opposite side of the body. This process continues, bending the body in a wave like motion. The vertebrate is propelled ahead. In large fishes, the tail provides the propulsive thrust. The amplitude of the wave is also greatest at the tail.

Propulsion varies in different kinds of fishes. Some propel by (a) side to side lashing of the tail - **ostraciform** (b) In others, the posterior half of the fish is thrown into waves - **carangiform** (c) In long fishes like the eel, the body is thrown into many waves and different parts of the body move simultaneously to the left and right - **anguilliform locomotion.**

3. Stabilising and steering

In fishes, the fins help them to swim. The median fins, dorsal and ventral fins (Fig. 16.5) help to stabilise the fish. They act as brakes when the fish has to stop movement. Paired fins, pectorals and pelvics steer and balance the body of the fish. A cartilaginous fish such as the *Scoliodon* or dog fish is heavier than the medium (water) and so in order to prevent it from sinking when the fish is not moving, paired fins are held at an angle to the long axis of the body (Fig. 16.33). The force exerted pushes the head upwards (positive pitch).

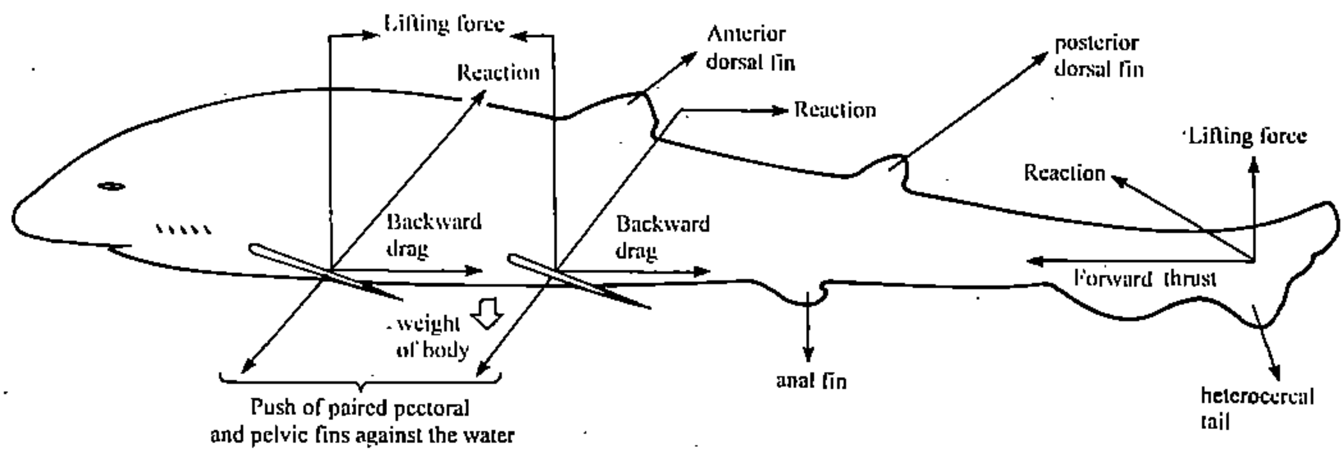


Fig. 16.33: Stabilising and steering of fish is due to the role of the median fins in stabilizing and due to the role of the paired fins in steering and balancing.

When the fish swims it is subjected to three kinds of displacement (a) turning (yaw) which is countered by median fins (b) up and down displacement (pitch) regulated by paired fins and (c) roll (tilt) regulated by all the fins (Fig. 16.34). When bony fish swim straight in water paired fins press against the body and improve the streamlined shape.

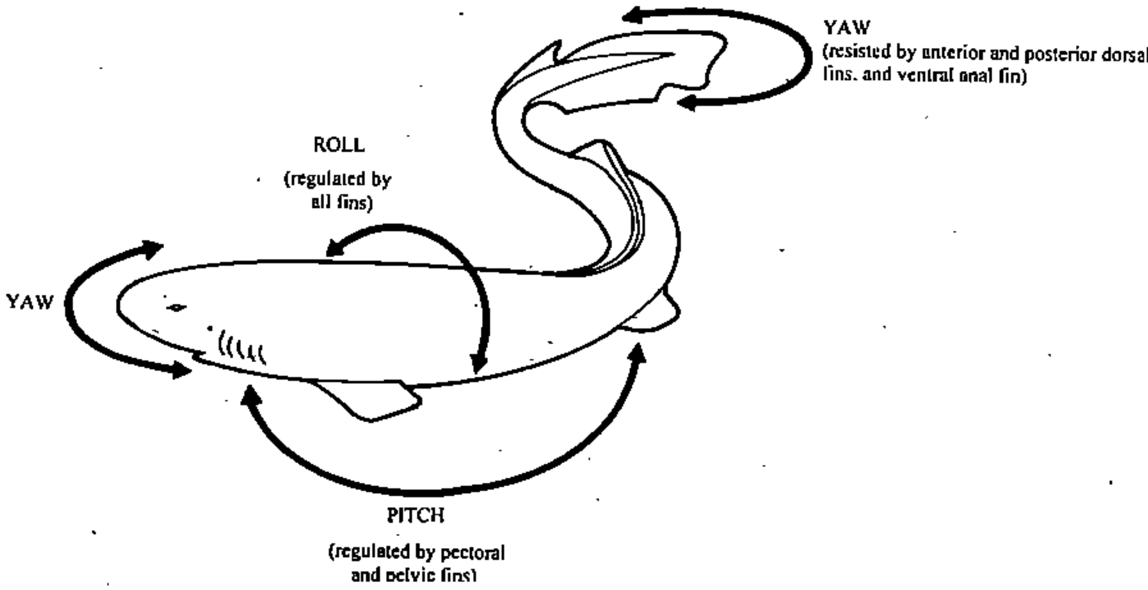


Fig. 16.34: The primary swimmers like fish counter various displacements during swimming.

4. Buoyancy

Bony fishes have a hydrostatic device called "air bladder" between the vetebral column and the gut (Fig. 16.35). It is vascularised. Fins of bony fishes unlike those of cartilaginous fishes living in the sea do not lift the body. It is the air bladder which keeps the body buoyant.

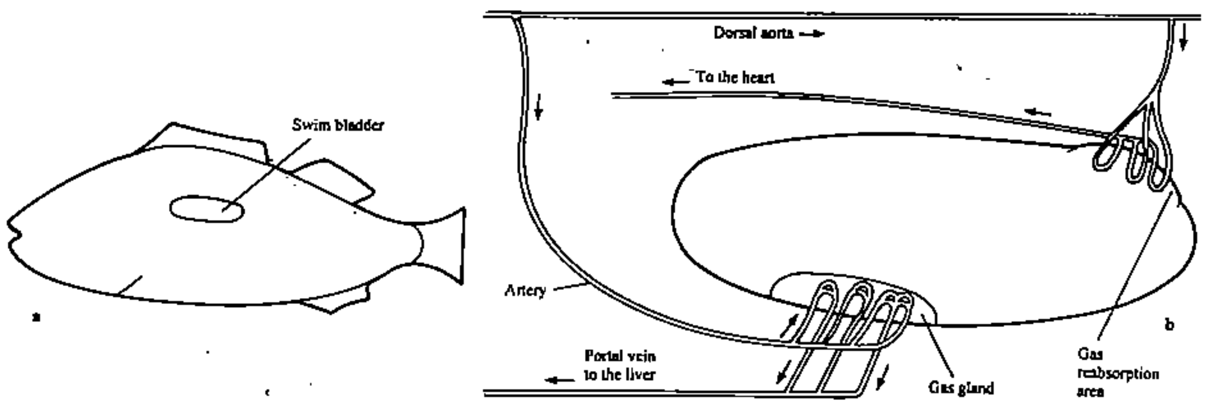


Fig. 16.35: Swim bladder. a) Internal view of bony fish showing location of air bladder or swim bladder which helps in buoyancy, b) Internal details of swim bladder.

Adaptations for locomotion in secondary swimmers

The tetrapod vertebrates which have taken to aquatic life have the following adaptations for locomotion in water. Among the amphibians, the water newt or mud puppy *Necturus* has a compressed fin like tail with flaps which are not supported by fin rays. Frogs swim with their webbed feet. They come up and breathe in air.

Among the reptiles, sea snakes (family Hydrophidae) have a vertically compressed rudder like tail (Fig. 16.32 c) for swimming. Their valvular nostrils help to prevent entry of water while in motion. The limbs of crocodiles are used for swimming. Furthermore, you also know that they have a secondary palate which helps them to breath in air while they are moving or stalled under water. Aquatic turtles have limbs modified into paddles.

Aquatic birds like cormorant and grebes swim in water with their webbed or lobed toes (Fig. 16.36). In penguins the featherless wings are flattened and united to form a powerful paddle or flipper moving only at the shoulder joint which helps them to swim (See Fig. 16.32 again).

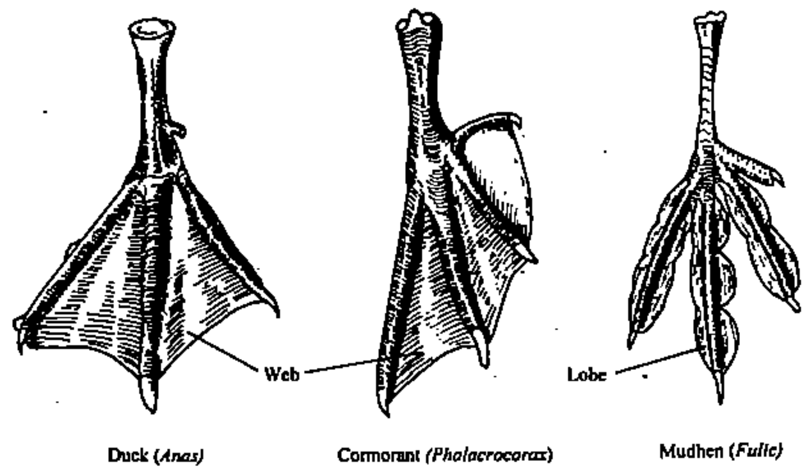


Fig. 16.36: Webbed and lobbed feet of aquatic birds.

Among the mammals, Orders Cetacea (whales, dolphins and porpoises) and Pinnipedia (seals, walruses and sea lions) exhibit aquatic locomotion. The egg-laying mammal duckbilled Platypus (*Ornithorhynchus*) also shows aquatic adaptations. Its feet are webbed (Fig. 16.37 a). Its small eyes and ears are enclosed in a backwardly directed furrow (Fig. 16.37 b) to prevent water from entering while moving. In Cetacea, the hand is modified into skin covered paddle. The streamlined body is smooth without hair. The nasal openings are far back on the face to prevent entry of water. Pinna is absent. In the sea lions, seals and walrus, the fore limbs are modified for swimming. In *Phoca* or wriggling seal, the hind limbs upto ankles are bound along with short tail within the skin and form the swimming organs. They also have streamlined body and no hair. Dugong and manatee (Order Serenia) have no hind limbs but the fore limbs are modified for swimming, as flippers or paddles.

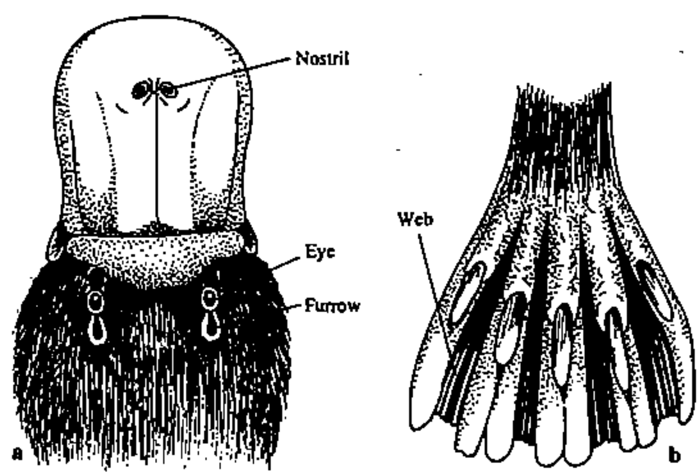


Fig. 16.37: Adaptation of duck billed platypus for aquatic life. (a) Head showing eyes embedded in furrows (b) Webbed feet.

The energy requirement for swimming is speed dependent. Whales have high metabolic rate and blubber forms a source of fuel. Energy consumed for swimming is relatively less than that for walking and flying.

Adaptation for diving : Secondary swimmers like penguins, seals and whales dive and stay under water for sometime. They exhale before diving. Deep under water, the lungs collapse forcing air out of alveoli, into bronchi, into trachea and out. This prevents the danger of 'bends'. Bends is caused by the dissolving of **nitrogen** from air into blood under pressure. The blood volume of diving animals is more and carries more **oxygen.** The muscle protein myoglobin stores lot of oxygen. The heart beat, basal metabolic rate and kidney function decreases during diving. An oxygen debt is caused which is paid off when the diver surfaces.

16.7.3 Locomotion in Air

An animal that can sustain itself in air is called a flier. Fliers are also termed volant. Volant vertebrates are among the most specialised vertebrates. They are adapted for movement in air and include birds and bats which can fly in air. This category also includes the flying fish, tree frogs and flying squirrel (mammalian order Dermaptera) that glide from tree to tree and can suspend in air for a short time. Some light bodied climbers travel horizontally through air while moving down. If the line from take off to landing is steeper than 45° to the horizontal, the animal is said to **parachute**, if it is less than 45°, the animal is said to **glide** (Fig. 16.38).

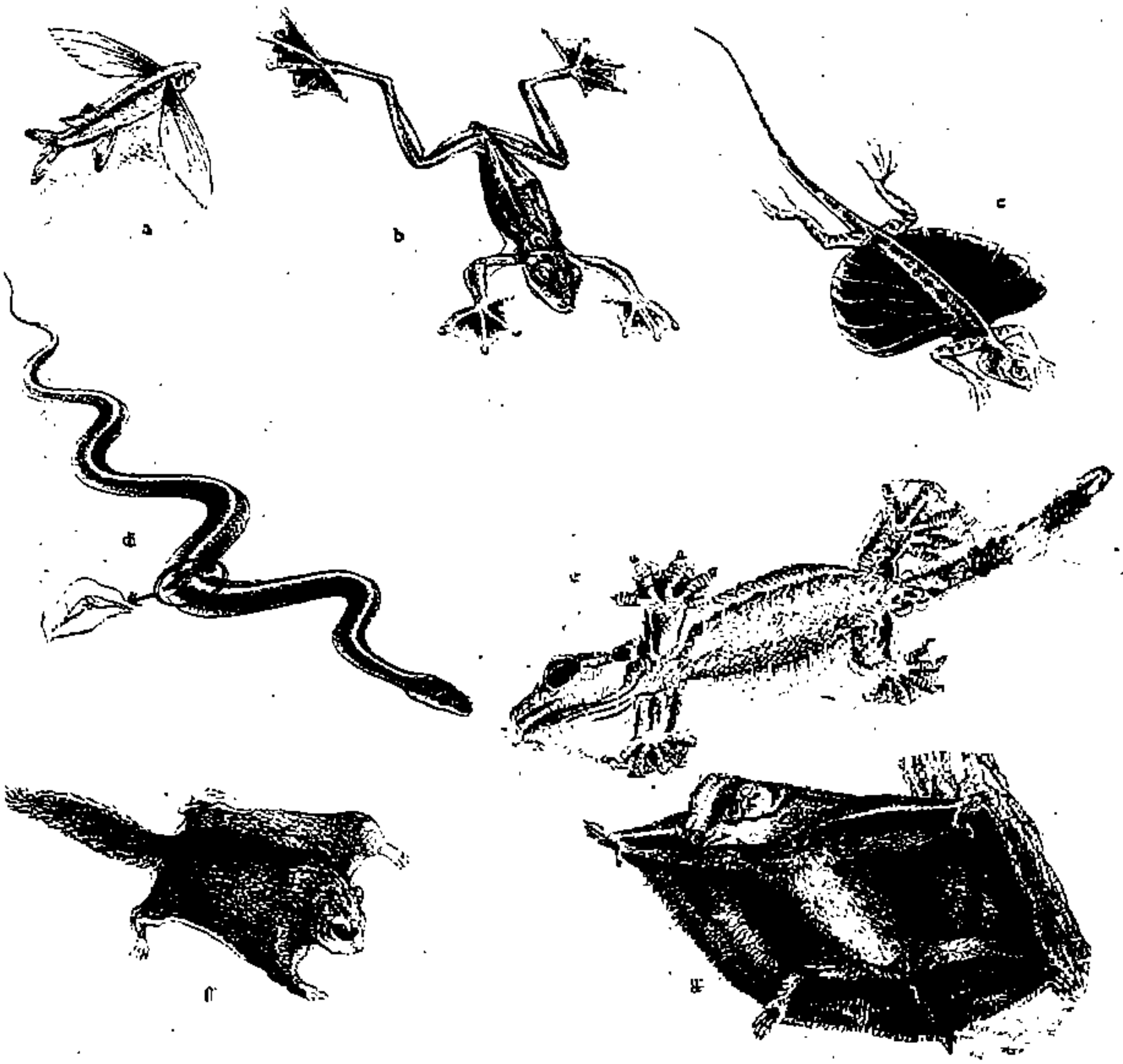


Fig. 16.38: Some vertebrate parachuters and gliders. (a) Flying fish showing large pectoral fin for gliding (b) Flying frog. When a flying frog leaps from tree to tree, the large webs between its toes act as parachute (c) Flying dragon (*Draco*) or flying lizard lives in trees. Its long ribs can be unfolded outward to support a web of skin on each side like glider wings and helps the *Draco* to fly (d) Flying snake of genus *Chrysopelea* are remarkable among gliding reptiles. They have long, slender bodies and when gliding they launch themselves from an appropriate branch into the air where they make a series of S-shapes, while at the same time flattening their body to increase the body's surface area, thereby creating as much lift as possible (e) Parachuting flying gecko. The gecko has a membrane that stretches out on both sides of its body, a flat tail, and webs between its toes enables this gecko to glide (f) Flying squirrels have an exceptionally bushy tail plus a membrane that stretches between the legs that help them to glide (g) Colugo or flying lemurs have the largest gliding flap of all mammals.

Advantages of flying

Volant animals have (i) access to flying insects as food. They can (ii) search rapidly for shelter, (iii) escape from non-flying predators; and (iv) can disperse and migrate to regions with favourable climate, food and nesting sites.

Volant Vertebrates - Examples

Parachuters

Parachuters are mostly arboreal and sail off from trees. Tree frogs (Family - Hylidae) do not have any special adaptations for parachuting but family Rhacophoridae includes the flying frogs which have webbed feet and small membranes between arms and thighs (Fig. 16.38 b).

Tree snakes hold their body horizontal, with ribs spread to the sides, and draw in their belly to form a concave surface towards the air stream. This helps the snake to be suspended in the air (Fig. 16.38 d).

Among lizards, Geckos have webbed toes and fringes on head and body, while *Draco*, the flying lizard has membrane called **patagium** between the fore and the hind limbs supported by ribs which help it to descend nearly 45° to the horizontal. Small tree squirrels spread their legs and tail to parachute (Fig. 16.38 f).

Gliders

Some fishes, lizards and mammals (Order Dermoptera) are gliders. Fish have an enlarged fin while the lizards and mammals possess a broad membrane to catch the air stream. The lizards and mammals usually climb a tree to gain height and then jump and by means of their membrane sail off, following a parabolic path.

Pectoral fins of flying fishes (Fig. 16.38 a) are large and spread out helping them to glide while there is wind, with their tails thrust in water. *Draco* (Fig. 16.38 c) can glide with the help of patagia which are membranes between the limbs. *Colugo* (Dermoptera) (Fig. 16.38 g) has the largest flight membrane - a flap of skin from the throat to the tip of the tail and webbed toes. Flying phalangers (Marsupials) have a membrane from elbow to knee. The membranes of some flying squirrels are supported by calcareous struts (calcars) from elbows (Fig. 16.38 f).

Fliers

Some fliers show fast and direct flight while others are slow and erratic. Birds (Fig. 16.39 a) as you have studied in Unit 3, section 3.4 are fine true fliers with long arms and with the robust second digit forming the wing covered with flight feathers and a wing membrane or patagium which is a fold of skin in the angle of the elbow. Among mammals, bats are also known as true the fliers and have common adaptations to aerial mode of life (Fig. 16.39 b).

Fig. 16.39: True fliers (a) bird (owl) (b) bat.

Adaptations for flight

The structural adaptations for flying are in the shape of the body, the skeleton, the integument, the muscles and the sense organs. The physiological adaptations are the ability to regulate temperature and feeding while in flight. In Block I of this course, Unit

3, you have studied the salient features of the form and function of birds including their various adaptations to flight in great detail (refer subsection 3.4.3 and 3.4.4 of section 3.4 of Unit 3 of this course). In this unit we will briefly review the main adaptive features of flight of birds and bats.

I. Body Shape and Skeleton

1. Body shape is streamlined, offering least resistance to flight.
2. Pneumatic or hollow spongy air filled bones.
3. Compact skull with fused bones.
4. Pointed beak in birds.
5. Some vertebrae fused in the vertebral column.
6. Vertebral column fused to pelvic girdle.
7. Well developed pectoral girdle supporting wings (Fig. 16.40 a).
8. Forelimbs modified into wings (Fig. 16.40 b).
9. Sternum has a broad keel or carina (Fig. 16.40) for the attachment of large pectoralis major (Flight muscle).
10. Bones of hind limbs are long so that wings are above the ground while taking off and do not flap against the ground.

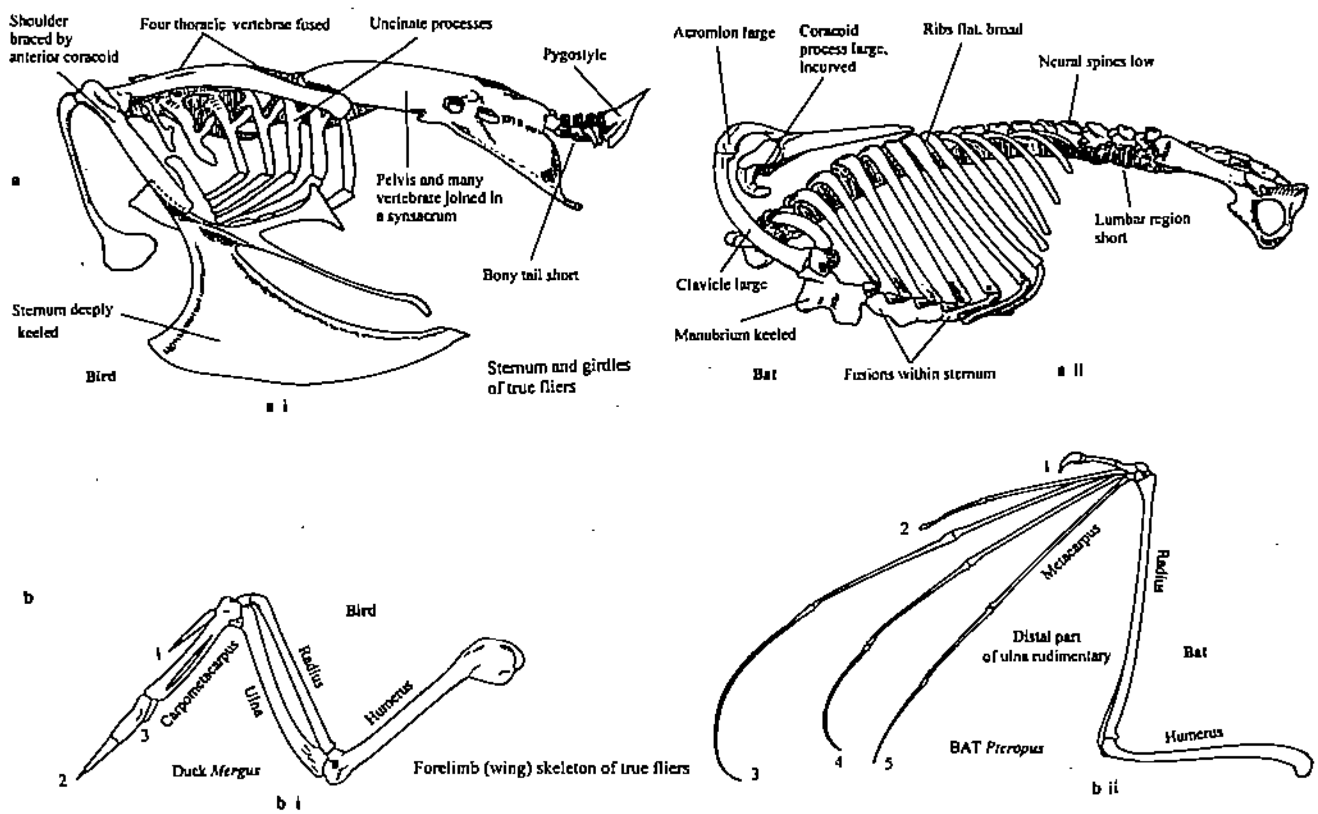


Fig. 16.40: Skeleton of the true fliers, bird and bat. a) Sternum and girdles of - (a, i) bird (a, ii) bat and b) Forelimb of (b, i) bird (b, ii) bat.

2. **Integument** - The skin of birds has the epidermal feathers. The four kinds of feathers you already know are (1) contour, (2) down and (3) filoplumes and (4) bristle (Refer Unit 3).

3. **Tail** - Birds have a short tail - an adaptation to cut down drag and increase maneuverability.

4. **Jaw** - In birds bill or beak is formed by toothless jaws.

5. **Reproductive system** - In birds sex organs are small and develop fully only at breeding season. There is only one functional ovary. All these reduce the weight and make the body light for flight.

Hyperventilation - While flying high, especially during migration, birds and bats hyperventilate (take in more air) to compensate for the low oxygen content at high altitudes. In bats CO_2 from body makes the blood acidic and constricts blood vessels. Birds hyperventilate without vasoconstriction.

6. **Visual acuity** is very high. A nictitating membrane removes particles from the eye while in flight. Long necked birds can rotate their necks to get good vision while flying.

7. **Body Temperature** is high. Birds and bats can regulate body temperature (homoeothermal). This has two advantages. (a) It counters the cooling effect of air when flying high (b) It ensures efficient muscle contraction.

8. **Muscle coordination** is excellent.

9. **Air sacs** (Fig. 16.37) are present in the body of the bird for making it buoyant. The air sacs help in respiration and are associated with the lungs. Their branches extend into hollow bones. Air sac system also cools the body.

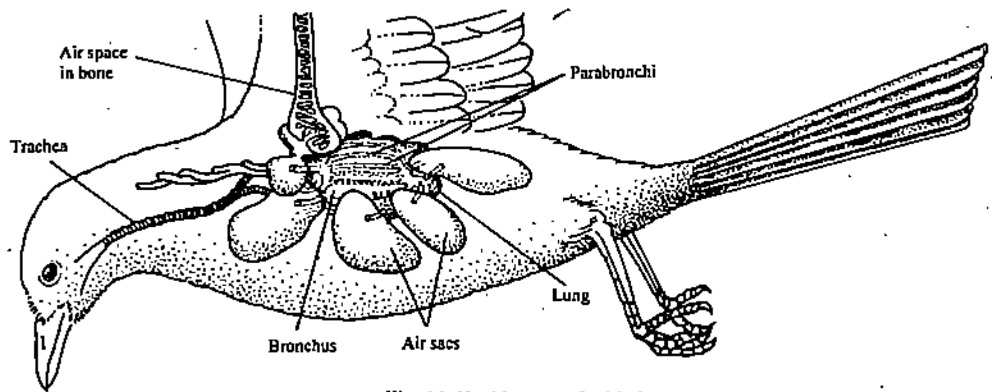


Fig. 16.41: Air sacs of a bird.

10. **Lift** - Bats carry their young and birds carry prey while flying. They are capable of lifting loads. **Acceleration and maneuverability** is excellent. Birds and bats can start flying, stop, change speed and direction remarkably fast. Flocks may do it together. Humming birds can fly backwards.

Mechanism of flight

Refer to subsection 3.4 of Unit 3 of this course for the mechanism of flight in birds. In this unit we will discuss the various kinds of flight.

There are three kinds of flight - (1) Flapping (2) Gliding (3) Soaring (4) Hovering.

1) **Flapping flight:** When the pectoralis major, the large flight muscles attached to keel contracts, the wings flap downwards as a result. As the wing tilts, it pushes air back causing forward movement. Pectoralis minor then contracts and the forearm with the wing moves sharply upwards and bends. This produces a lift to the body. The bird lands by spreading out its tail. The feathers regulate the air resistance by fitting closely or separating.

2) **Gliding :** During gliding, wings are held out at an angle of about 90° to the body and bird loses height. Force acting on it is called driving force and the pull of gravity acting downwards is called sinking force.

3) **Soaring:** When lift equals sinking force the bird glides through air in constant velocity: this is called soaring.

4) **Hovering:** The bird may stay at the same place and flap its wings. Wings move back and forward and the upward thrust which develops counterbalances the bird's weight. This is called hovering. A lot of energy is expended while hovering.

16.7.4 Locomotion on Ground

Cursorial animals move on hard surface and travel long distances. Animals of this category include frogs, lizards, snakes, birds and mammals. Speed is their prime requisite. Cursors may be quadripedal (walking on four limbs) as you can see in Fig. 16.42 a, or bipedal (locomotion on two legs) as shown in Fig. 16.42 b. They may walk on whole of the sole **(plantigrade)** or on their digits-finger walking (or **digitigrade**) or on the tips of the digits (hoof walking) or **unguligrade** (Refer to Fig. 16.44 also). You should also read section 11.5 of Unit 11 to recall these terms.

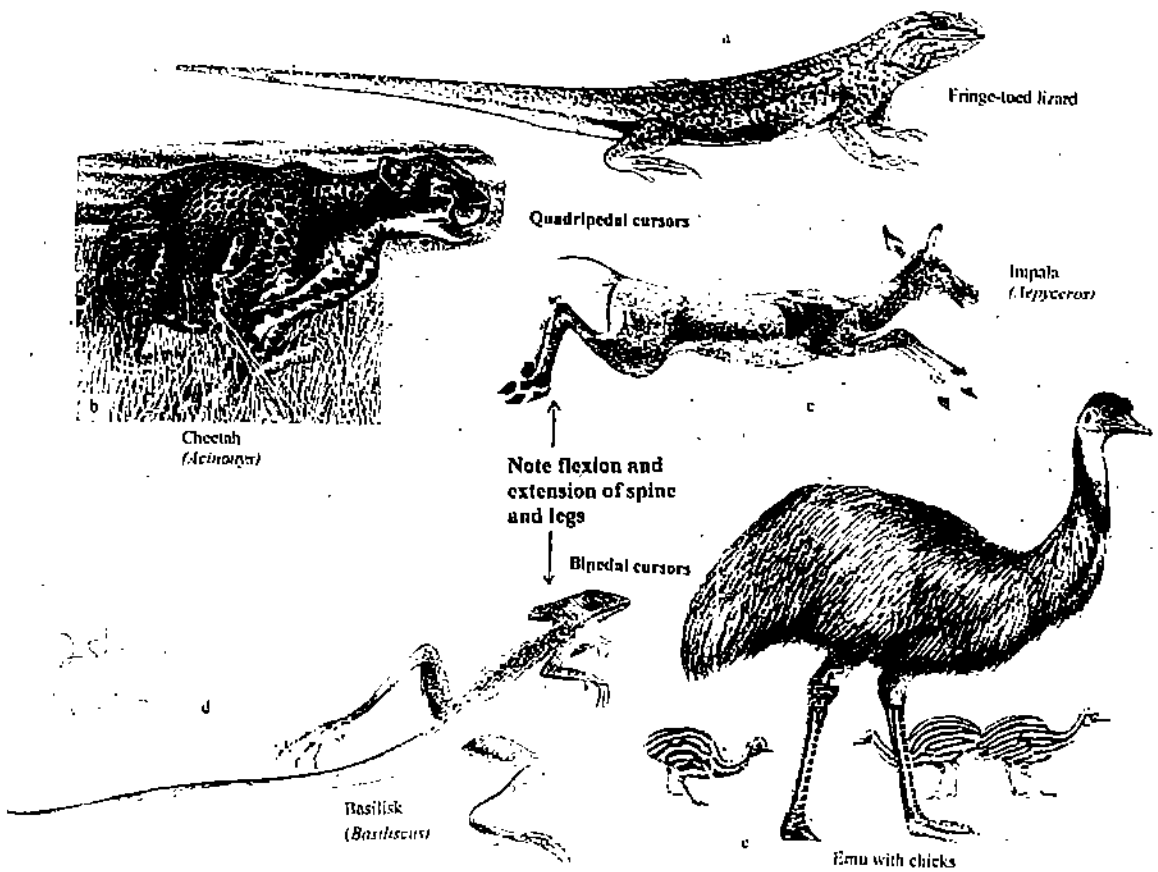


Fig. 16.42: Cursorial vertebrates (a) Quadripedal Cursors - (a, i) Fringe toed lizard (a, ii) Cheetah (a, iii) Impala (*Aepyceros*). (b) Bipedel Cursors - (b, i) Basilisk (*Basiliscus*) (b, ii) Emu with chicks.

Animals which can jump show **saltatorial locomotion** (Fig. 16.43 a & b). They use bipedal locomotion for jumping and if the two hind limbs are lifted and brought together in unison for a number of successive jumps, the gait is termed **ricochet** (Fig. 16.43 b). Another category of cursors are the limbless burrowing vertebrates whose locomotion is still different.

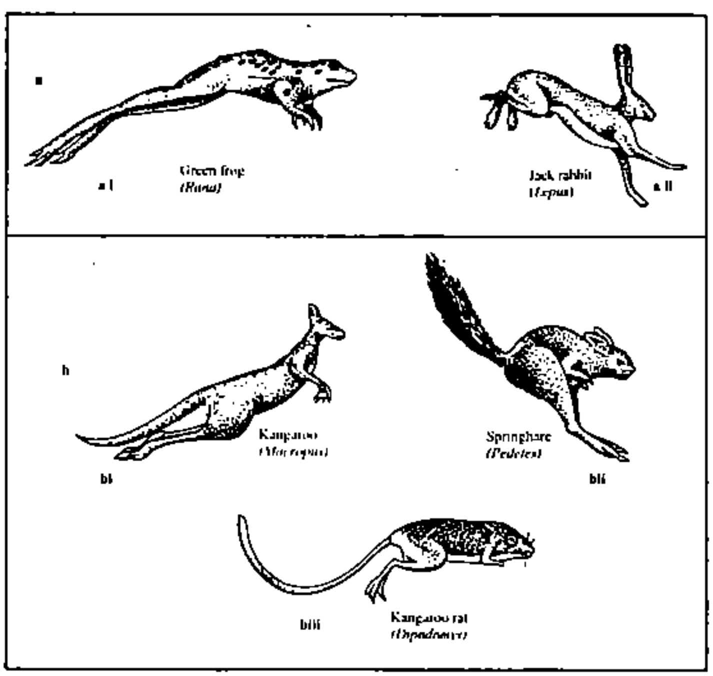


Fig. 16.43: Saltatorial locomotion in vertebrates. (a) Saltator Vertebrates - (a, i) frog (a, ii) Jack rabbit. b) Richochetal Saltators or high jumpers (b, i) Kangaroo, (b, ii) Springhare, (b, iii) Kangaroo rat. Note the proportion of limbs and balancing tail in the high jumpers.

1. Adaptation for cursorial locomotion

Cursors use least energy when stationery but expend a lot of energy when they move. The body is adapted for walking, running and jumping in the following manner.

1. **Body contour:** The body contours are streamlined without any projections in order to offer least resistance while attaining speed.

2. **Legs**

   (i) **Length and proportion of legs:** Legs propel cursorial animals: The longer the leg, the longer is the stride. Legs of cursors are relatively longer in proportion to the other parts of the body. The distal segments (wrist and forearm and calf and ankle) lengthen more than the proximal segments of the limbs (upper arm and thigh region). In cursorial ungulates the radius (bone of the fore arm) is longer than humerus (bone of the upper arm) and tibia (calf bone) is as long or much longer than the femur (thigh bone), Metacarpals (wrist bones) and metatarsals (ankle bones) are fused and lengthen most (Fig. 16.44). Tarsals are greatly elongated in the frog also. In birds, legs are longest in the wading birds but not the runners. Cursorial lizards, however, have relatively long hind legs.

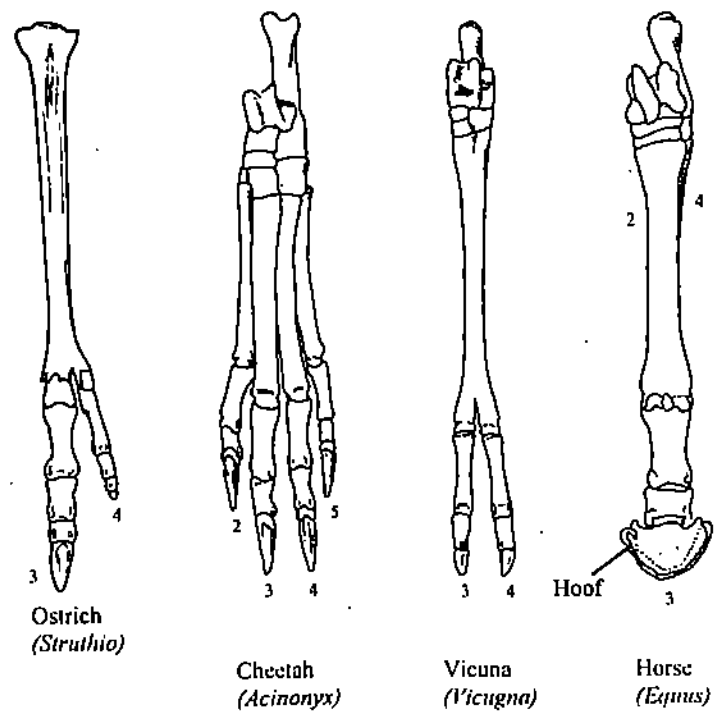


Fig. 16.44: Distal hind limb bones of various cursors showing lengthening of metatarsal, squaring or fusion of tarsals and reduction of digits.

   (ii) **Foot posture:** When human beings rise on the tips of toes, the length of their legs increases. Otherwise human foot does not contribute to the length of the leg. Bears, opossums and many vertebrates which walk but rarely run have plantigrade (sole walking) feet. Running dinosaurs, birds and carnivores (dog, cat, tiger) do "finger walking" and are digitigrade. Ungulates (horse, cattle, pig) are unguligrade (hoof walking). The effective leg length is increased by standing on tips (Fig. 16.45).

3. **Girdles and limbs**

Pectoral girdle

The shoulder blade or scapula can freely rotate in the same plane in which the leg swings. In the quadrupedal cursors, the collar bone or clavicle is either vestigal (carnivores) or absent (ungulates).

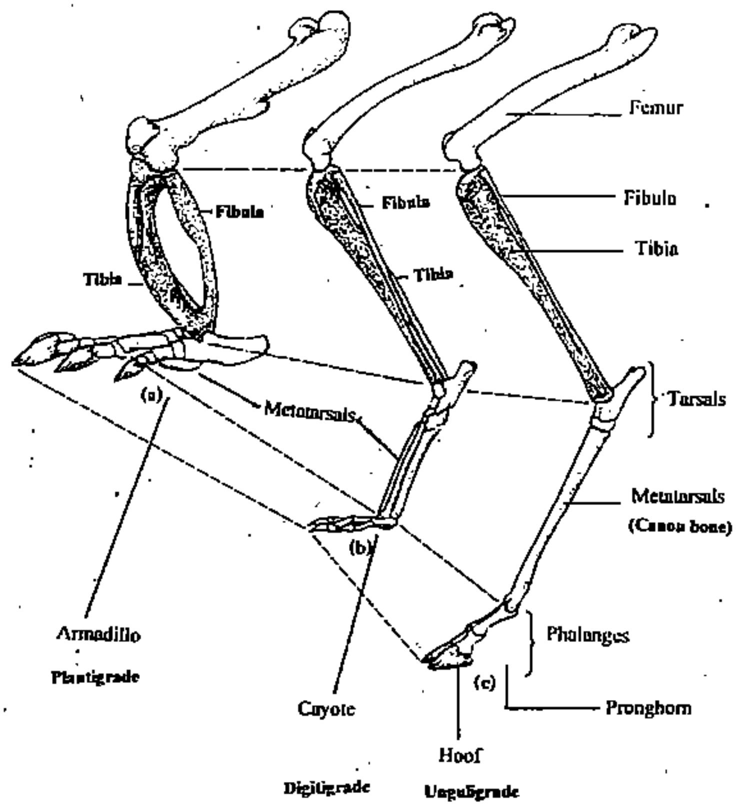


Fig. 16.45: Skeleton of hind limb in different cursorial foot postures. (a) Plantigrade - an armadillo has a plantigrade foot but it is modified for digging (b) Digitigrade as seen in cayote (carnivore) (c) Unguligrade as seen in the ungulate pronghorn deer.

Limbs

The locomotor structure is reduced in unguligrade cursors in order to economise on effort for walking and running.

(i) Ulna is fused to radius and fibula becomes a thin **splint bone** (Fig. 16.46). Also refer back to Fig. 16.45.

(ii) The muscles manipulating the digits, rotating the forearm and twisting the foot are also reduced.

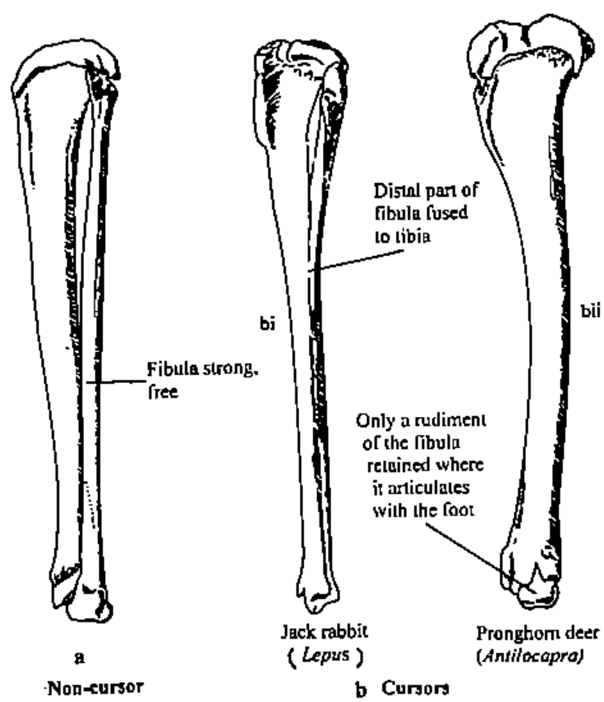


Fig. 16.46: Comparative reduction of fibula in (a) Non Cursor and in (b) Cursor – (b, i) moderate cursor like *Lepus* and (b, ii) specialised cursor like pronghorn deer (*Antilocapra*).

(iii) The metacarpals and the metatarsals fuse to form single units - **cannon bone** in ungulates (Fig. 16.45). Cannon bones add to the length of the foot.
(iv) Tetrapods are pentadactyl but in the unquligrades the number of digits is reduced to two or one. This reduction is related to attaining greater speed.
(v) Digits of the digitigrade and unguligrade cursors are protected by **shock proof** hooves (Fig. 16.45).
(vi) Muscles of the limbs contract faster to increase the rate of stride.

4. **Role of the spine**

Cursorial lizards undulate their spine when moving. In humans, the spine is S-shaped or sinuous. This is an adaptation for bipedal gait.

5. **Joints** : Joints function as hinges and permit motion only in the line of travel.

6. **Tail** : In cursors, tail helps to maintain to balance.

II. Adaptations of Saltators

Saltation and bipedal running

Frogs, garden lizards, birds, rabbits jump. Kangaroos are ricochetal and can accelerate faster than all other saltators. The ricochetals are high jumpers and can change speed and direction better than the quadrupeds. They can escape fast but expend a lot of energy doing so. Their hind legs are much longer than the fore legs. A fairly long tail helps in maintaining balance (Refer figs. 16.43 a & b).

(i) In saltators the relative lengthening of hind limbs and their distal segments is greater.
(ii) Bipeds such as humans swing their legs alternately and increase the length of their stride by oscillating the pelvis around the long axis of the sinuous vertebral column.
(iii) Tail while running is elevated in order to have the centre of mass over hind feet.
(iv) In frogs and jumping mammals, the presacral part of the vertebral column is short. This concentrates the weight in line with the thrusting hind legs.

Mechanism of walking, running and jumping

1. **Walking in quadrupeds**

When a dog or cat walks, the vertebral column remains rigid and the extensor muscle of hind limb contracts and extends it, exerting a backward force against the ground. This thrusts the animal forward and slightly upwards. When the flexor muscle contracts, the limb is pulled above ground and forward. In this way one limb is raised at a time while the other three form a tripod of support, balancing the rest of the body. The sequence of, movement of legs is, first left forelimb, then right hind limb, then right fore limb and then left hind limb.

2. **Bipedal walking**

Body weight is balanced on two legs while standing. For taking a step, the calf muscle contracts and the heel is raised (Fig. 16.47).

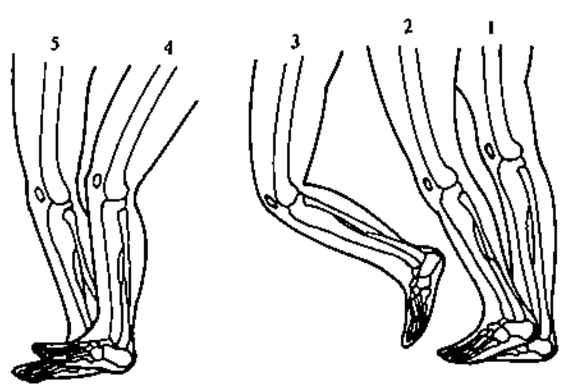
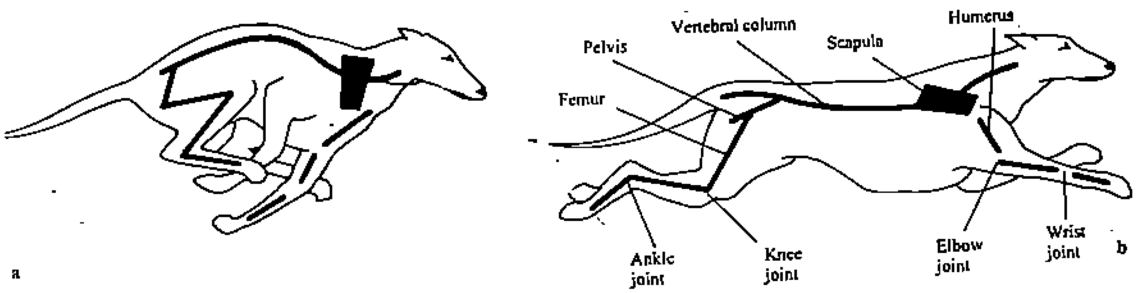


Fig. 16.47: Bipedal walking - 1 to 5 are positions of right leg of humans while taking one step.

The right foot is pressed against the ground and a forward thrust is exerted. The right limb pushes against the ground and the knee bends slightly. The weight of the body comes on left foot which is on the ground. The right limb extends and the heel touches the ound. As the body moves forward, its weight is transferred from the left side to the ght heel and then to the right toe. Backward pressure is exerted against the substratum rough the right big toe. The sequence of events is then repeated by the left leg. ig.16.47).

Running

running, the tripod means of suspension during walking is abandoned. The forelimbs ove together, followed by the hindlimbs. Contact with the ground is much less and one nb touches the ground at a time. In fast running vertebrates all four legs of quadrupeds, both legs of bipeds may be in the air (unsupported intervals). Strong trunk muscles ch the flexible backbone increasing the thrust of limbs so that the stride is lengthened ig. 16.48).



g. 16.48: Running (in a dog) (a) arched spine and feet under body (b) spine extended and limbs extended fully.

Jumping

take off, in order to jump, requires that each joint in the hind limb is straightened out means of the contraction of strong extensor muscles. Force exerted on the ground is ansmitted to the vertebral column from the limbs via the pelvic girdle. The saltator is opelled upwards and forwards into the air by the force against the force of gravity. The re limbs are attached to shoulder girdle in a flexible manner and decrease the shock of e impact of landing from a height (Fig. 16.49).

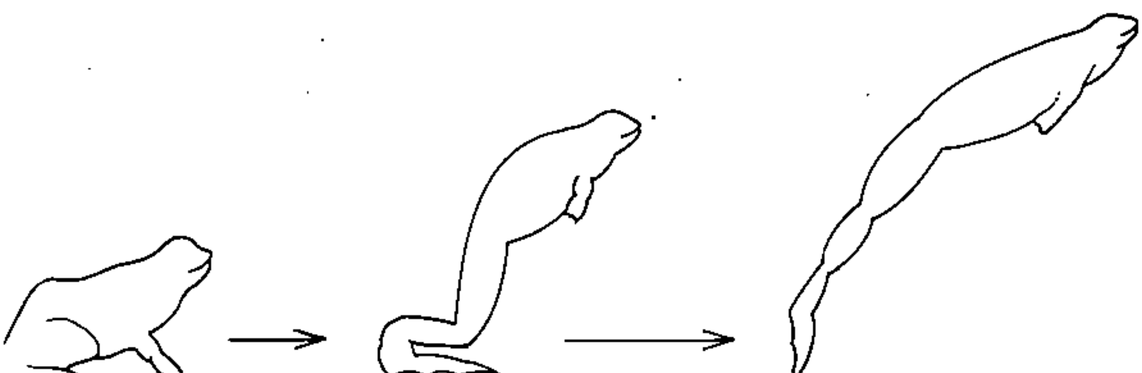


Fig. 16.49: The take-off and jump of a frog.

Crawling without appendages

ig. 16.50 shows some animals which live underground during most or all their lives. A umber of these underground dwellers, also termed subterranean animals, make tunnels urrowers). Some dig for food or shelter and are termed fossorial animals.

Alligators thrust their litter into tunnels made by others.

imbless progression on land is often related to burrowing. (Refer Unit-3, Block - I f LSE-10). The best examples of limbless animals or crawlers are snakes, the mbless lizards *Anguis* and *Ophiasaurus* and the limbless amphibian *Uraeotyphlus* nd *Siphonops*.

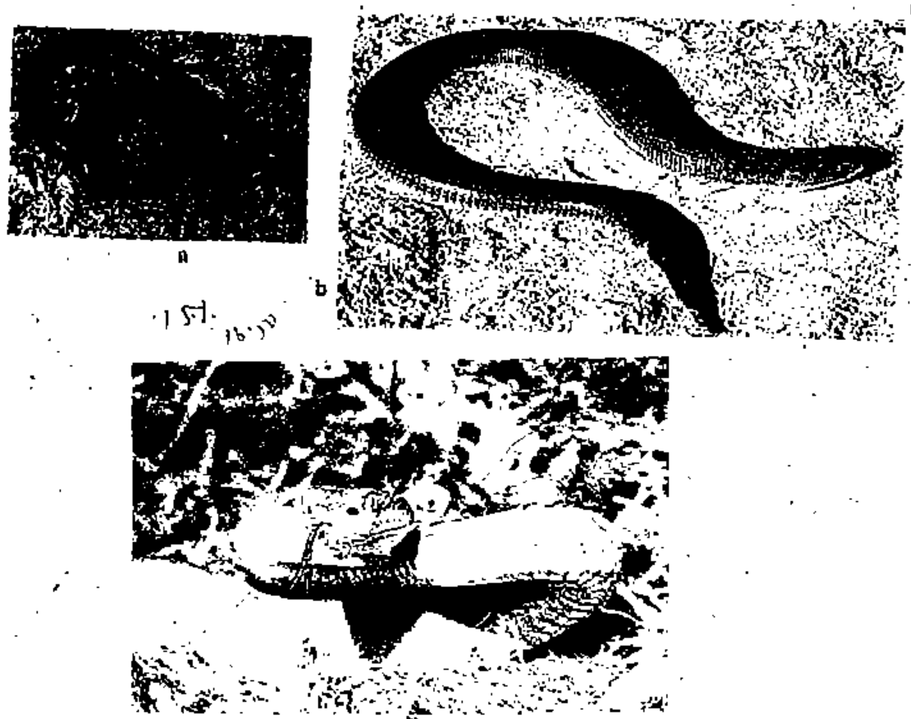


Fig. 16.50: Limbless vertebrates. a) The limbless amphibian, caecilian *Siphonops* b) The limbless glass lizard *Ophiosaurus* c) Pope's pit viper snake.

There are four ways by which these crawlers move (Fig. 16.51).

(i) **Lateral undulation :** Lateral undulation is the most typical pattern of movement in limbless animals. This movement follows an S-shaped path with the animal propelling itself by exerting lateral force against surface irregularities. The animal's body is thrown into loops forming waves which start behind the head and move posteriorly. The coils or loops of the body locate protuberances like pebbles, plants etc from the ground and push-up on them. The resultants of these forces move the animal forward (Fig. 16.51 a).

(ii) **Rectilinear movement :** Many heavy bodied limbless animals use rectilinear movement. In snakes and limbless lizards the skin fits loosely over the ventral part of the body. It is distensible. Muscles from ribs coming to the scutes (ventral scales) rest on ground. Two or three regions of the body rest on the ground to support the snake's weight. Some of the large ventral scales of these regions catch on the irregularities on the ground and are pulled posteriorly, while the intervening sections are lifted free of the ground and pulled forward by the muscles. The body thus moves in a straight line in a slow motion and can tunnel its way into the burrow. (Fig. 16.51 b).

(iii) **Concertina :** Concertina movement enables the snake to move in a narrow passage, as for example when climbing a tree, by using the irregular channels in the bark. In this movement the body is folded much like an accordion and the posterior end wraps around a small branch or is wedged in a crevice. Then the body is extended and gains new contact and the rear part of the body is pulled forward (Fig. 16.51 c).

(iv) **Side winding :** The desert snakes travel rapidly on sand or loose soil. Parallel tracks are made on the sand by the head and neck. When the snake moves, it touches two or three tracks at a time with parts arching between tracks. Parts of the body along the tracks are stationary while those between tracks are arched above the ground as they are moving (Fig. 16.51 d). The overall direction of travel is laterally and forward, and a series of J-shaped tracks is left in the sand.

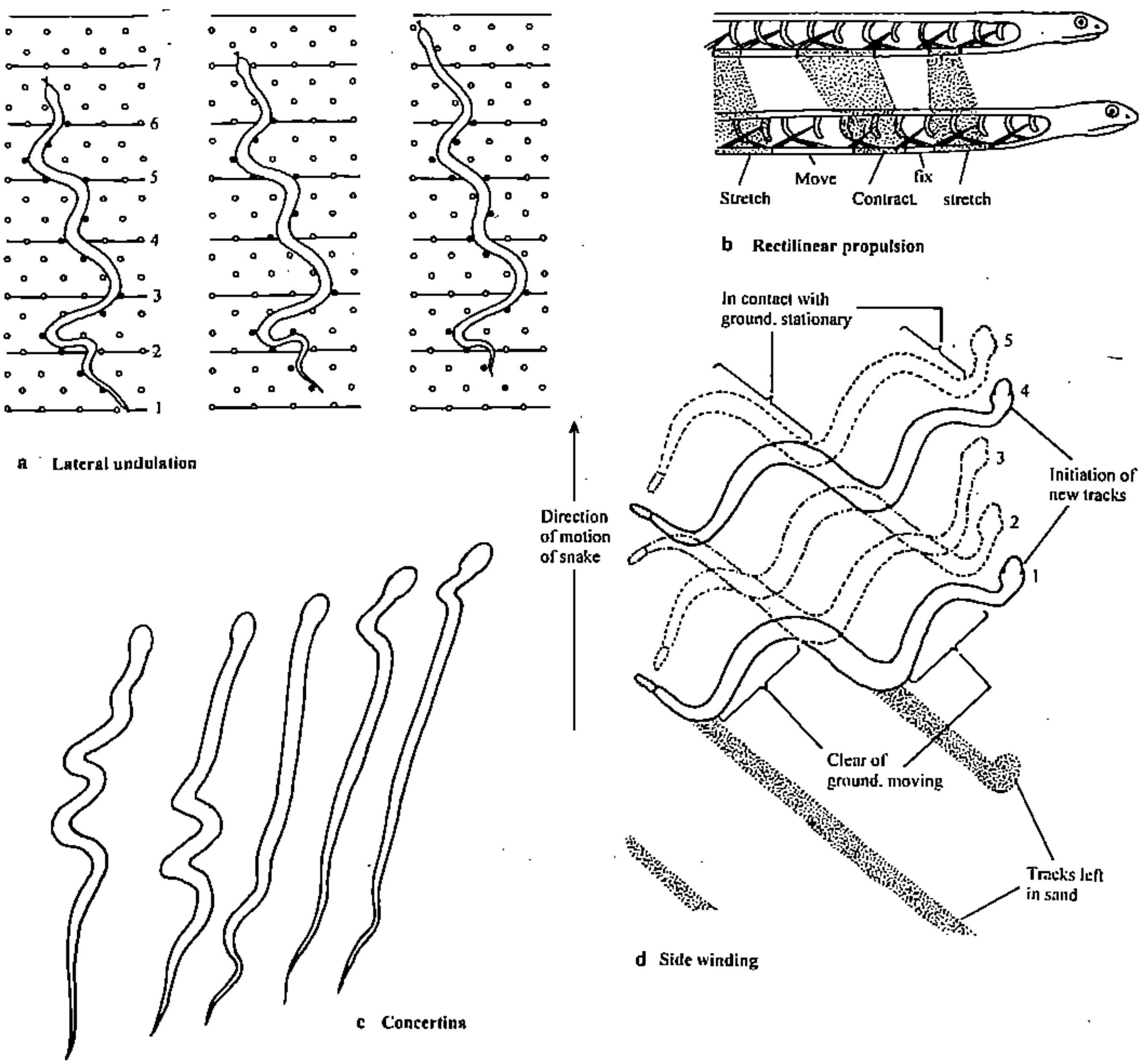


Fig. 16.51: Types of Crawling movements of limbless vertebrates. (a) Lateral undulation (b) Rectilinear propulsion (c) Concertina movement (d) Side winding.

16.7.5 Scansorial Locomotion

Some animals climb trees, rocks and walls. The advantages of climbing are as follows:

i. Food like honey from hives birds eggs, spiders and insects can be obtained from trees,
ii. The animals can defend themselves from non-climbing predators,
iii. They can see points of dangers,
iv. Climbing or scansorial or arboreal predators follow prey onto trees eg. arboreal viper waits for scansorial rodents on trees.

The following vertebrates are adapted for climbing either on trees or walls or rocks (Fig. 16.52 and 16.53). Also refer to Fig. 16.38.

Adaptations in non-mammalian vertebrates

Among fishes (Fig. 16.52 a) - climbing perch or *Anabas*
Among amphibian (Fig. 16.52 b) tree frog *Hyla* and flying frog *Rhacophorus*
Among reptiles (Fig. 16.52 c) - garden lizard *Calotes*, Chamaeleon, *Geck* and arboreal snakes
Among birds (Fig. 16.52 d) - woodpeckers, crossbills, parrots, nuthatchers, wall creepers.

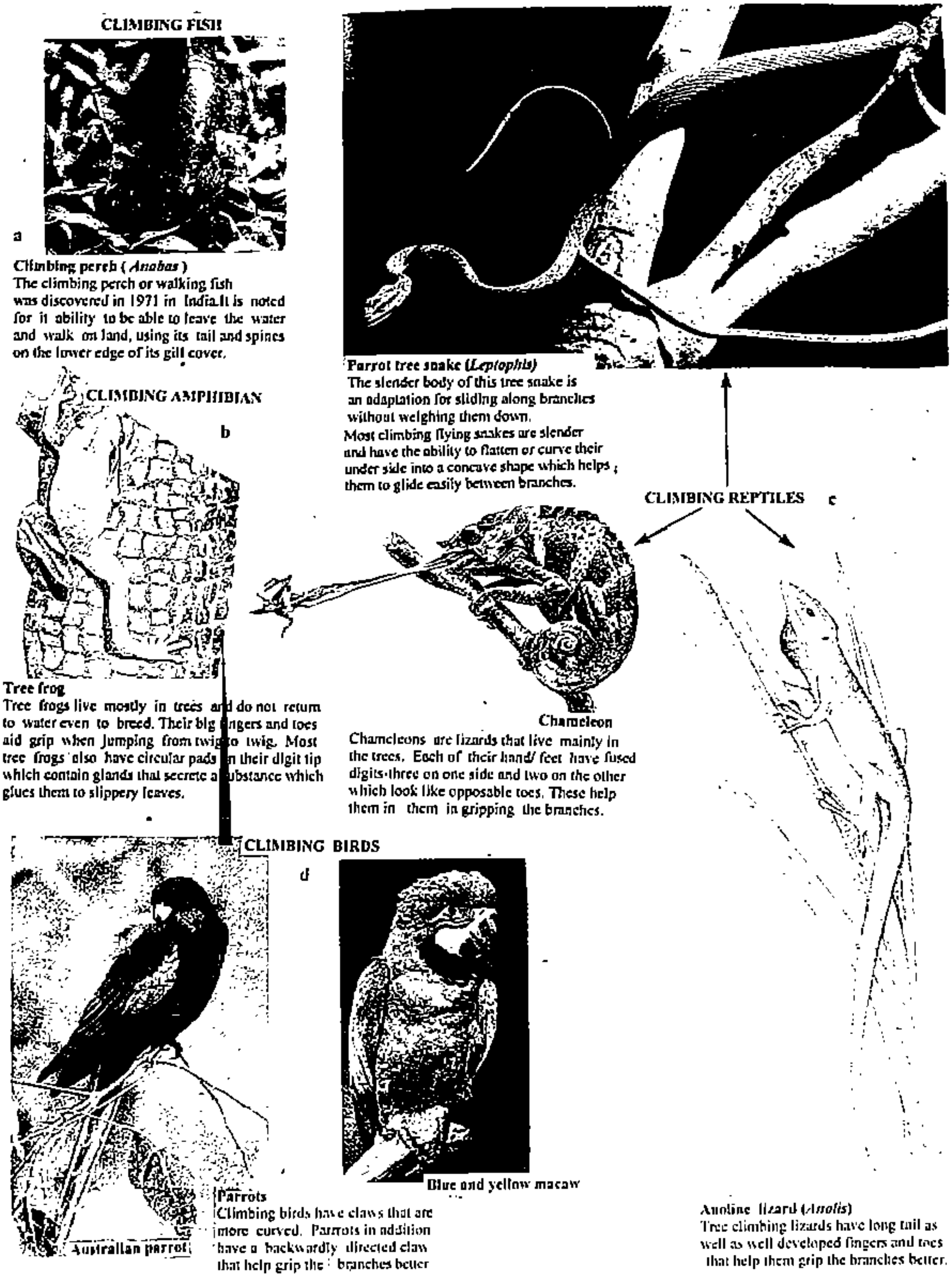


Fig. 16.52: Some non-mammalian, scansorial vertebrates which are adapted for climbing. (a) Climbing fish. (b) Climbing amphian. (c) Climbing reptiles. (d) Climbing birds.

Adaptation in mammals

Among marsupials - opossums (Fig. 16.53 a)
Among insectivores - tree shrews
Among Dermoptera - *Colugo* (Refer again to Fig. 16.38 g)
Among Chiroptera - bats (Refer Fig. 16.39 again)
Among edentates - sloths (Fig. 16.53 b)
Among primates - monkey, langurs, lorises pottos etc (Fig. 16.53 b)
Among rodents - squirrels, chipmunk, tree rats, dormice (See also Fig. 16.38 f)
Among carnivores - raccoon, weasel, bear, mongoose cats, foxes
Among ungulates - mountain goats, sheep, chamois (Refer 16.21)

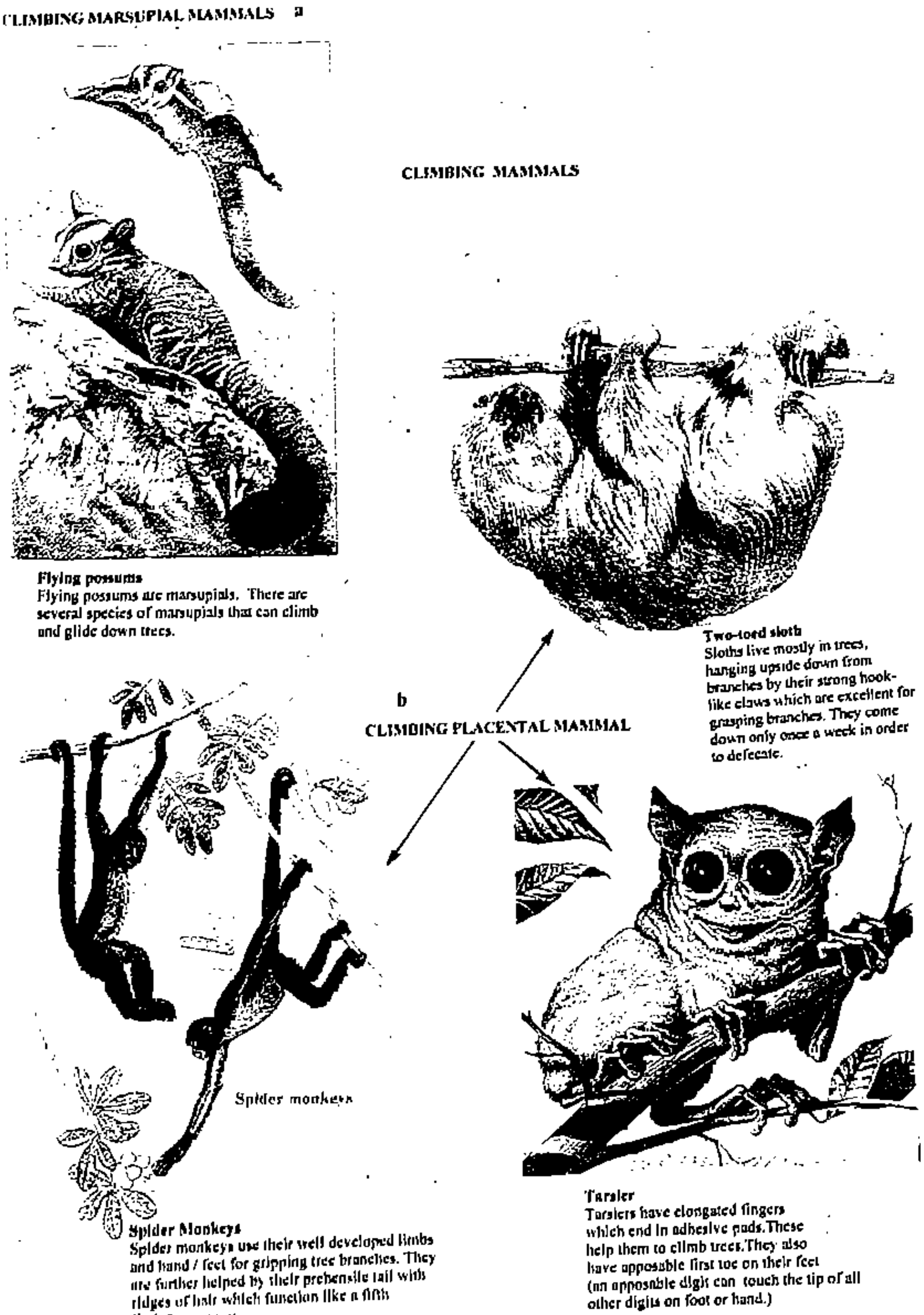


Fig. 16.53: Some mammalian scansorial vertebrates which are adapted for climbing. (a) Climbing marsupial mammals (b) Climbing placental mammals.

Scansorial adaptations

Those climbers which walk on almost horizontal branches do not have any special adaptations except that their tails and feet are **prehensile**

Arboreal snakes, lizards, tree squirrels, proboscis, howler monkeys and langurs jump from branch to branch. They have a long strong flexible back, long limbs, slender bones and muscle attachments similar to cursors. The long hind legs, flexed knee and general limb mechanics are like that of saltators. However, the femur is **not** shorter than fibia. The foot can grip the substrate as in *Tarsius*.

The orangutan, lorises and the sloths (Fig. 16.53 b) which hang upside down secure a support and pull themselves to reach another support. The proximal and middle segments of the limbs are nearly equal but the feet are large for gripping, which is more important to them than propulsion. The thorax tends to be long. Sloth reach other branches for which they have complex musculature at the anterior vertebrae, preventing dorsoflexion of the spine. The head of the humerus and femur are rounded, the ulna and radius are for pronation and supination. The distal end of ulna has a styloid process which forms a pivot around which the carpus moves. Fibula is large and free (Fig. 16.54 a).

In general, the bones are light and slender and the muscles such as flexors, pronators, supinators and abductors are very well developed.

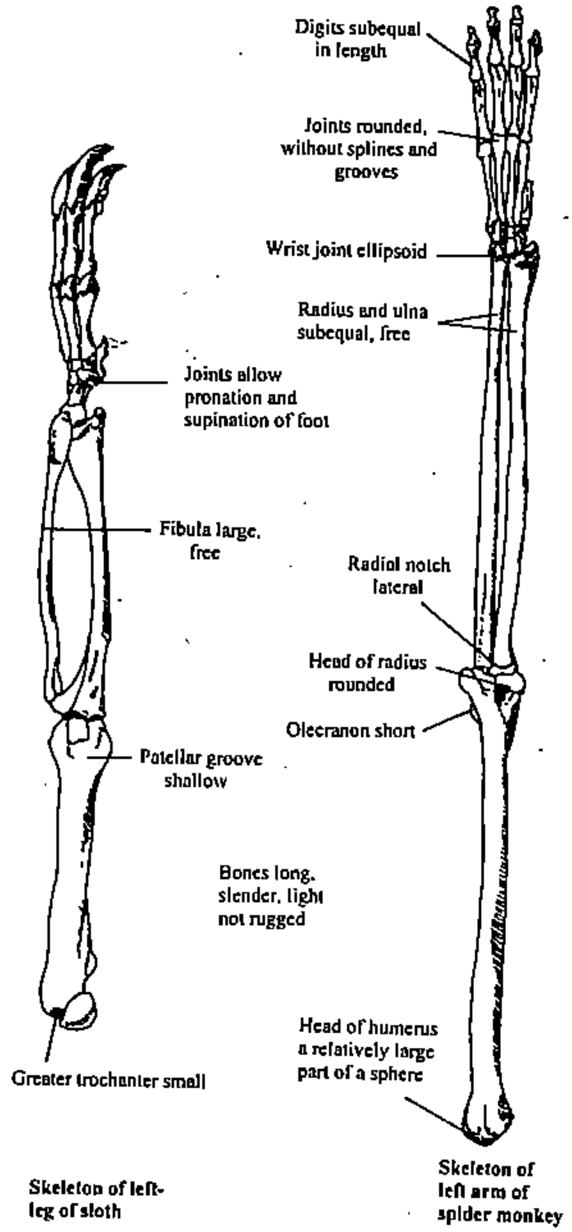


Fig. 16.54: Adaptive modifications in the skeleton of limbs of climbers.

Brachiation or arm swinging under branches

To swing from branch to branch, climbers use only fore limbs for support. Gibbons, Siamang, Langur and other monkeys have very long fore limbs - twice as long as the trunk. The fossa (depression) on the humerus is deep and can accomodate the olecranon process of the ulna so that the elbow can be straightened.

The collor bone (clavicle) is long; the scapula lies flat on the back. The muscles of the back and arm are so inserted that they release the tension.

The back is short and compact and the trunk can swing as a single unit. The lumbar area does not contribute to locomotion so the vertebrae have short centra. The spine rotates with each swing. Large eyes face forward to perceive depth and also overlapping vision.

Grasping

In order to prevents slipping in any direction, climbers have strong digital flexor muscles for grasping. Scansorial snakes grasp with coil of the body. The first digit is opposed in tree frogs to hold on. In Chamaeleon, the digits are divided into two groups of two and three digits to grasp a branch while moving on it. In the birds, the second and third digit are opposed to the first and fourth for grasping. Soles and digits of graspers are naked and sensitive. Monkeys have an opposable thumb and a large toe. Fig. 16.55 shows the hand/foot of some climbed for grasping.

The tail also functions as a grasping organ. In climbers it is prehensile, long, strong, sensitive and curved at the end. Salamanders, chamaeleons, snakes, monkeys and pangolins curve the tail ventrally while porcupines curve it dorsally. The prehensile tails tend to be flexible at the base.

The arboreals keep their balance by lowering the centre of gravity. They flex their legs to hold the body low. Long tails also help to balance. Tailless climbers hang, swing or move slowly.

The appendages of scansorials have cushion like footpads as in tree frogs and primates. Claws are also used to cling to the substrate as they enter crevices.

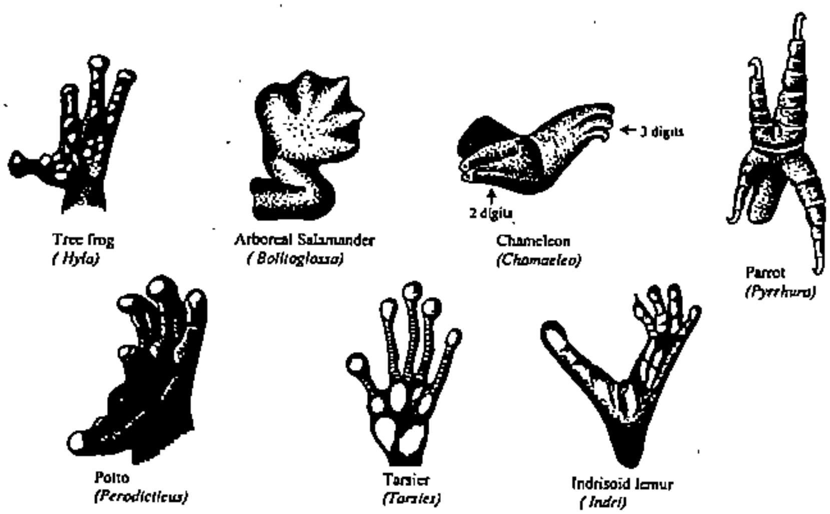


Fig. 16.55: Prehensile hand/foot of climbers used for grasping. Note the cushion-like foot pads at ends of digits which are useful for adhering.

Adhering

Tree frogs may have glands on their ball-like finger tips or may press their moist tummy for adhering. Salamanders have adhesive pads on their feet. The wall lizard *Gecko* has sharp claws which help it to cling to rough surfaces. For walking on smooth substrates, such as walls, lizards, have a remarkable adaptive mechanism. Under each toe, there are 16 to 21 broad lamellae with hair like setae. Each seta branches into bristles having saucer like end plates. Blood sinuses under the lamellae cushion the toes and adjust the pressure so that a maximum number of end plates reach into the irregularities of the surface. A collective close contact causes the surface tension to make the animal adhere to the substrate (Fig. 16.56).

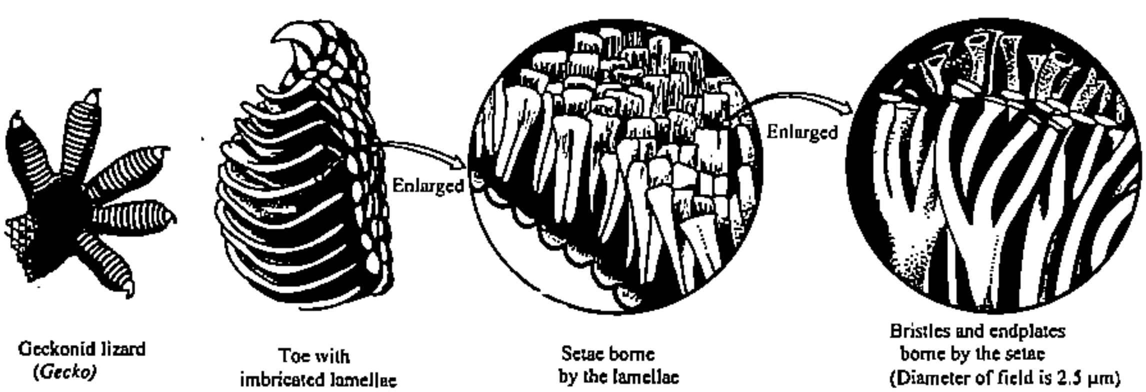


Fig. 16.56: Foot of Geckonid lizard showing adaptation for adhering on walls.

SAQ 5

i) State one difference between axial and appendicular locomotion.

....

....

....

ii) Match the terms for locomotion in column A with those for activity in column B.

	Column A		**Column B**
1.	Scansorial	a.	fly in air
2.	Ricochetal	b.	move both feet together
3.	Cursorial	c.	climb trees
4.	Saltatorial	d.	run on ground
5.	Volant	e.	jump on ground

iii) State an adaptation of feet for movement in water in (a) frog (b) penguin (c) seal.

....

....

....

....

....

iv) Give the biological name of a volant (a) amphibian (b) reptile (c) mammal.

....

....

....

v) What is a patagium?

....

....

....

vi) Give three adaptations for flight in skeleton of birds.

....

....

....

....

....

vii) What do plantigrade, digitigrade and unguligrade locomotion mean?

....

....

....

viii) Give one adaptation for grasping a tree branch in (a) chameleon (b) monkey (c) tree frog.

....

....

....

....

ix) Why are the hind legs of bipedal cursors long?

....

....

x) Which type of locomotion consumes the most energy, swimming, walking or flying?

....

....

16.8 SUMMARY

- Vertebrate animals have specialised adaptations such as locomotion on water, air, ground and trees as well as colouration, bioluminiscence, echolocation. They also have adaptations for defence.
- Colour of animals is due to pigments or biochromes contained in cells called chromatophores.
- Animal pigments for different colours are melanin (brown or black), carotenoids (yellow and red), pteridines and ommochromes (yellow xanthophores and red erythrophores).
- Structural colours are due to scattering which cause iridiscent colours to shine.
- Colour vision is due to cones present in the retina which have specific cells to recognise specific colours.
- Fish, birds and primates have good colour vision.
- In animals colouration is adaptive. Adaptive colouration is of two types. (1) protective or cryptic - animal is so coloured that it blends with the surrounding. (2) warning or aposematic - animals are brightly coloured which advertise their toxicity.
- Examples of protective colouration : animals living on trees are green; those living in snow are white. Flat fish and garden lizard can change colour according to surroundings. The body colouration of half white and half brown in the anteater and the stripes of zebra disrupt the outline of the body and protect them from predators.
- Warning colours are bright yellow and red and are the colours of poisonous animals eg. wasps. *Heloderma.*
- Mimicry is defined as resemblance in external appearance, shape and colour between organisms belonging to widely separated groups. An animal which resembles another animal is called a **mimic**. That which is copied is called **model**.
- Mimicry is of two kinds. When unprotected species resemble distasteful species or poisonous species it is termed **Batesian mimicry**. **Müllerian mimicry** is when two or more unrelated but protected species resemble each other.
- Example of protective mimicry; (1) many insects are shaped like leaves. (2) non-poisonous snake is coloured like poisonous snake; moth may mimic a wasp. (warning mimicry) (3) other forms of mimicry are alluring mimicry in which predators behaviour gives the idea of a bait. In conscious mimicry, the prey feigns death in order to fool the predator.
- **Bioluminiscence** is emission of light by living organisms.
- The light-emitting chemical in bioluminiscence is **luciferin**. In the presence of oxygen and an enzyme **luciferase**, luciferin is oxidised and emits light.
- Both Luciferin and Luciferase are present in photogenic glands of the bioluminiscent animal.
- Light emission serves several purposes, such as capture of prey, escape from predators and attracting mates for reproduction.
- Animals show various adaptations for defence (1) In order to defend themselves, (2) their young and (3) the territory in which they live.
- Various means of escaping the predators are i) running away at great speed e.g. Kangaroo. ii) using teeth, claws, horns etc. e.g., cat, dog, deer. iii) forming a protective ball of their scaly covering or retracting within a hard shell, e.g. ant eater, turtles. iv) benumbing or killing predators by poisonous secretions, e.g., several amphibians and snakes. v) exhibiting threatening postures and other devices to warn off predators, e.g. *Phyrnosoma* and various snakes. vi) giving out stinking

secretions, e.g. skunk. vii) birds resort to warning calls and mob the predator. viii) lizards break off their tail and run away when chased by predators. ix) some animal. feign death eg. opossums. x) animals mark their territories in various ways.

- **Echolocation** is exhibited by bats and whales who emit ultrasonic cries. They can hear and guage the distance of the obstacle with the help of resultant echo of these cries. They capture prey and navigate in the dark by echolocation. Bat is adapted to hear its own echoes as well sounds made by insects on which it feeds. Echodetector cells are present in the bat brain. Dolphins and other aquatic mammals have nasal sacs which produce sound through external nostils, blow holes.
- **Locomotion** movment in vertebrates is by skeletal muscles and appendages such as fins in fish and limbs in vertebrates.
- locomotion is classified into (I) **Aquatic** e.g. fish the primary swimmers and (b) walruses, otters, turtles, water snakes etc as secondary swimmers.
  (II) **Volant** animals which fly in air.
  (III) **Cursorial** animals which which walk or run on land.
  (IV) **Scansorial** animals also called arboreal or climbers which climb trees or rocks.
- Aquatic locomotion require the following adaptations a) streamlined body, b) smooth skin for countering drag, c) segmental muscles and d) tail for propulsion e) fins for steering, stabilising and countering displacement f) air bladder in bony fishes for buoyancy. Propulsion is a) by side to side lashing of tail (ostraciform), b) posterior half thrown into waves (carangiform) or, c) eel like with body movement similar to waves (angnilliform).
- In aquatic birds, feet are webbed. In turtles and mammals fore limbs form paddles.
- Divers like penguins and whales are physiologically adapted for reduced oxygen (O_2) consumption when under water.
- Volant vertebrates have the following adaptations: a) streamlined shaped, b) light skeleton with air spaces, c) fused bones, d) forelimbs modified into wings with epidermal feathers, e) keeled sternum for attachment of flight muscles, f) acute vision, g) homoiothermy, h) air sacs for ventilation, i) excellent muscle contraction.
- Flying lizards and mammals have a membrane called pataguim which helps them for gliding. Bat wing is a pataguim attached to long digits.
- **Cursorial adaptations** are a) stream lined body, b) long legs, c) long distal segments, d) fused metacarpals and metatarsals, e) plantigrade, digitigrade or unguligrade locomotion, f) bipidal or quadripedal movement, g) flexible spine.
- Jumping cursorial animals are called **saltators**. They have (a) much longer hind limbs than forelimbs, b) tail well developed for balancing. Saltators which jump with both legs in unison for a few successive strides are called **ricochetal.**
- **Limbless cursorial** vertebrates or **crawlers** by four kinds of movements - i) lateral undulation, ii) rectilinear movement iii) concertina movement; and vi) side winding movement.
- Scansorials or climbers have a) prehensile digits and tail, b) skeleton of hand permits allround movement, c) foot pads or claws for grasping the tree lizards have lamellated feet for adhering.

16.9 TERMINAL QUESTIONS

1. Distinguish between protective and warning colouration.

....

....

....

....

....

2. Cite five examples of protective colouration.

....

....

....

....

....

3. Write notes on Batesian and Muellerian mimicry.

....

....

....

....

....

4. Cite one example each of protective, warning, alluring and conscious mimicry and mention the purpose for mimicry in each case.

....

....

....

....

....

....

....

....

....

....

5. Explain five different means of defence in animals with examples.

....

....

....

....

....

....

....

....

....

....

6. Explain the mechanism of bioluminescence.

....

....

....

....

....

....

....

....

....

....

7. Enumerate the various adaptations for aerial mode of life.

8. How are aquatic animals adapted for movement in water. Add a note on adaptation for diving.

9. What are ricochetals? Give one example. How are they different from other saltators.

....

....

10. What are the adaptations for arboreal life?

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

11. How does the lizard move on walls?

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

12. Explain the different ways by which limbless animals move.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

13. How is a cursorial mammal adapted for terrestrial locomotion?

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

16.10 ANSWERS

Self-assessment Questions

1. i) Chromatophore; ii) melanin; iii) acquired; iv) Cryptic, protective; v) mimicry; vi) Batesian; vii) alluring.

2. i) The phenomenon of emitting light by organisms.
   ii) Luciferin and Luciferase.
   iii) Protein
   iv) Catching a prey, escaping a predator, attracting a mate
   v) Luciferin, ATP, O_2 and products - oxidised Luciferia, AMP, Pi and light.

3. i) In ancient times, red Indians poisoned their arrows with its poison.
   ii) Warning colouration, warning mimicry, autotomy, feigning death, protective colouration, threatening display, armour, claws, hoofs and teeth.
   iii) by a) - aposematic colouration
   b) - autotomy
   c) - vocalisation

4. i) The ability of an animal to detect obstacles and prey from the echoes of its own sounds is termed echolocation.
   ii) Nasal sacs opening into external nostrils are called blow holes.
   iii) *Lollocalia*, *Steatornis* or guacharo or oil bird.

5. i) Axial locomotion is by muscles in aquatic organisms while appendicular locomotion is by limbs in non aquatics, especially in animals of aerial and terrestrial habitat.

   ii) 1 - c, 2 - b, 3 - d, 4 - e, 5 - a

   iii) a) webbed feet, smooth skin; b) featherless wings, physiological adaptation for diving, webbed feet; c) streamlined body, no pinna, forelimbs modified into flippers for swimming.

   iv) a) *Rhacophorus*; b) *Gecko* sp. *Draco*; c) *Colugo/Glaucomys*, any bat.

   v) A fold of skin/skin membrane in volant animals for flying.

   vi) pneumatic bones, fused bones, keel, compact skull, elongated forelimbs bones, reduced number or phalanges in birds and long phalanges in bats and long hind limb bones.

   vii) walking on the sole of foot; walking on digits; walking on tips of digits.

   viii) a) digits divided into two groups; b) prehensile tail, opposable thumb and large toe; c) foot pads at tip of toes.

   ix) because hind legs propel the body during locomotion.

   x) flying.

Terminal Questions

1. Refer 16.2.2
2. Refer 16.2.2
3. Refer 16.3.1
4. Refer 16.3.3
5. Refer 16.5.2
6. Refer 16.4.2
7. Refer 16.7.2
8. Refer 16.7.1
9. Refer 16.7.3
10. Refer end of 16.7.3
11. Refer last paragraph of the lesson
12. Refer 16.7.3
13. Refer 16.7.3

GLOSSARY

Adaptation: An evolutionary process by which an organism becomes fitted to the environment in which it lives; a structure fitted for a particular environment; the physiological habituation of a receptor to a particular stimulus such that the receptor ceases to respond unless the stimulus becomes more intense.

Agonistic behaviour: Aggressive behaviour between animals, usually used in reference to such behaviour between individuals of the same species.

Altruism: Helpful behaviour that raises the receiver's direct fitness while lowering the donors direct fitness.

Aposematic colouration: A conspicuous colour pattern that helps to protect an animal by advertising that it is toxic or dangerous also found in some harmless species that mimic dangerous ones.

Biological clock: An internal tuning mechanism of animals that is involved in controlling circadian rhythms and other cycles. Also plays a role in migration and navigation.

Chromatophore: A pigment containing cell capable of producing colour change in the skin.

Circadian rhythm: A roughly 24 hours cycle of behaviour that expresses itself independent of environment.

Circannual rhythm: Annual cycle of behaviour that expresses itself independent of environmental changes.

Cryptic colouration: A colour pattern that conceals an animals by helping it visually blend with its surroundings, often found in prey species and sometimes in predators that stalk or lie in wait for their prey.

Cursorial: Animals having limbs adapted for running.

Disruptive colouration: Colouration which breaks the body outline so that the animal is able to camouflage itself in the surroundings.

Dominance hierarchy: A social ranking within a group in which some individuals give way to others, often conceding useful resource to other without a fight.

Ethology: The study of proximate mechanisms and adaptive value of animal behaviour.

Fixed action pattern: An innate highly stereotyped response that is triggered by a well-defined, simple stimulus; once the pattern is activated the response is performed completely.

Habituation: A gradual decrease in response to successive stimulation due to changes in the central nervous system.

Home range: An area that an animal occupies but does not defend in contrast to territory, which in defended.

Imprinting: A form of learning in which individuals exposed to certain by stimuli, early in life, form an association with an object and may later show sexual behaviour towards similar objects.

Innate releasing mechanism: A hypothetical, neural mechanism responsible for controlling an innate response to a sign stimulus.

Instinct: A behaviour pattern that reliably develops in most individuals, promoting a functional response to a releaser the first time the action is performed.

Kin selection: A form of natural selection that occurs when individuals differ in ways that affect their parental care or helping behaviour and thus the survival of their own offspring or kin.

Mimicry: An adaptation whereby an animal becomes camouflaged by taking on the appearance of some other living or non-living object.

Mobbing behaviour: A behaviour in which prey closely approach and attempt to harass the predator.

Monogamy: A mating system in which one male mates with one female in a breeding season.

Polygyny: A mating system in which a male fertilises the eggs of several females in a breeding season.

Polyandry: A mating system in which a female has several mating partners in a breeding season.

Proximate cause: An immediate underlying cause based on the operation of internal mechanisms possessed by an individual.

Releaser: A sign stimulus given by an individual as a social signal to another.

Saltators: Animals that use leaping, jumping or sudden movements for locomotion.

Scansorial: Habitually climbing or animals adapted for climbing.

Volant: Animals adapted to flying, nimble and rapid.

Visual acuity: Sharpness of vision, ability to see over large distances, acute vision.

Ultimate cause: The evolutionary, historical reasons why something is the way it is.

FURTHER READING

1. An Introduction to Animal Behaviour, Aubrey Manning and Marian Stamp Dawkin (Fourth Edition) Cambridge University Press.
2. Animal Behaviour, Reena Mathur (1994) Rastogi and Company, Meerut.
3. The Oxford Companion to Animal Behaviour edited by David McFarland, Oxford University Press (1987).

NOTES