M.Sc. Final Year

Zoology, Paper I

COMPARATIVE ANATOMY OF VERTEBRATES

मध्यप्रदेश भोज (मुक्त) विश्वविद्यालय – भोपाल

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SYLLABI-BOOK MAPPING TABLE

Comparative Anatomy of Vertebrates

Syllabi	Mapping in Book
UNIT-I 1. Ancestory of Chordates 2. Inter Relationship of Urochordata and Cephalochordata and their Relationship with other Deuterostomes. 3. Tunicates: Reproduction, Development and Metamorphosis. 4. General Organization, Affinities and Systemic Position of Amphioxus. 5. Organs and Mechanism of Feeding in Urochordate and Cephalochordate.	**Unit-1:** Chordates: Ancestory and Basic Concepts **(Pages 3-55)**
UNIT-II 1. Origin, Evolution, General Organization and Affinities of "Ostracoderms". 2. General Organization, Specialised, Generalised and Degenerated Characters of "Cylosomes". 3. Origin, Evolution and General Organization of Early Gnathostomes "Placoderms". 4. General Account of Elasmobranchii, Holocephali, Dipnoi and Crossopterygii. 5. Integument and its Derivatives in Vertebrates. 6. Flight and Gliding in Vertebrates.	**Unit-2:** Chordates: Origin, Evolution and General Organization of Various Forms **(Pages 57-118)**
UNIT-III 1. General Plan of Circulation in Various Groups: (a) Blood. (b) Evolution of Heart. (c) Evolution of Aortic Arches and Portal Systems 2. Respiratory System: (a) Characters of Respiratory Tissue. (b) Internal and External Respiration. (c) Comparative Account of Respiratory Organs. 3. Skeletal System: (a) Forms, Function, Body Size and Skeletal Elements of the Body. (b) Comparative Account of Jaw Suspensorium, Vertebral Column. (c) Limbs and Girdles.	**Unit-3:** Circulatory, Respiratory, and Skeletal System in Vertebrates **(Pages 119-180)**
UNIT-IV 1. Evolution of Urinogenital System in Vertebrate Series. 2. Sense Organs: (a) Simple Receptors. (b) Organs of Olfaction and Taste. (c) Lateral Line System. (d) Electro Reception. 3. Nervous System: (a) Comparative Anatomy of the Brain in Relation to its Functions. (b) Nerves - Cranial, Peripheral and Autonomous Nervous Systems.	**Unit-4:** Urinogenital, Sensory, and Nervous System in Vertebrates **(Pages 181-234)**

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INTRODUCTION

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The comparative anatomy is the study of distinct animal species' body structures in order to comprehend the adaptive modifications that have occurred in the course of evolution from common ancestors. The work of French naturalist Pierre Belon, who demonstrated in 1555 that the bones of humans and birds are made up of similar elements arranged in the same way, is the foundation of modern comparative anatomy. With the work of two French naturalists, Georges-Louis Leclerc, Comte De Buffon, and Louis-Jean-Marie Daubenton, who studied the anatomies of a wide range of species, comparative anatomy advanced significantly in the 18th century. In the early nineteenth century, French biologist Georges Cuvier established a stronger scientific foundation for the topic by claiming that animals' structural and functional traits are the result of their interaction with their environment. In this book, we will study the comparative anatomy of vertebrates.

Vertebrates originated about 525 million years ago during the Cambrian explosion, which saw the rise in organism diversity. Vertebrate, also called Craniata, are any animal of the subphylum Vertebrata, which is the predominant subphylum of the phylum Chordata. They have backbones, from which they derive their name. The vertebrates are also characterized by a muscular system consisting primarily of bilaterally paired masses and a Central Nervous System (CNS) partly enclosed within the backbone. Characteristically, the vertebrates range in size from tiny fish to the whales, which include the largest animals ever to have existed.

Fundamentally, the vertebrates comprise all species of animals within the subphylum 'Vertebrata', i.e., 'Chordates with Backbones'. Vertebrates represent the overwhelming majority of the phylum Chordata, with currently about 69,276 species described. It includes the jawless fishes and jawed vertebrates, which include the cartilaginous fishes (sharks, rays, and ratfish) and the bony fishes. As per the cladistics analysis, vertebrates can be subdivided into five major groups or classes – Pisces (Fishes), Amphibia (Aamphibians), Reptilia (Reptiles), Aves (Birds), and Mammalia (Mammals including Humans).

This book, *Comparative Anatomy of Vertebrates*, has been designed keeping in mind the Self-Instruction Mode (SIM) format and follows a simple pattern, wherein each unit of the book begins with the Introduction followed by the Objectives for the topic. The content is then presented in a simple and easy-to-understand manner, and is interspersed with Check Your Progress questions to reinforce the student's understanding of the topic. A list of Self-Assessment Questions and Exercises is also provided at the end of each unit. The Summary and Key Terms further act as useful tools for students and are meant for effective recapitulation of the text.

UNIT 1 CHORDATES: ANCESTORY AND BASIC CONCEPTS

Structure

1.0 INTRODUCTION

A chordate is a member of the phylum chordata. All chordates have five synapomorphies, or primary traits at some point during their larval or maturity stages that separate them from all other taxa. A notochord, dorsal hollow nerve cord, endostyle or thyroid, pharyngeal slits, and a post-anal tail are among the five synapomorphies. Chordates are named after their distinctive ‘notochord’, which is important for chordate’s structure and movement. Chordates are also bilaterally symmetrical, have a coelom, a circulatory system, and metameric segmentation.

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In this unit, we will discuss the concept of chordate and its ancestry, along with the inter-relationship of Urochordata, Cephalochordata, and other Deuterostomes. It will also focus on the reproduction, development, and metamorphosis of Tunicates, along with general organization, affinities, and systemic position of Amphioxus.

1.1 OBJECTIVES

After going through this unit, you will be able to

- Discuss the concept of chordate and its ancestry
- Explain the inter-relationship of Urochordata, Cephalochordata, and other Deuterostomes
- Describe the reproduction, development, and metamorphosis of Tunicates
- Evaluate the general organization, affinities, and systemic position of *Amphioxus*

1.2 CHORDATA

Chordata (Gr. *Chorde*, string or cord; *ata*, bearing). Animals with vertebral column or back-bone *viz*., protochordates or acraniates (Hemichordates, Urochordates and Cephalochordates) and Vertebrates or Craniates (Pisces, Amphibians, Reptiles, Aves and Mammalians). Most of the chordates are free-living and none is strictly parasite. There are some 65,000 known living chordates besides the fossil remains of many extinct forms. However, these animals exhibit some common characters which show their common ancestry. But there is considerable controversy regarding the origin of chordates.

1.2.1 Fundamental Characteristics of Chordata

All the chordates exhibit following three primary distinguishing characteristics at some stage in their life history:

(1) **Presence of Notochord (Gr. *Notos* or *noton*, back; *Chorde*, string):** It is a stiff, elastic, longitudinal supporting rod-like skeletal or structure lying between the nerve cord and alimentary canal. It is composed of large vacuolated turgid cells containing a gelatinous matrix and enclosed by an outer fibrous, connective tissue sheath called chordal sheath and an inner elastic sheath of connective tissue called elastic – interna. It serves as a primitive internal skeleton and acts as a rigid axis but permits movements of the body. It may persist throughout life, as in lancelet, lamprey and some fishes, or it may be replaced partially or completely in adult vertebrates by vertebral column, a backbone.

(2) **Presence of Dorsal Hollow or Tubular, Fluid-Filled Nervecord:** It is situated dorsal to both the alimentary canal and the notochord and runs from one end to the other. The nerve cord or neural tube is derived by infolding

of a mid-dorsal of the ectodermal neural plate or strip of the embryo and encloses a cavity or canal called neurocoel. This dorsal tubular nerve cord persists throughout life in most chordates, but in a few it degenerates before maturity.

(3) **Presence of Pharyngeal Gill Slits:** All chordates possess at some stage of their life, a series of paired lateral gill slits or branchial clefts or pharyngeal clefts or gill clefts perforate through the pharyngeal wall of the gut behind the mouth. Gill clefts which do not bear gills are usually called visceral clefts. Each gill slit develops in the embryonic life by out-pocketing's or evagination of endoderm in pharynx and a corresponding in-pocketing or invagination of ectoderm on the outside of the body. The intervening wall ruptures so as to form a gill-slit. They serve primarily for the passage of water from the pharynx to outside, thus bathing the gills for respiration. The water current secondarily helps in filter-feeding by retaining food particles in the pharynx.

The above three common characters are present during early embryonic life of all the chordates. But all the three characters rarely persist in the adult (e.g., *Branchiostoma*/ *Amphioxus*) but they are modified or even lost in the adult stages of higher chordates. Only one of these three basic features of chordates is present in adults of most of them, this is the dorsal tubular nerve cord, even this has its hollow lumen greatly reduced in some, and Urochordata the central nervous system degenerates in the adult. The notochord disappears during development in most vertebrates, while the nerve cord and the pharyngeal cleft or their derivatives remain in the adult. The three common chordate characters were probably characteristic of the ancestral chordates. They distinguish chordates from all other animals and appear to reveal their common ancestry.

1.2.2 General Characteristics of Chordata

The characteristics of chordata are:

i. Aquatic, aerial or terrestrial all free living with no fully parasitic forms.
ii. Bilaterally symmetrical and metamerically segmented.
iii. Exoskeleton often present well developed in most vertebrates.
iv. Body wall triploblastic with three germinal layers: ectoderm, mesoderm and endoderm.
v. Coelomate animals with a true coelom, enterocoelic or schizocoelic in origin.
vi. A skeletal rod, the notochord, present at some stage in life cycle.
vii. Digestive system complete with digestive glands.
viii. Blood vascular system closed.
ix. Heart ventral with dorsal and ventral blood vessels.
x. Hepatic portal system well developed.
xi. Excretory system comprising proto –or meso-or meta-nephric kidneys.

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Table. 1.1 Differences between Chordata and Non-Chordata

S.No.	Characters	Chordata	Non-Chordata
1	Notochord	Present	Absent
2.	Nerve cord	Dorsal hollow / tubular or replaced by vertebral column	Solid ventral
3.	Pharyngeal gill slits	Present at some stage of life	Absent
4.	Heart	Ventral	Dorsal/ laterally/absent
5.	Flow of Blood	Dorsally backward and ventrally forward	Dorsally forward and ventrally backward
6.	Derivation of Limbs	Limbs derived from several segments	Limbs derived from single segments
7.	Opening of Anus	Open before the last segment	Open into the last segment
8.	Coelom	True coelomate	Acoelomate, pseudocoelomate or true coelomate
9.	Gut Position	Ventral to nerve cord	Dorsal to nerve cord
10.	Hepatic portal system	Present	Absent
11.	Respiration	Through Gills / Lungs	Through body surface, gills or tracheae
12.	Roots of segmental nerves	Dorsal and Ventral separate	Dorsal and ventral roots not separate
13.	Reproduction	Sexual reproduction predominant	Asexual reproduction predominant
14.	Regeneration power	Usually poor	Usually good
15.	Body temperature	Cold/ worm blooded	Cold blooded

1.2.3 Ancestry or Origin of Chordates

Chordates may have evolved from some freshwater forms as Chamberlain (1900) pointed out that all modern chordates possess glomerular kidneys that are designed to remove excess water from body. However, early ancestors of chordates were soft bodied so no definite fossil remains. The fossils of chordates have all been recovered from marine sediments and even modern protochordates are all marine forms. Glomerular kidneys are also found in some marine forms such as myxinoids and sharks. That makes the marine origin of chordates more plausible. They must have originated prior to Cambrian period as the oldest fossils of known vertebrates have been collected from the *Cambrian* beds or strata of *Palaeozoic* era. Hence it is believed that the first chordate might have originated prior to Cambrian period, that is about 600 million years ago. It is believed that fixed *Pterobranchs* (Hemichordata) were the first chordates formed on the earth. It gives rise to *Ascidians*. The larvae of Ascidians developed into *Amphioxus* and fishes by neoteny.

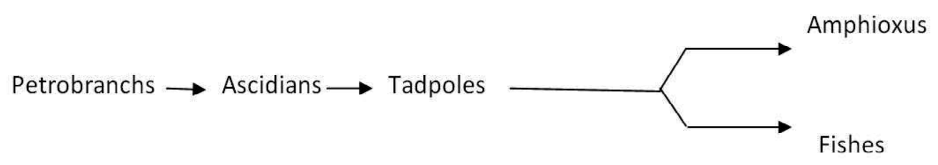

Fig. 1.1 *Pterobranchian origin of chordates*

Most of the scientists consider that the chordates have originated from non-chordates or invertebrates. According to Barrington (1965), the ancestor of chordates was a sessile lophophorate or arm feeding creature.

It is believed that chordates are evolved from some invertebrate *deuterostome* ancestor. Deuterostomia is a group comprising Lophophorate, echinoderms, hemichordates and chordates where blastopore develops into anus. They also have similarities in embryonic development, type of coelom and larval stages. Chordate ancestors were soft bodied animals. Hence they were not preserved as Fossils. Fossils of the earliest vertebrates are known from the Silurian-Devonian period, about 400 million years ago.

Theories of Invertebrate Ancestry of Chordates

There are several theories have been put forwarded to explain the origin of chordates either directly from some non-chordate groups or through the intervention of some protochordate but these theories have serious drawbacks and are far from being satisfactory and have only a historical value. Only the echinoderm theory has received some acceptance.

Coelenterate theory suggests that the chordates evolved from coelenterates. But the coelenterates are at a very low level of metazoan grade of organization. Radial symmetry coelenteron, cnidoblasts, etc., were first and advanced characters were developed to give rise to chordates. This theory infers that chordates might have acquired higher characters independently. It is not correct and hence, this theory is not acceptable.

Annelid theory was proposed by Semper (1976) and Minot (1897). According to them, the annelids are the ancestors of the chordates. The annelids show bilateral symmetry, mesmerism, head, lateral coelom complete digestive tract, closed circulatory system, hemoglobin, etc., like chordates. The resemblance is enhanced if, an annelid is turned upside down. This is based upon the resemblance of primitive chordates such as the Ammocoetes larva of the lamprey to an inverted annelid.

The digestive system of annelid and chordates is a simple tube with a ventral mouth at one end and an anus at the other. The annelid nervous system consists of a pair of ventral nerve cords and cerebral ganglia. If the annelid worm is inverted the ventral nerve cord becomes dorsal as in chordates.

In the circulatory system of annelid, the blood flows anteriorly in the dorsal vessel and posteriorly in the ventral vessel. When this is inverted, it would resemble the circulatory system of chordates in which the dorsal aorta carries blood posteriorly and the ventral aorta carries blood anteriorly. But this theory is not convincing because fundamentally a chordate cannot be compared with an annelid.

i. There is no structure in any annelids which even remotely suggest a notochord.

ii. In annelids, the nerve cord is a solid structure located mid-ventrally but in chordates, the nerve cord is a mid-dorsally placed hollow tube.

iii. There is no gill slit in annelids.

iv. The segmentation in annelids shows complete division of the body into rings where as in chordates only the myotomal region is segmented.

v. The annelids shows the typical protostome embryology like spiral cleavage and schizocoelic coelom formation. But chordates show the

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deuterostome embryology like radial cleavage and enterocoelic coelom formation.

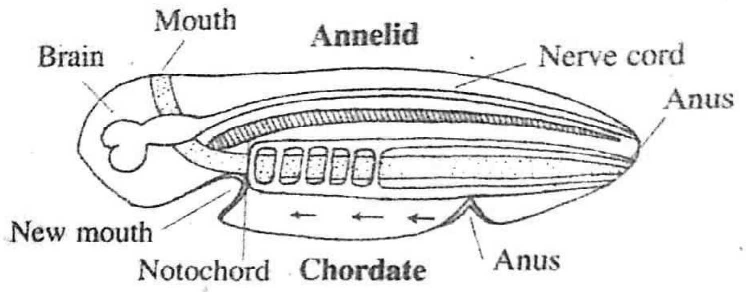

***Fig. 1.2** The derivation of chordate from an annelid*

Considering all these objections, the phylogenetic relationship between the annelids and the chordates cannot be established.

Deuterostome Line of Chordate Evolution

On the basis of embryonic and larval developments, bilateria is divided into two major divisions. (1) Protostomia and (2) Deuterostomia. The protostomia includes from annelida to arthropoda while deuterostomia includes echinodermata, pogonophora and chordates.

***Table. 1.2** Basic Differences between Protostomia and Deuterostomia*

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

Following common features of all deuterostomes suggests strong evidence of a closer evolutionary relationship between the three principal deuterostome phyla- Echinodermata, Hemichordata and Chordata:

i. Early cleavage of zygote is indeterminate.

ii. Blastopore of gastrula develops into anus.

iii. Coelom (enterocoelous except vertebrates) is formed by the fusion of pockets developed from the endoderm of developing archenteron of the embryo.

iv. Pelagio larve of echinoderms and hemichordates have a close resemblance vertebrate does not have a floating larva.

v. Deterostomes use creatine as phosphagen whereas, invertebrates use arginine. Some hemichordates as well as echnoids use both.

Echinoderm Ancestory of Chordates

On the basis of comparative studies of larval stages of echinoderms and hemichordate, Johannes Muller (1860) and by Bateson and Garstang (1886) suggest that chordates have been evolved from echinoderms. Tornaria larva of hemichordates is closely resembles to the echinoderm larvae (Bipinnaria, Auricularia, Dipleurula and Doliolaria). Both are small, transparent, free swimming and bilaterally symmetrical and both possess:

i. Similar ciliary and coelomic cavity bands and apical tuft of cilia.

ii. Digestive tract divisible into foregut, midgut and hindgut.

iii. In both, dorsal blastopore becomes anus.

iv. Coelomic sacs are enterocoelic in origin.

v. Heart vesicle of *Balanoglossus* is homologous to madreporic vesicle of echinoderm larvae.

vi. *Branchiostoma* as well as, in echinoderms, the mesoderm formation from gut pouches is similar.

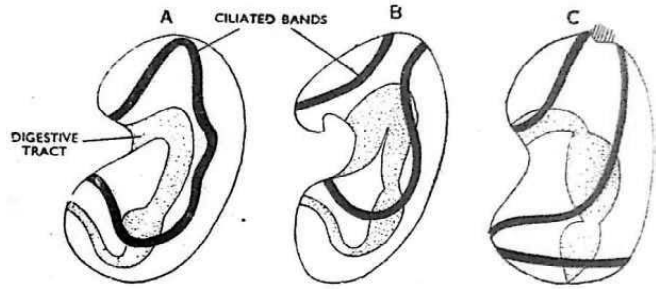

Fig. 1.3 *The Larvae of Echinoderms and Hemichordates Resemble Each Other. (A) Larva of Balanoglossus; (B) Larva of Star fish; (C) Larva of Sea Cucumber*

This striking larval resemblance led Johannes Muller, W. Garstang and DeBeers to suggest a common ancestry for the echinoderms and the hemichordates. They proposed that probably the echinoderm larva, *auricularia* become sexually mature and later this neotenic larva gave rise to chordates.

Cambrian and ordovician fossil records of carpoid echinoderms lead Torsten and Gisten to assume that carapoid echinoderms might have evolved from tornaria like creatures which have begun to settle down to lead sedentary life. Besides this, it was also claimed that in the the lower Silurian period, one carapoid echinoderm had the calyx perforated by a series of 16 small apertures. These apertures are compared with the gill slits of *Branchiostoma*. The carpoid echinoderms further showed superficial resemblance with some pteraspid ostracoderms.

The discovery of fossil echinoderms called calcichordata which further confirms echinoderm ancestry of chordates. calcichordates were asymmetrical animals which demonstrate affinities with both echinoderms and chordates but their skeleton is made of $CaCO_3$ whereas in vertebrates the bones are made of hydrated calcium and phosphate. They had large pharynx with a series of gill slits, each covered with flaps for filter feeding, a small segmented body and a postanal tail. A perforated pharynx for filter feeding appears to have evolved in diverse groups of animals during Cambrian-Orodovician periods when planktons were abundant in water.

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The phylogenetic relationship between the echinoderms and the chordates has been shown by biochemical studies also. Most of the invertebrates use arginine phosphate for transfer of energy but ophiuroides, cephalochordates, ascidians, and vertebrates use creatine phosphate. On the other hand, hemichordates and some echinoderms use both arginine and creatine phosphate as phosphate carrier and transfer of energy during muscles contraction. Serological studies also show that hemichordates and lower chordates resemble the echinoderms.

The descent of chordata from the echinodermata by the direct transformation of any echinoderm or its neotenous larva into a chordate is no longer accepted now-a-days. Instead they had a common immediate ancestor.

Hemichordata Ancestory of Chordates

There is a strong suggestive evidence that the early evolutionary stage of Deuterostomia was sessile or sedentary. However, the tornaria larva of hemichordates shows phylogenetic relationship with echinoderm larvae and hemichordates also show affinities with chordates. The pharynx perforated by gill-slits is likely an adaption to sedentary habit. No doubt, hemichordates are sedentary and have pharyngeal gill slits and a hollow dorsal nerve cord. Nevertheless, presence of a true notochord is doubtful and their adult body plan is quite different from vertebrates. Therefore, the prospect of some hemichordate as a likely ancestor of vertebrates seems to be impossible.

Ascidian Ancestry of Chordates

W. Garstang (1928) and N.J. Berrill (1955) gave importance to the tadpole-like larva of urochordates which carries typical chordate characters, namely, a notochord in tail along with segmented myotomes, dorsal hollow nerve cord, sense organs and pharyngeal gill slits. The Ascidian theory was proposed by Gastang (1928) supported by Berrill (1955) and Romer (1959). According to this theory the ancestor of chordates was marine, sessile or fixed, filter-feeding *Ascidian*. But, their body plans are so divergent that it is impossible to imagine a direct evolutionary transformation of an adult ascidian into a vertebrate. On the other hand, the ascidian larva (Tadpole larva) are tadpole-like, elongated, bilaterally symmetrical and free-swimming creatures with pharyngeal gill slits, notochord, dorsal hollow nerve tube, and a muscular postanal tail. They represent only slightly modified living creature of the ancestral chordate that gave rise to the vertebrate line of evolution.

The *Ascidian* tadpole larva developed into the present day adult *Ascidian* by retrogressive metamorphosis. According to this theory, some of the larvae failed to metamorphose into adult but they become adults by neoteny and by losing the sedentary adult stage. These neotenous forms migrated to freshwater through estuaries and become the vertebrates. Some of these neotenous forms re-entered the sea and becomes *Amphioxus*. The sessile nature of the primitive chordate ancestory, hemichordates primitive pterbranch and echinoderms is considered by the workers resulting from common ancestry. However, the ascidian theory of chordate origin does not seem to be perfect. The principal drawback is that the theory considers sessile ascidians to be ancestral to chordates. Whereas, they are highly specialized because sessility is a specialized condition wherever it occurs in the animal kingdom.

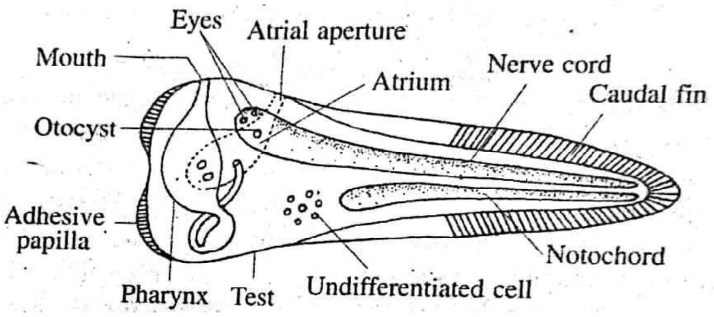

Fig. 1.4 *A free Swimming Ascidian Larva. It Gave Rise to Amphioxus and Vertebrates by Neoteny*

Cephalochordate Ancestry of Chordates

Chamberlain (1900) studied the primitive and advanced characters of cephalochordates and proposed that while extant cephalochordates possess all chordate characters in typical state, they also show some primitive features of non-chordates, such as, absence of heart, head, sense organs, respiratory pigment, filter-feeding mode of food capture and excretion by solenocytes. Fossils of 60 specimens from mid-Cambrian of the earliest chordate, *Pikaia gracilens* have been discovered from Burgess Shale in British Columbia, Canada. The amphioxus-like fossils show streamlined, ribbon-shaped, 5 cm long body having notochord in the posterior two-third of body and myomeres. It has a small head with two tentacles and gill slits in the neck region.

Other chordate-like fossils are: *Cathaymyrus* from early Cambrian sediments in China and *Palaeobranchiostomata* from early Permian from South Africa that appears to be more similar to Amphioxus.

Barrington's Hypothesis and Lophophorate Theory

The lophophorate theory was proposed by E.J.W. Barrington (1965) which is based on the deuterostome line of chordate evolution. According to this theory, a small, sessile or semisessile, lophophorate or arm feeding creature was the common ancestor of echinoderms and chordates. From this ancestral stalk were derived early stalked echinoderms and pogonophores. Romer (1959) suggested that ancestral Lophophorate was an invertebrate deuterostomes with a crown of sedentary tentacles. Its mucous-laden ciliated tentacles served to trap planktons as they were waved in water as do the modern lophophorates and pterobranch hemichordates, *Cephalodiscus* and *Rhabdopleura.*

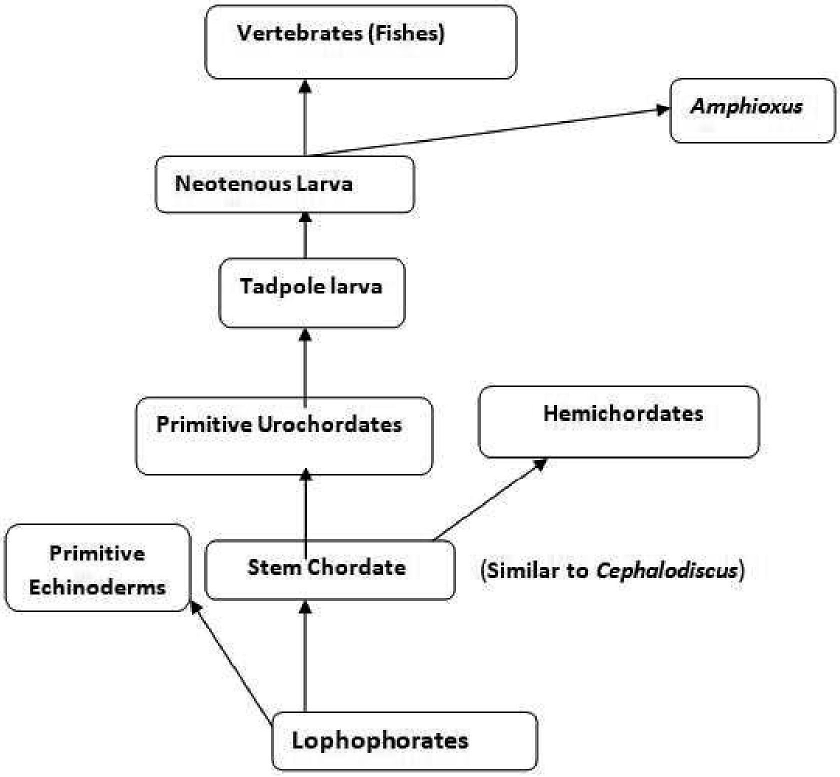

Fig. 1.5 *Scheme of Lophophorate Theory for Origin of Chordates*

The next logical step was the formation of a sessile filter feeder or stem chordate. In the stem chordates, the external tentacles were replaced by internal filtering apparatus which develops external gill-slits and a mucus-secreting endostyle. The sive-like pharynx trap the food or planktons as the water current passed through it. *Cephalodiscus*, a living pterobranch hemichordate shows the transitional stage between the two modes of feeding because it possesses both ciliated arms and a single pair of pharyngeal gill slits besides the crown of tentacles. This type of stem chordate gave rise to free living hemichordates with pharyngotremy (i.e. perforated pharynx with internal food-trapping mechanism) on one hand and sessile urochordates (*Ascidians*) on the other hand. Some ancestral urochordates developed tadpole larvae with all the typical somatic features of the chordates. According to Garstang, the larva became elongated and increased in size, the longitudinal ciliary bands shifted mid-dorsally and changed to the hollow nerve cord, the aboral cilia developed into the endostyle, and muscle fibres evolved in the tail. Some of this typical chordate larva by pedogenesis (neoteny) suppressed the sessile adult stage developed gonads precociously and became the ancestor of cephalochordates (Amphioxus) and vertebrates (fishes). The hypothetical chordate ancestry in the above light is as follows:-

Auricularia larva → **Tornaria larva** → **Tunicate / Tadpole larva** → **Amphioxus** → **Ostracoderm**
(Echinoderm) (Hemichordata) (Ascidian/Urochordata) (Cephalochordata) **(**earlier fishes/ vertebrate**)**

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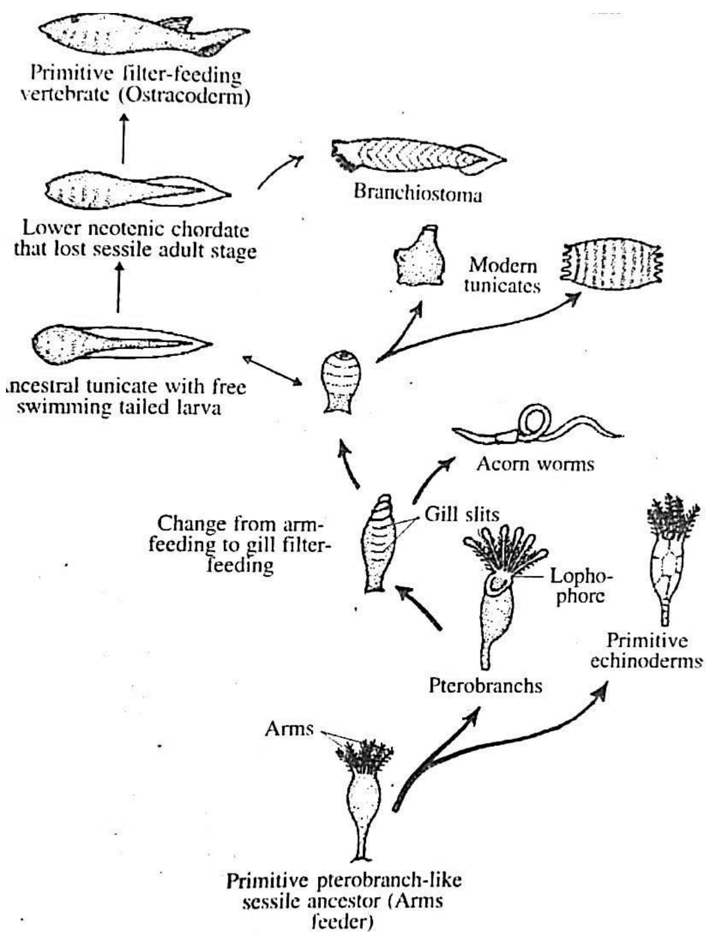

Fig. 1.6 *Phylogenetic Tree Suggesting the Possible Mode of Origin of Vertebrates*

1.3 INTER-RELATIONSHIP OF UROCHORDATA AND CEPHALOCHORDATA, AND THEIR RELATIONSHIP WITH OTHER DEUTEROSTOMES

In this section, we will discuss the inter-relationship of urochordata, and cephalochordata, and other deuterostomes.

1.3.1 Urochordata

The Urochordates are also known as Tunicates (L. *Tunica*, an outer covering) or Asciadians (Gr. *Askos*, a leather bag). Tunicates or Urochordates are small marine animals with larvae that swim freely and adults that attach themselves to the ocean floor. The tunicates were first regarded as invertebrates. In 1866 Kowalevsky kept them in chordates. Their chordate features are clearly seen in the larval stages. Majority of them are sedentary and some are pelagic. The life-history of urochordates passes through a dramatic change.

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The 1,300 species of urochordates, like all chordates, possess rod like notochord that provides resistance against muscular contractions and allows for more efficient movement; a dorsal, hollow, tubular nerve cord that forms the central nervous system; pharyngeal gill slits in the beginning of the digestive tract that allow filter feeding and help in respiration by exchanging gas between water and blood; and a postanal tail.

The chordate characters of tunicates are more pronounced during larval period. While in adults they are more like invertebrates than chordates. Therefore, the characters are described in two heads — larval characters and adult characters.

General Characteristics of Urochordates

The features of urochordates include:

i. Exclusively marine, solitary or colonial, fixed or pelagic, found in all the seas.

ii. Body shows considerable variation in size, form and colour.

iii. The body is unsegmented and without tail.

iv. The body is covered by a test or tunic. It is formed by tunicine $(C_6H_{10}O_6)_n$ which is similar to cellulose. Hence, the name Tunicata.

v. Body wall shows one-layered epidermis, dermis is made by connective tissue and muscles, and atrial epithehum.

vi. Coelom is absent. However, an ectodermal lined atrial cavity surrounds the pharynx, into this cavity the gill slits, anus and gon,oducts or genital ducts will open. It opens through atrial aperture lies on the top of atrial siphon.

vii. Larva has notochord in the tail. It disappears during metamorphosis, so adults are without notochord.

viii. Respiratory system contains numerous stigmata or gills –slits in the pharyngeal wall.

ix. Alimentary canal complete with large pharynx or branchial sac with endostyle and ciliary mode of feeding is common.

x. Heart is ventral, tube like and central in position, which periodically reverses the flow of blood.

xi. Nervous system is represented by a single dorsal ganglion in the adult; however, in larva a dorsal tubular nerve cord is present.

xii. Excretion is carried by nephrocytes, neural gland and pyloric glands.

xiii. Usually bisexual with external cross fertilization.

xiv. Development is indirect through an ascidian tadpole larva. Metamorphosis is retrogressive.

xv. Asexual reproduction is by budding. In some tunicates, alternation of generations is also found.

Phylogenetic Relationship or Affinities of Urochordata

The ascidian tadpole larva possesses all the basic chordate characters such as; (1) rod-like notochord forming axial skeleton of tail,(ii) dorsal tubular nerve cord, and (iii) gill-slits in the pharyngeal wall. This is probably because both urochordates and other chordates have originated from a common ancestor.

Relationship with Cephalochordates

The similarities and differences between urochordata and cephalochordates are discussed below:

Similarities

The adult tunicates/urochordates (*Herdmania*) are related to cephalochordates (*Amphioxus* or *Branchiostoma*) on the following characters:

i. Ciliary filter feeding or food concentration mechanism and respiratory mechanism are similar in both.

ii. Large pharynx with endostyle are similar in both.

iii. The branchialtenticles of *Herdmania* are similar to velar tentacle of *Amphioxus*.

iv. Atrium also develops in both.

v. Besides the fundamental three chordate characteristics, the ascidian tadpole larva of *Herdmania* and *Branchiostoma* (*Amphioxus*) also shows striking similarities:

vi. Presence of notochord, dorsal tubular nerve cord and pharyngeal gill-slits

vii. Pharynx with endostyle.

viii. Atrial complex similar.

ix. Identical early stages of development.

x. Presence of sensory organ, otocyst and single median eye (ocellus) in both.

xi. Tail with median dorsal and ventral fins.

Dissimilarities

Though a number of similarities exist between them, however, following dissimilarities are seen in both.

i. The notochord and nerve cord absent in adult Herdmania while present in *Amphioxus*.

ii. The coelom is absent in Herdmania.

iii. A body covering, i.e., test is present in Herdmania but absent in *Amphioxus*.

iv. Liver and heart are present in Herdmania.

v. They are bisexual and the metamorphosis of larva is retrogressive in Herdmania.

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Table. 1.3 Differences between Urochordata and Cephalochordata

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

Relationship with Other Deuterostomes

The affinities with hemichordata is described below:

Similarities

Hemichordates shows following similarities with *Balanoglossus*, a hemichordates.

i. In both the pharynx is perforated to branchial apertures or gill slits and having similar accessories.

ii. Development of nervous system almost similar in both.

iii. Occurrence of restricted notochord.

Dissimilarities

Both groups have following dissimilarities.

i. Ascidians are free swimming or fixed while *Balanoglossus* is tubicolous (lives in tube like burrows).

ii. Body of hemichordates divisible into proboscis, collar and trunk but in urochordates it is compact.

iii. Notochord is present only in the tail region of ascidian tadpole larva where as the nature of buccal diverticulum or stomochord of *Balanoglossus* is doubtful so that they are considered nowadays as an independent nonchordata phylum.

Affinities with Vertebrates

The urochordates are also related to the vertebrates.

i. The ascidian tadpole larva can be compared with a larval fish.

ii. Presence of dorsal tubular nerve cord, notochord and pharyngeal gill slits in tadpole.

iii. Muscular postanal tail of tadpole is covered by vertical caudal fin.

iv. Cleavage and gastrulation in ascidian development are similar to those of vertebrates.

v. Neural gland of adult is homologous with vertebrate pituitary.

vi. Endostyle is homologous with thyroid gland of vertebrate.

vii. Typhlosole in the ascidian intestine is comparable to the spiral valve of elasmobranch fish intestine.

From the above discussion, it is evident that urochordates are primitive and degenerate of ancestral chordates. Willey (1964) was the opinion that the tadpole larva of ascidian is a relic of part free-swimming chordate ancestor while the adults are regarded to be secondary sessile and degenerate to such an extent that they have become adapted to sessile life. The tadpole larva is regarded to represent the ancestor of chordate.

1.3.2 Subphylum-Cephalochordata

The subphylum Cephalochordata (Gr. *Kepale*, hard; *chorde*, cord) is a very small group of little fish-like animals with a single class Letocardii, a single family Branchiostomidae, and only two genera, *Branchiostoma* or *Amphioxus* (commonly known as lancelets) with 8 species and *Asymmetron* with 7 species. *Asymmetron* differs from *Amphioxus* in having unpaired gonads on the right side of the body and asymmetrical metapleural folds. Cephalochordates are small, eel-like, unprepossessing animals that spend much of their time buried in sand. However, because of their remarkable morphology, they have proved crucial in understanding the morphology and evolution of chordates in general including vertebrates.

General Characteristics of Cephalochordates

The general characteristics of cephalochordates are:

i. Body is fish -like and is adapted for burrowing and swimming.

ii. Paired appendages are absent. Median unpaired dorsal, ventral and caudal fins are present.

iii. Cephalochordates have all the typical chordate features.

iv. Body- wall is single layered thick, non-ciliated epidermis, dermis, connective tissue, striated muscle and parietal peritoneum.

v. It has no exoskeleton.

vi. Body is differentiated into trunk and tail only.

vii. Dorsal muscles are very thick and segmentally arranged.

viii. Notochord extends the entire length of body, i.e., from the anterior end to posterior end.

ix. True enterocoelic coelom is present, however, it is reduced in the pharyngeal region by atrium.

x. Alimentary canal is long. It includes a large pharynx with many gill-slits. Ciliary mode of feeding is developed.

xi. Respiration occurs by diffusion through general body surface and by gill-slits.

xii. Circulatory system is closed. Heart and respiratory pigments are absent. Corpuscles are few.

xiii. Hepatic portal system is present.

xiv. Excretory system shows paired protonephridia with solenocytes.

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xv. Nervous system is built on vertebrate plan comprising central, peripheral and autonomic nervous system.

xvi. Brain is not present.

xvii. Two pairs of cerebral and several pairs of spinal nerves are present.

xviii. Sexes are separate. Gonads are several and segmentally arranged and are without gonoducts.

xix. Fertilization is external. Development indirect with a larval stage.

xx. Asexual reproduction never occurs.

Phylogenetic Relationship or Affinities of Cephalochordata

The relationship of cephalochordata with urochordates is described below.

Similarities

Branchiostoma (Cephalochordata) shows following similarities with urochordates:

i. In presence of epipharyngeal groove, endostyle and pharyngeal bands.

ii. In the perforation of pharyngeal wall by numerous gill-slits which open into atrial cavity.

iii. In ciliary mode of feeding.

iv. An ectoderm-lined atrial cavity (atrium) open to outside through atriopore (atrial siphon).

v. Identical early stages (holoblastic cleavage, gastrulation by invagination) of development.

vi. Developments of notochord and nerve cord are similar in both.

vii. The ascidian tadpole larva having a continuous notochord, above it a dorsal hollow nerve cord, and a post-anal tail with median caudal fin without fin rays.

Dissimilarities

However, *Branchiostoma,* differs from urochordates in following characters:

i. Urochordates are sedentary but *Branchiostoma* is free swimming.

ii. Test is present in urochordates but absent is *Branchiostoma.*

iii. Alimentary canal is straight in *Branchiostoma* but 'U' shaped in urochordates.

iv. Nephridia present in *Branchiostoma* but absent in urochordates.

v. The heart, liver and Gonoducts are absent in *Branchiostoma* but present in urochordates.

vi. *Branchiostoma* is unisexual (testis and ovaries are separate) but ascidians are bisexual (hermaphrodite gonads) and asexual reproduction is also reported in them.

vii. Body of urochordates are unsegmented but cephalochordates are metamerically segmented.

viii. The ascidian larva undergoes to retrogressive metamorphosis and becomes the adult.

Relationship with Other Deuterostomes

The development of coelom from the archenteron (enterocoelic) and asymmetrical development of larva brings the *Branchiostoma* nearer the echinoderms.

Affinities with Echinodermata

Branchiostomata resembles echinoderms in the following characters:

i. Asymmetrical body.
ii. Enterocoelous coelom.
iii. Perforations in the calyx of fossil crinoids resembling the gill slits of *Branchiostomata.*
iv. The energy-rich compound phosphocreatine is present both in ophiuroids and *Branchiostomata.*

Affinities with Hemichordata

Branchiostomata resembles hemichordates in the following characters:

i. Presence of Gill-slits and gill bars.
ii. Filter fedding
iii. Enterocoelous coelom
iv. Presence of Numerous gonads and absence of gonoducts.

Branchiostomata differs from hemichordates in the the following characters:

i. Absence of segmented muscles
ii. Absence of chordate type of nervous system.

Affinities with Cyclostomata

The Ammocoete larva of lamprey (Cyclostomata) and *Branchiostoma* show a striking similarity in many characters, such as:

i. Elongated, slender fish-like body.
ii. Continuous dorsal median fin.
iii. Mouth surrounded by an oral hood and guarded by a velum
iv. Pharynx having endostyle and gill slits.
v. Besides these fundamental chordate characters, their adults show metameric myotomes, persistent gill slits, velum and a postanal tail.

Affinities with other Vertebrates

Besides cyclostomes, *Branchiostoma* also resembles other vertebrates in several ways, such as:

i. Body wall is differentiated into epidermis and dermis.
ii. Mouth is ventrally situated.
iii. Coelom is similar to that of chordates.
iv. Notochord is situated on the dorsal side beneath the nerve cord.
v. Presence of midgut diverticulum that can be compared with the liver.
vi. Pharyngeal gill slits are present.

vii. Dorsal tubular nerve cord is present.
viii. Metamerically arranged myotomes are present.
ix. Similar arrangement of main longitudinal vessels with forward flow of blood in ventral and backward flow in dorsal blood vessel.
x. Development is similar to that of chordates.
xi. Presence of hepatic portal system.

However, *Branchiostoma,* differs from vertebrates in following aspects:

i. Absence of head, brain and cranium/ skull and no vertebral column.
ii. Presence of single layered epidermis.
iii. Ciliary mode of feeding.
iv. Absence of heart, kidneys and paired appendages.
v. Presence of atrium around the pharynx.
vi. Presence of colorless blood without respiratory pigment.
vii. Absence of special sense organs like eyes, ears and other sense organs.
viii. Presence of numerous gonads.

On the basis of above discussion it can be concluded that *Branchiostoma* seems to be a simplified or degenerative chordate. The specialized characters are secondary adaptations based on the peculiar mode of life. *Branchiostoma* is definitely a chordate but it cannot be placed with urochordates or vertebrates.

Check Your Progress

1. What do you understand by chordates?
2. Define notochord.
3. Define urochordates.
4. What are cephalochordates?

1.4 TUNICATES

A tunicate is a marine invertebrate animal, a member of the subphylum Tunicata. It is part of the chordata, a phylum which includes all animals with dorsal nerve cords and notochords. The subphylum was at one time called urochordata, and the term urochordates is still sometimes used for these animals. The tunicate, also called urochordate, includes all member of the subphylum tunicata (Urochordata) of the phylum chordata. These are small marine animals, and found in great numbers throughout the seas of the world. The adult members are commonly embedded in a tough secreted tunic containing cellulose (a glucose polysaccharide not normally found in animals). The less modified forms are benthic (bottom-dwelling and sessile), while the more advanced forms are pelagic (floating and swimming in open water). A characteristic tadpole larva develops in the life cycle, and in one group (the appendicularians, or larvaceans) the adult closely resembles this larva, which has many features in common with other chordates. Most chordate features disappear at or after metamorphosis.

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1.4.1 Reproduction in Tunicates

Generally tunicates reproduce sexually but some reproduce asexually by budding. In some tunicate alternation of generations is also found.

Asexual Reproduction in Tunicates

Tunicates are interesting among chordates because they show an asexual method of reproduction called budding. They have long back known for their remarkable capacity for regeneration. Fundamentally budding and regeneration are alike so it seems that budding is an explanation of regenerating capacity.

In general structure, the Tunicates have much in common but the differences in the sub division are rather important. In budding, as it determines the exact nature of bud we have to deal basically with three different types.

i. Zooids are divided into an elongated thorax and abdomen.
ii. Holostometus forms no division in thorax e.g. *Perophora*.
iii. Colonial forms like *Botrviis*.

Formation of Bud

Buds are usually produced as epidermal strobilization dividing the zooids by transverse constriction of epidermis. Thus girdle of epidermis cuts through gut, epicardium etc. till a completely separated bud is formed, the number of buds however differs from 2-8 depending upon size. Generally, there is an elongation or region where the buds are formed. Budding here follows a process of extensive and active growth. The constriction appears successively from anterior to posterior side when a definite interval is over and after the appearance of previous constriction. This is simplest process of bud formation.

Budding in Family: Diazonidae

i. Merostomeous forms (body divided into head, thorax, abdomen etc).
ii. Thorax undergoes regression. The siphons are closed. As a result of this thorax questionally condenses.
iii. Due to autolysis thorax and oesophagus being dissolved.
iv. During this certain cells are loaded with nutritive materials. Trophocytes and thesocytes descend into abdominal portion.
v. Epidermal constriction appears like beads.
vi. Regeneration of the organ from the buds depends on the constriction of the latter epidermis.

Diazonia: The regeneration is greater and only post abdomen with heart and gonads remain new individuals or bud individuals.

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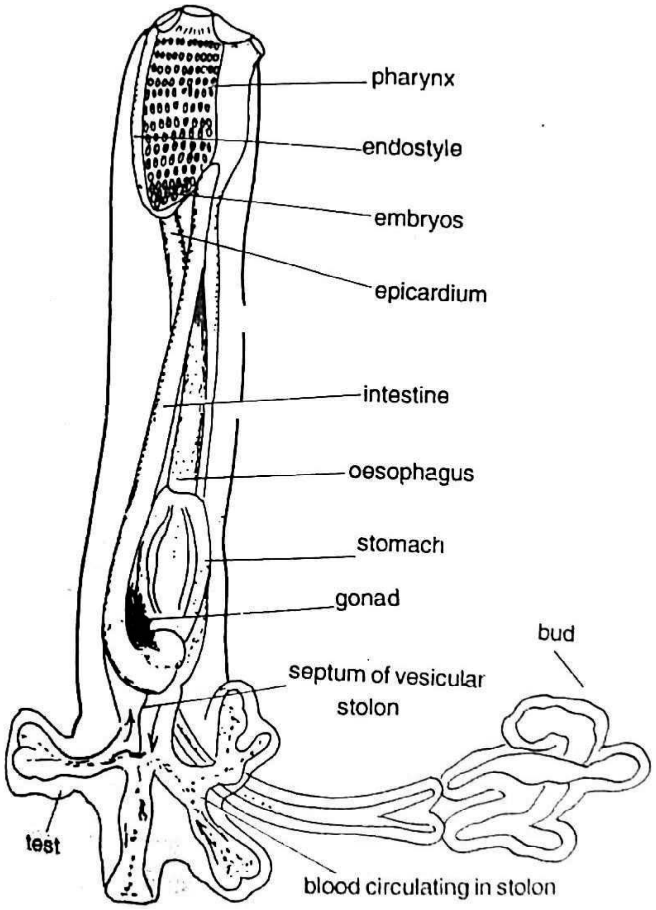

Fig. 1.7 *Budding in Clavelina*

In clavelina asexual reproduction occurs by budding from stolon, forming blasozooids. Before winter zooids disappear, their substances from food laden trophocytes, which bud off new zooids after winter. *Clavellina* is significant as it forms a connecting link between simple and compound ascidians.

Budding in Family: Syncicdae

Budding in the family, syncicdae involves:

i. Morehellium colonial zooids merosomates and post abdomen ends are smaller than *Diazonia*.

ii. Anterior part degraded, post part being filled with Archeocytes of post abdomen.

iii. Post abdomen consists of 3-4 buds.

iv. Forming tissue and epicardium and hence bud has very few adult structures. It is more recognized than regeneration.

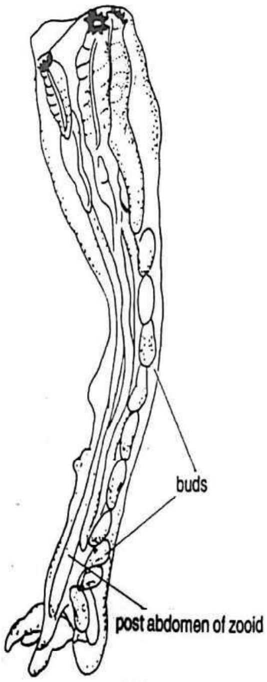

Fig. 1.8 *Bedding in Circinolium*

Budding in Family: Distomidae

Budding in the family distomidae involves:

(A). Archidistoma:

i. Merostomatus with one post abdomen. Thoracic region absorbed.
ii. Trophocytes accumulate in oesophagus and abdominal part.
iii. This region consists of 2-3 buds.
iv. Epicardium and formation of tissue.

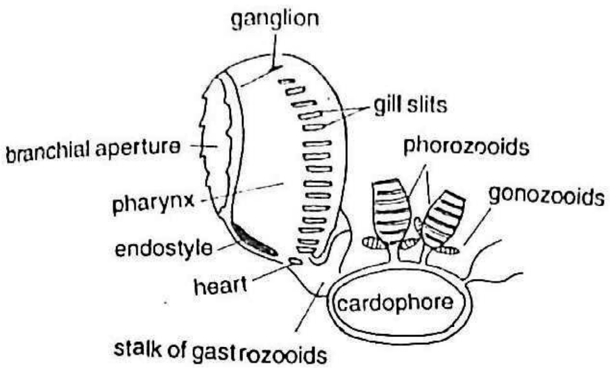

Fig. 1.9 *Part of Cadophore*

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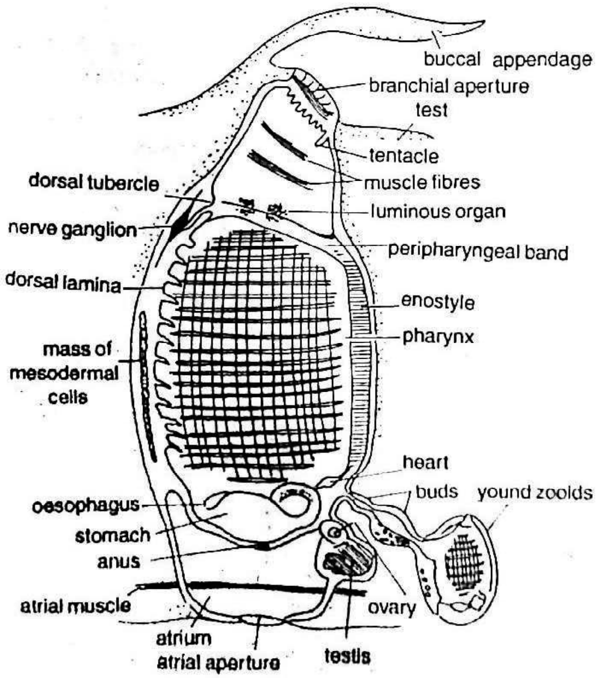

Fig. 1.10 Pyrosoma Zooids and a Part of Cadophore

(B). Endistoma:

i. No regeneration of thorax and no trophocytes.

ii. Whole zooids constitutes oesophagus and intestinal cells, epicardial groove formed but there is no strobilization.

iii. The individual elongates to form new zooids.

iv. In some epicardial grooves the zooids may be divided into two.

(C). Distapidea:

i. Has a common cloacal cavity.

ii. Oviduct double looped forming brood pouch.

iii. Pouch stomal vessel hypertrophied.

iv. Autolysis of parent individual reparts the brood pouch. During this two small masses develop in the region of oesophagus and pharynx from epicardium.

v. Complete autolysis – the buds lie near brood pouch.

vi. Embryo from brood sac escapes the immature bud.

vii. Tadpole also has two buds and functions as endostyle, and oesophagus, and epicardium are formation of tissues.

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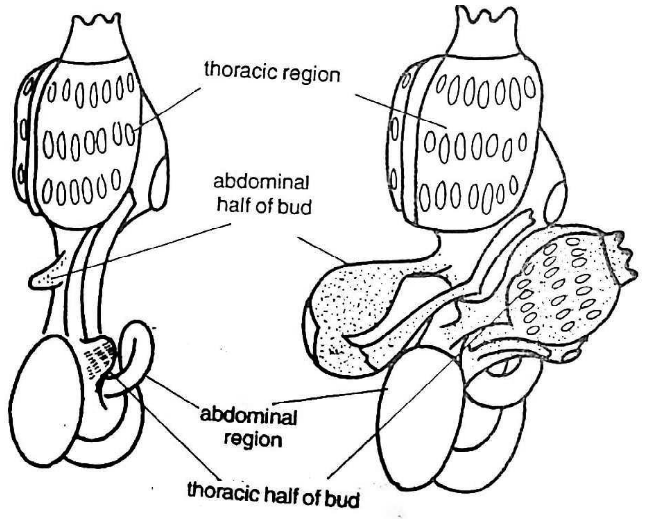

Fig. 1.11 *Tyrosoma zooids and a part of Cadophore*

(D). Collela:

i. Pedunculata and colonial species.
ii. Peduncle formed from stomach.
iii. Individuals degenerate and buds arise at the junction of colony and stolon.
iv. Stolonic vessels divided into two by a mesenchymatous septum. Cells proliferate from this and represent formative tissue.

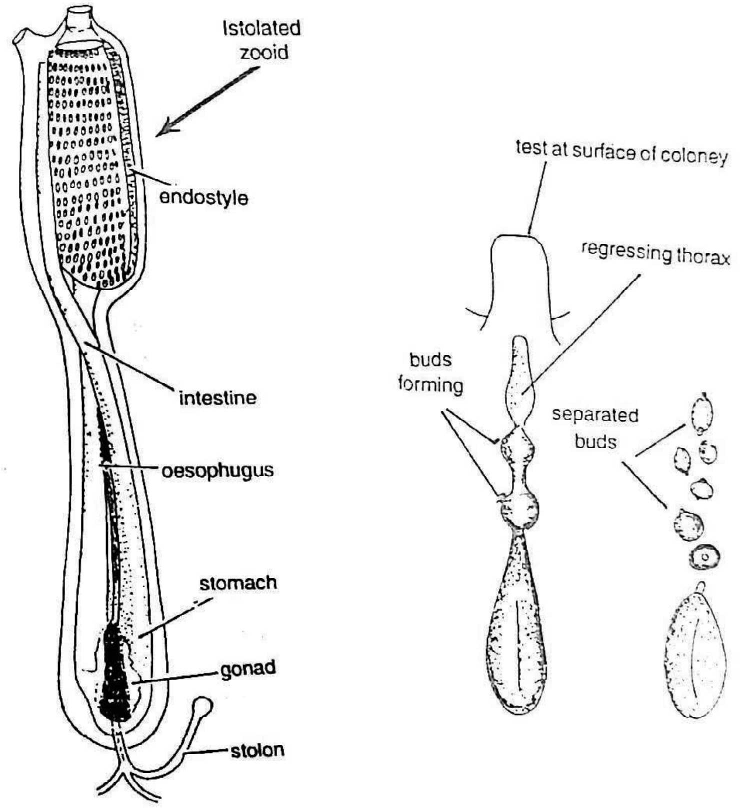

Fig. 1.12 *Budding in Diazona*

Budding in Family: Didaminadae

The budding in the family didaminadae involves:

i. Epidermal out growth appears in oesophageal region, one anterior and one posterior.

ii. Epidermal pouches now grow into it.

iii. These out growths are partial buds. The anterior one develop abdomen and posterior one thorax.

iv. Merostomatus with a very short abdomen and without a posterior abdomen.

Budding in Family: Calvellinae

The budding in the family calvellinae involves:

i. Merostomatus, no posterior abdomen, stolonic vessels large.

ii. Trophocytes accumulate in large number and pass into body cavity, blood vessel, posterior part of zooid and stolonic vessels.

iii. Budding start after the degeneration of several zooids.

iv. Lobed mass of cells detach each other. Lobe is a capsule of giving rise to a bud, but only one develops. Rest serve as nutrition,

v. Buds consists of epidermis, trophocytes and vascular mesenchymes.

vi. No epicardium.

Budding in Family: Perophonidae

The budding in the family perophonidae involves:

i. Holostomous with stolon

ii. Budding during active life.

iii. Ventral vessel grew to greater length and a sort of distance from the growing tip to the local epidermal thickening develops.

iv. Mesnchymatous tissue is also given into it from the septum.

v. No epicardium.

vi. Buds remain attached to the vessel epidermis only. Bud is always layered.

Budding in Family: Styclidae

The budding in the family styclidae involves:

i. Holostomous without ventral blood vessel.

ii. Distances with posterior side attached to some sub-stratum. The atrial siphons also in close contact with the substratum. Outer wall bulges out with its atrial cavity.

iii. The bud thus has epidermis, epithelium and mantle.

iv. In outer cases the differences lies in the place and time of formation of bud.

Budding in Family: Botrylloidae

One bud arise from the right side of the ova zooid and develops fully in three days. The older individuals degenerate and bud new ones. But before they are fully formed they also bud on their right sides.

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Budding in Thalacea

The budding in thalacea involves:

i. The budding stolon is an epidermal out growth from body wall of the base of the endostyle.
ii. The inner contents are the extensions of the endostyle and are peripharyngeal in origin.
iii. Budding starts with epidermis as in ascidians.
iv. The details of budding differ as far as the length of the stolons.
v. No budding in appendicularia.
vi. A more or less orderly process of reproduction without involving the death of colony.
vii. It results in the compact masses of tissue reminants in ectodermal envelops.
viii. The process is known from of colonial ascidians only.
ix. It generally takes place in adverse conditions.

Bud Maintenance

The maintenance of budding involves:

i. Buds once established require nutrition for the growth until able to feed,
ii. Heavily loaded buds with reserve food. Examples - *Diazonia, Archidistoma*.
iii. Buds live in external nutritive medium.
iv. Modification of maintaining organic continuity with parent. Example- *Salpa, Pyrosoma*.
v. Establishing a new connection, for example-*Botryllus*.

Constitution of Bud

The constitution of bud is:

i. All buds have an outer layer of epidermis which is one layered in thickness.
ii. The inner constituents, however, differ.
iii. The epidermis and epicardium and section of intestine and dorsal cord.
iv. Epidermis and epicardium and dorsal cord.
v. Epidermis and endostyle and meseanchyme.

For example: *Salpia, Doliolum*

Tissue Patches

Epidermis which shows tunicin secretion and is beyond embryonic ectodermal stage gives epidermis only. The thalacian epidermis is however, immature and is multipotent and gives neural ganaglion and glands unlike other buds epidermis and are incapable of producing these structures. Intestinal epidermis gives rise to intestine and dorsal cord tissue, neural gland and neural ganglion.

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Sexual Reproduction in Tunicates

Herdmania is hermaphrodite or bisexual and there are two large gonads embedded in the mantle and projects into the peri-branchial or atrial cavity. The left gonads lie in the loop of the intestine and the right one is situated just parallel and dorsal to the heart (pericardium). Each gonad is about 3-4 cm long and consists of a series of paired lobes, which are 10-24 in number and are situated in two rows. The posterior unpaired lobe is the largest. Lobes are arranged on either side of the genital duct.

The gonads are known as ovatestes or hermaphrodite gland because each lobe of gonad has brick red testicular tissue (produces sperms) on the outer side and pinkish ovarian tissue (produces ova) towards inner side. The ovarian parts of the gonad are connected by narrow ductules, which form a common oviduct. Similarly the testicular parts are connected by thinner sperm-ductules, which join to form the sperm-duct or vas deferens that runs parallel to the oviduct. The oviduct open into atrium or atrial cavity a little behind the anus, by an oviducal aperture and spermatic ductules also open into atrium by a spermiducal aperture a little behind the oviducal aperture. Both genital ducts and gonoducts are internally lined with ciliated epithelium. Cilia of sperm-duct are larger than those of the oviduct.

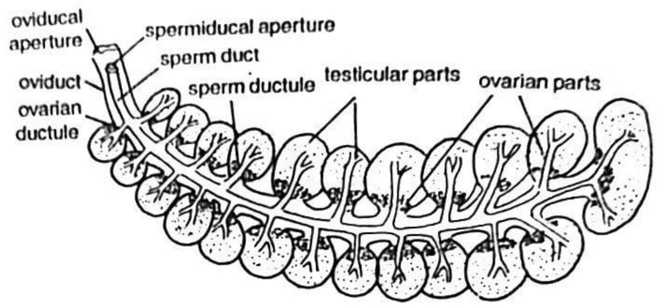

Fig. 1.13 *Herdmania; Left Gonad Seen from Inner Side.*

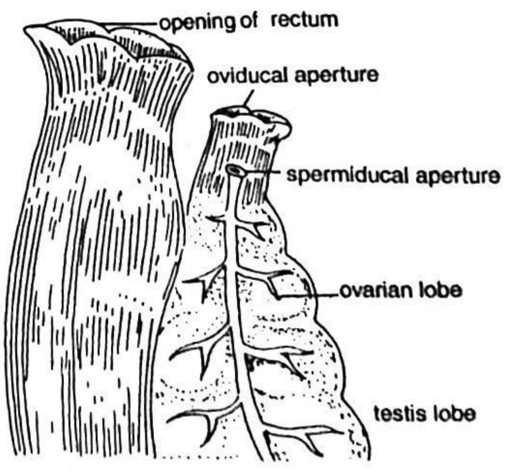

Fig. 1.14 *Herdmania; Showing Opening of Rectum, Oviduct, and Spermatic Duct.*

The testicular part produces spermatozoa. A mature sperm spermatozoan or sperm is microscopic, about 4 μ (micron) in length and differentiated into head, neck or middle piece and a long straight tail. Head bears beak like acrosome. The ovarian part produces ova or eggs. A mature ovum is about 0.3mm in diameter. It is microlecithal and isolecithal, *i.e.,* considerable amount of yolk equally is distributed in the cytoplasm.

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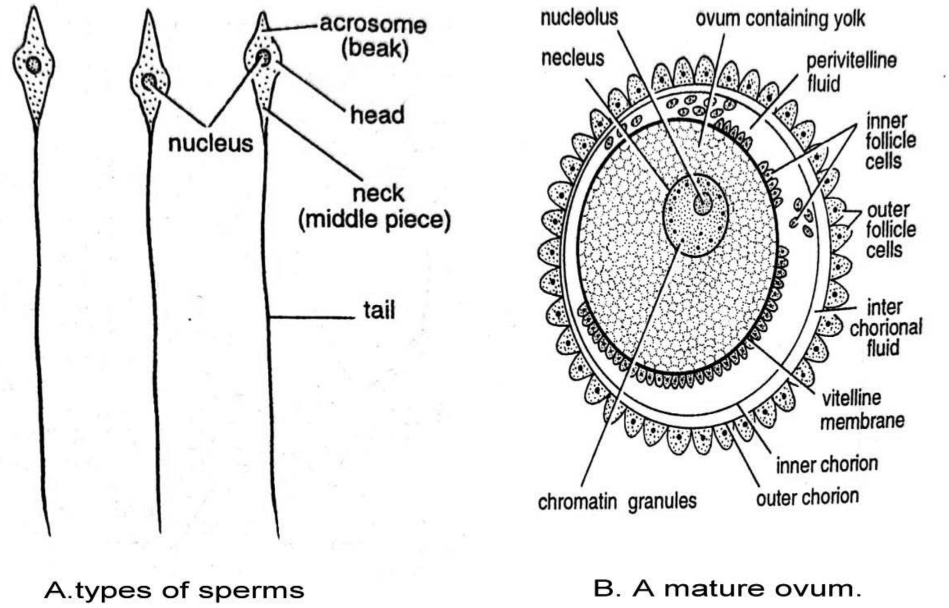

Fig. 1.15 *Herdmania Gametes*

The nucleus is large and eccentric. It is surrounded by thin vitelline membrane and tough chorion (inner and outer chorion). Between the two membranes is the perivitelline fluid containing a few scattered follicular cells of the ovary that secrete the chorion. Some follicular cells are arranged to form an *inner follicular layer* round the vitelline membrane. Follicular cells of ovary finally secrete the outer chorion. The inner chorionic fluid separates the outer and inner chorionic membrane.

Fertilization

Fertilization is external and takes place in sea water. Although Herdmania is hermaphrodite but cross fertilization as a rule due to protogynus (Ovarian region mature before testicular region) condition.

1.4.2 Development in Tunicates Cleavage

Cleavage in ascidian is holoblastic, approximately equal and of determinate type. About half a hour after fertilization, the first meridional (vertical) cleavage divides the zygote into two blastomeres. The second division is also meridional and occurs at the right angle of first cleavage. The third cleavage is horizontal as a result 8 cells are formed arranged in two tires. By further divisions a flattened blastula is formed having a small segmentation cavity called blastocoels. Blastula contains 64-128 blastomers.

Gastrulation

Gastrulation starts after sixth cleavage by emboly (formation of gastrula from a blastula by invagination of the germ layers) and is completed by the time of seventh cleavage. The presumptive endodermal cells gradually sink into the blastocoels. The blastocoel becomes progressively reduced and finally disappears and the

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endoderm comes to lie in contact with the presumptive ectoderm. Thus, a single-layered blastula is converted into a two-layered, cup-shaped gastrula. Its cavity is known as archenteron and its opening is called blastopore. It forms the posterior end of embryo and gradually closes by the growth of its margin. The gastrulation is completed within 110 minutes.

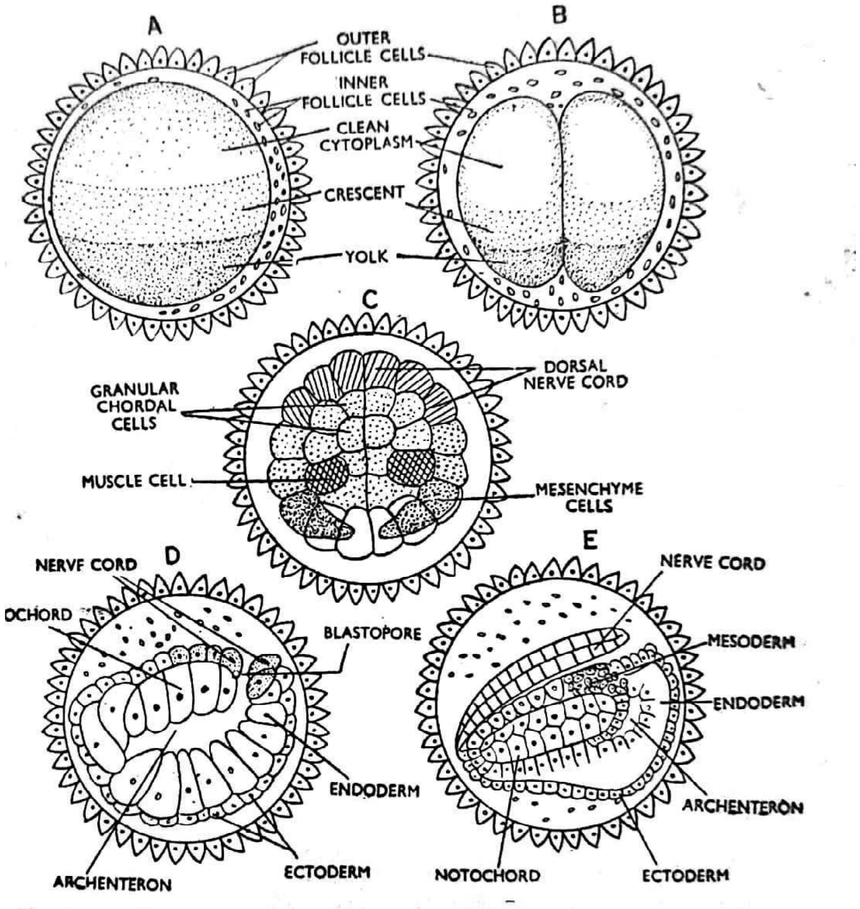

Fig. 1.16 Embryonic Development of Ascidian (Herdmania)

The fully formed gastrula has an elongated two layered body with a large archenteron. Its outer layer is formed of presumptive ectoderm cells all over, except a band of presumptive neural plate on the dorsal side. The inner layer is formed of presumptive endoderm together with cells of presumptive notochord mid-dorsally and presumptive mesodermal strips dorso-laterally.

Post-gastrular Development or Organogenesis

The post-gastrular development involves following:

Neurogenesis or Neurulation (Neural Tube Formation)

The upper surface of the neural plate gets flattened and finally invaginates along the median line. It marks the beginning of neural groove. Its margin grows and completes the formation of neural tube. The neural tube extends into the tail. Its anterior part enlarges to form a cerebral vesicle. In the cerebral vesicle ocelli and statolith are formed. At the anterior end, the neural canal remains open to the exterior for some times by an opening called, the neuropore. The embryo at this stage is known as neurula.

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Notogenesis

Notochord is formed from the presumptive notochords lying in the roof of the archenteron. They arrange to form an elongated cord of cells which becomes completely constricted off from the archenteron and round up to form an elongated rod-shaped notochord. It lies immediately underneath the neural canal.

Mesogenesis or Mesoderm formation

The presumptive mesoderm strips separate from the archenteron and give rise to a pair of longitudinal strands of cells forming the mesodermal rudiments. Now the archenteron is entirely formed by endoderm.

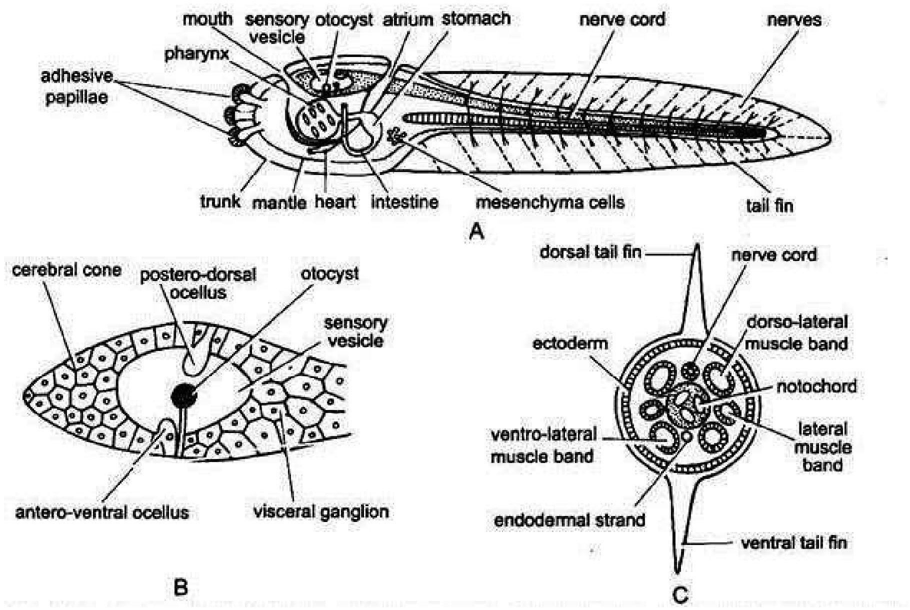

Fig. 1.17 *Herdmania; A. Tadpole larva, B. Sensory Vesicle, C. Tail of Tadpole in T.S.*

Formation of Larva

The embryo becomes pear shaped and its posterior end forms the tail rudiment. At the anterior region, the trunk now becomes oval. At its anterior end appear three processes of the ectoderm called the rudiments of the adhesive papillae. The tadpole larva of ascidians soon after hatching measures about 12 mm in length. The body is distinguishable into trunk and a tail region. The details regarding tadpole larva is as follows:

i. The body of larva is covered by a thin layer of large rectangular ectodermal cells.
ii. The entire body of the tadpole can be divided into two parts: the trunk and tail.
iii. The anterior end of the trunk is provided with three adhesive papillae which are made up of ectodermal cells. These are secretory in nature and help in attachment during metamorphosis.
iv. The dorsal part of trunk region is occupied by a sensory vesicle and a visceral ganglion, while the remaining portion of the trunk is filled up by large ectodermal cells which soon form the pharynx, oesophagus, stomach and intestine.

v. The sensory vesicle is a hollow and oval body with a single cell layered wall. The anterior end is prolonged into a conical mass of nerve cells, called cerebral cone. It bears:
   - **Ocilli**: There are two ocilli of which the larger one is situated postero-dorsally while the smaller one is antero-ventral in position;
   - **Otolith or Otocyst**: It is unicellular with a dark pigmented body at its distal end. It remains attached obliquely from the ventral wall of the vesicle.

vi. Visceral ganglion is a solid mass of nervous tissue lying just behind the sensory vesicle.

vii. The flattened tail region is very long and forms a tail fin. It bears:
   - **Nerve cord**: It is a tube like structure which is the posterior prolongation of the visceral ganglion. It occupies the whole length of tail and being situated dorsally to the notochord;
   - **Notochord**: It is a solid cylindrical rod which is confined only in tail region. The anterior end of the notochord extends a short distance anteriorly so as to touch the ectodermal cells of the trunk. It is made of a row of turgid cells;
   - **Ectodermal strands**: A stands of ectodermal cells are present, just on the ventral side of the notochord;
   - **Tail muscles**: Along with the notochord and nerve tube the tail is also provided with tail muscles which are arranged in six bands, three on each side of notochord. Of these three bands of each side, one is dorsolateral, other ventrolateral and the third is lateral to notochord.

1.4.3 Metamorphosis in Tunicates or Retrogressive Metamorphosis

After about three hours of hatching and non-feeding, the free swimming larva becomes geopositive and photonegative, i.e., it drops down to the bottom and get attached to the substratum. Now the larva undergoes into rapid visible changes which are as follows:

i. The along with notochord, nerve-cord, muscles and tail fin begins to reduce and finally disappears. Therefore, larva becomes pear shaped.

ii. The adhesive papillae are lost. Four ectodermal ampullae are formed. These ampullae help in attachment.

iii. The cerebral vesicle along with otolith and ocelli are lost and visceral ganglion reduced to a small nerve ganglion placed below the neural gland. Neural gland arises as a proliferation from the wall of hypophysial duct.

iv. Pharynx enlarges and number of stigmata increases accordingly. It is now known as branchial sac.

v. Stomach, intestine, and liver develop.

vi. Heart, pericardium, and gonads appear.

vii. Body becomes surrounded by test (A hard shell found in some marine animals) or tunic all over.

viii. Brachial and atrial aperture become functional.

ix. Endostyle, dorsal tubercle and peripharyngeal band appears or formed.

x. The body between the point of fixation and mouth (branchial aperture) increases rapidly and causes its rotation through 180^0 so that the branchial siphon is carried to the opposite end.

xi. The part of body around branchial and artial apertures gets elongated to form the siphon.

Thus, the free swimming, active larva of tunicates bearing well developed notochord and nerve tube undergoes a rapid changes during metamorphosis in which along with the formation of adult organs. The notochord and nerve tube completely disappears and ultimately the active larva changes into fixed inactive adult which is lost almost all the chordates characters. The larva is photosensitive and geo-negative but adult is photonegative and geopositive. Therefore, this type of metamorphosis in which the changes are towards the loss of the important chordates character is known as retrogressive metamorphosis.

Significance of ascidians tadpole larva

The tadpole larva of ascidians has following chordate characters-

i. Presence of Notochord.

ii. Presence of hollow tubular nerve cord.

iii. Presence of pharyngeal gill-slits.

iv. Presence of tail with tail fin.

On the basis of above characters, Kowalevsky (1869), recognize the chordate nature of ascidians and removed them from the invertebrates. Thus, the ascidian larva helps in tracing the relation of ascidian to chordate and establishes its systematic position.

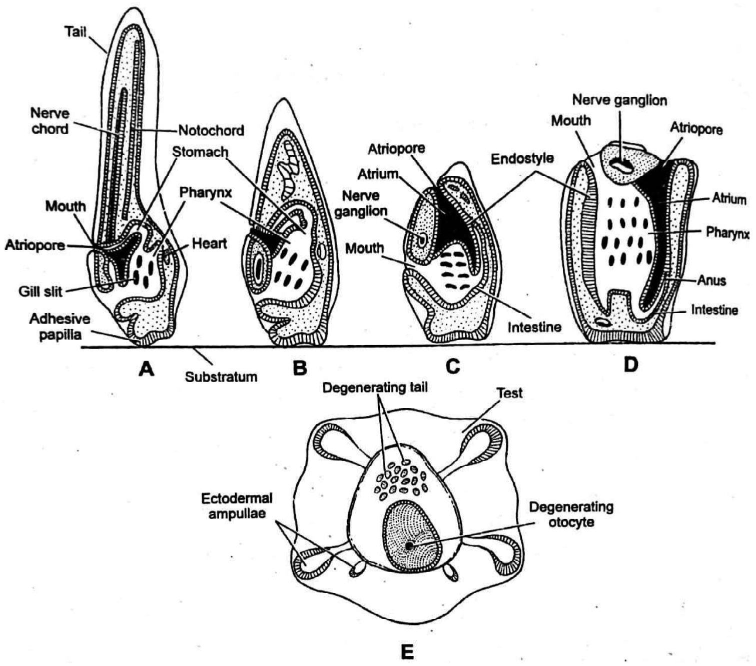

Fig. 1.18 Different Stages of Retrogressive Metamorphosis in Ascidian Tadpole Larva

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Check Your Progress

5. Define Tunicates.
6. What is the size of gonad in Herdmania?
7. When does gastrulation begin in Tunicates?

1.5 GENERAL ORGANIZATION OF CEPHALOCHORDATA (*AMPHIOXUS*)

The subphylum cephalochordata (Gr. *Kepale*, hard; *chorde*, cord) is a very small group of little fish-like animals with a single class Letocardii, a single family Branchiostomidae, and only two genera, *Branchiostoma* or *Amphioxus* (commonly known as lancelets) with eight species and *Asymmetron* with seven species. *Asymmetron* differs from *Amphioxus* in having unpaired gonads on the right side of the body and asymmetrical metapleural folds. Cephalochordates are small, eel-like, unprepossessing animals that show chordate characters and spend much of their time buried in sand. The notochord extends the entire length of the body. They show a dorsal, tubular neural tube without a definite brain. However, because of their remarkable morphology, they have proved crucial in understanding the morphology and evolution of chordates in general including vertebrates.

1.5.1 Characteristics of Cephalochordates (*Amphioxus*)

The characteristics of cephalochordates include:

General Characters

Body is fish -like and is adapted for burrowing and swimming.

i. Paired appendages are absent. Median unpaired dorsal, ventral and caudal fins are present.
ii. Cephalochordates have all the typical chordate features.
iii. Body- wall is single layered thick, non-ciliated epidermis, dermis, connective tissue, striated muscle and parietal peritoneum.
iv. It has no exoskeleton.
v. Body is differentiated into trunk and tail only.
vi. Dorsal muscles are very thick and segmentally arranged.
vii. Notochord extends the entire length of body i.e. from the anterior end to posterior end.
viii. True enterocoelic coelom is present, however, it is reduced in the pharyngeal region by atrium.
ix. Alimentary canal is long. It includes a large pharynx with many gill-slits. Ciliary mode of feeding is developed.
x. Respiration occurs by diffusion through general body surface and by gill-slits.

xi. Circulatory system is closed. Heart and respiratory pigments are absent. Corpuscles are few.

xii. Hepatic portal system is present.

xiii. Excretory system shows paired protonephridia with solenocytes.

xiv. Nervous system is built on vertebrate plan comprising central, peripheral and autonomic nervous system.

xv. Nerve cord dorsal, tubular without ganglia and brain. Dorsal and ventral nerve roots separate.

xvi. Brain is not present.

xvii. Two pairs of cerebral and several pairs of spinal nerves are present.

xviii. Sexes are separate. Gonads are several and segmentally arranged and are without gonoducts.

xix. Fertilization is external. Development indirect with a larval stage.

xx. Asexual reproduction never occurs.

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Primitive Characteristics

Primitive characters are those which appeared long ago and have disappeared in the higher members, but still persist in the lower members. The following are the primitive characters retained by *Amphioxus*:

i. Ciliary feeding

ii. Absence of head

iii. Absence of paired appendages

iv. Asymmetry

v. One cell thick epidermis

vi. Complete metameric segmentation

vii. Enterocoelous coelom

viii. Endostyle

ix. Straight gut

x. Simple circulatory and nervous systems

xi. Protonephridia.

xii. Lack of paired sense organs

xiii. Persistent notochord

xiv. Segmental gonads

xv. Single gut diverticulum

Specialized Characteristics

Amphioxus developed some specialized characters which are peculiar to itself. They are as follows:

i. Large pharynx

ii. Numerous gill slits

iii. Atrium
iv. Notochord extending far into the head
v. Oral hood

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vi. Asymmetry

Degenerate Characteristics

Amphioxus exhibits the following degenerate characters:

i. Sedentary life
ii. Brain and sense organs are reduced
iii. Notochord extending for to the cerebral vesicle

1.5.2 Affinities or Phylogenetic Relationship of *Amphioxus*

Branchiostoma or *Amphioxus* was first discovered by Pallas in 1778 and he regarded it as a mollusc with a name Limax. Costa (1834) named it *Branchiostoma*. Garstang (1928), Berrill (1955), Ramer (1959) and Barrimgton (1965) proposed that *Branchiostoma* originated from sessile urochordates. The sessile urochordate produced free swimming tadpole larvae. Some of these larvae gave rise to *Branchiostoma* as well as vertebrates by neoteny. *Amphioxus* is an interesting animal. It is an assemblage of invertebrate, chordate, and unique characters.

Affinities with Annelids

Amphioxus resembles annelids in the following characteristics:

i. Bilaterally symmetrical body
ii. Metamerical segmentation
iii. Protonephridia
iv. Coelom
v. Closed circulatory system
vi. Filter feeding

But annelids differ from cephalochordates in the absence of chordate characters and the presence of schizocoelic coelom.

Affinities with Mollusca

Amphioxus resembles an oyster because it exhibits ciliary mode of feeding and respiratory current similar to those of molluscs. This made Pallas (1778) to consider it as slug and named it as *Limax lanceolatus*.

Affinities with Echinodermata

Amphioxus resembles echinoderms in the following characteristics:

i. Asymmetrical body
ii. Enterocoelous coelom
iii. Perforation in the calyx of fossil crinoids resembling the gill slits of *Amphioxus*

iv. The energy rich compound phosphocreatine is present both in ophiuroids and *Amphioxus*

It is believed that all these similarities are due to a remote common ancestry.

Affinities with Hemichordata

Amphioxus resembles hemichordates in the following characteristics:

i. Gill slits and gill bars
ii. Filter feeding
iii. Enterocoelous coelom
iv. Numerous gonads and gonoducts

But *amphioxus* differ from hemichordates in the absence of segmented muscles and in the absence of chordate type of nervous system.

Affinities with Urochordata

Branchiostoma (cephalochordata) shows following similarities with urochordates:

i. In presence of epipharyngeal groove, endostyle and pharyngeal bands
ii. In the perforation of pharyngeal wall by numerous gill-slits which open into atrial cavity
iii. In ciliary mode of feeding
iv. An ectoderm-lined atrial cavity (atrium) open to outside through atriopore (atrial siphon)
v. Identical early stages (holoblastic cleavage, gastrulation by invagination) of development
vi. Developments of notochord and nerve cord are similar in both
vii. The ascidian tadpole larva having a continuous notochord, above it a dorsal hollow nerve cord, and a post-anal tail with median caudal fin without fin rays

However, *Branchiostoma,* differs from urochordates in following characters:

i. Urochordates are sedentary but *Branchiostoma* is free swimming.
ii. Test is present in urochordates but absent is *Branchiostoma.*
iii. Alimentary canal is straight in *Branchiostoma* but 'U' shaped in urochordates.
iv. Nephridia present in *Branchiostoma* but absent in urochordates.
v. The heart, liver and gonoducts are absent in *Branchiostoma* but present in urochordates.
vi. *Branchiostoma* is unisexual (testis and ovaries are separate) but ascidians are bisexual (hermaphrodite gonads) and asexual reproduction is also reported in them.
vii. Body of urochordates are unsegmented but cephalochordates are metamerically segmented.
viii. The ascidian larva undergoes to retrogressive metamorphosis and becomes the adult.

Affinities with Cyclostomata

The ammocoete larva of lamprey (Cyclostomata) and *Branchiostoma* show a striking similarity in many characters, such as:

i. Elongated, slender fish-like body
ii. Continuous dorsal median fin
iii. Mouth surrounded by an oral hood and guarded by a velum
iv. Pharynx having endostyle and gill slits
v. Besides these fundamental chordate characteristics, their adults show metameric myotomes, persistent gill slits, velum and a postanal tail

Affinities with other Vertebrates

Besides cyclostomes, *Branchiostoma* also resembles other vertebrates in several ways, such as:

i. Body wall is differentiated into epidermis and dermis
ii. Mouth is ventrally situated
iii. Coelom is similar to that of chordates
iv. Notochord is situated on the dorsal side beneath the nerve cord
v. Presence of midgut diverticulum that can be compared with the liver
vi. Pharyngeal gill slits are present
vii. Dorsal tubular nerve cord is present
viii. Metamerically arranged myotomes are present
ix. Similar arrangement of main longitudinal vessels with forward flow of blood in ventral and backward flow in dorsal blood vessel
x. Development is similar to that of chordates
xi. Presence of hepatic portal system

However, *Branchiostoma,* differs from vertebrates in following respects:

i. Absence of head, brain and cranium/skull and no vertebral column
ii. Presence of single layered epidermis
iii. Ciliary mode of feeding
iv. Absence of heart, kidneys and paired appendages
v. Presence of atrium around the pharynx
vi. Presence of colourless blood without respiratory pigment
vii. Absence of special sense organs like eyes, ears and other sense organs
viii. Presence of numerous gonads

1.5.3 Systematic Position of *Amphioxus*

Cephalochordates (*Branchiostoma*/*Amphioxus*) possess all the important chordate characters so that it is definitely a chordate. However, their true systemic position in the phylum remains controversial. They are definitely more covered than the hemichordates.

Wiley (1894) stated that *Amphioxus* is a prototype chordate which can be placed along the main line of chordate evolution.

Garstang (1928) and Berrilli (1958) stated that *Amphioxus* evolved from a neotenic ascidian tadpole larva which failed to metamorphosis. But this view is no longer upheld. The specialized characteristics of *Amphioxus* indicate that it is not on the direct line of evolution of chordates.

Costa (1834), Yarrel (1836) and Gregory (1936) consider *Amphioxus* to be a modified and degenerate form of some jawless vertebrates (Cyclostomes or Agnatha). Some others believe that *Amphioxus* is a permanent paedogenetic larval form of some species of cyclostomes. But the absence of craniate or vertebrate characters (head, cranium, skull, vertebral column, specialized sense organs etc.,) and presence of protonephridia, shows that it is very primitive chordates.

On the basis of above discussion it can be concluded that *Amphioxus* seems to be a simplified or degenerative chordate. The specialized characteristics are secondary adaptations based on the peculiar mode of life. An animal showing degeneration in one hand and specialization on the other, cannot possibly react to any evolutionary change. Hence it is considered that *Amphioxus* is not on the direct line of evolution of vertebrates. It is a blind off shoot in the evolution of chordates. Thus it can be concluded that *Amphioxus* is definitely a chordate but it cannot be placed with urochordates or vertebrates.

1.6 FEEDING ORGAN AND MECHANISM OF FEEDING (DIGESTIVE SYSTEM) IN UROCHORDATA (*HERDMANIA*)

The feeding organ system or digestive system of tunicate includes the alimentary canal and digestive glands.

1.6.1 Alimentary Canal

Alimentary canal is complete and coiled. It is divisible into four zones: (i) Ingressive zone comprising mouth and buccal cavity; (ii) Progressive zone includes pharynx, oesophagus and stomach; (iii) Degressive zone includes intestine; (iv) Egressive zone comprises the rectum.

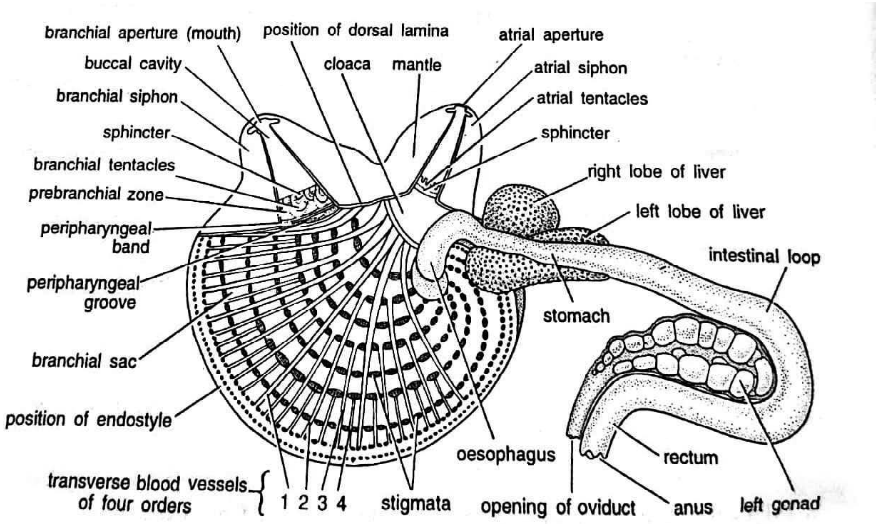

Fig. 1.19 Herdmania (Tunicate): Alimentary Canal

Mouth

The mouth or branchial aperture lies on the top of branchial siphon. It is guarded by four sensitive flaps form lips. These lips are contractile in nature. It leads into buccal cavity.

Buccal Cavity

It is lined by the ectoderm. At the base of the siphon is a ring of delicate, branched tentacle. Tentacles are about 64 in number and are of four kinds-8 longer, 8 medium, 16 smaller and 32 smallest. They act as sieve and straining the water current passing into branchial sac and filter the fine particles of food and prevent the entry of large food particle into pharynx. They are richly supplied with blood capillaries and nerve fibres. They also test the quality of water hence work as chemoreceptor organs.

Pharynx

The pharynx is large sac-like structure and occupies the major part of atrial cavity. It is endodermal in origin and divided into two unequal zones: Pre-branchial zone and branchial sac.

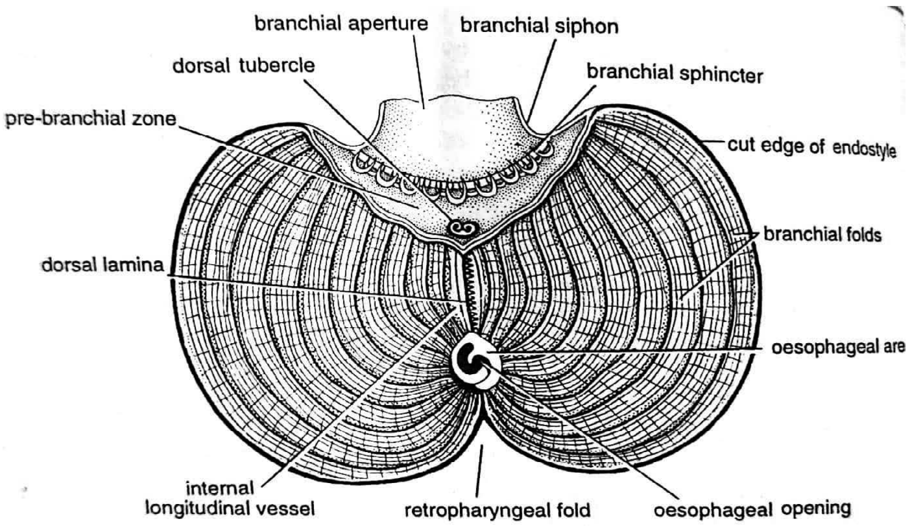

Fig. 1.20 *Herdmania; Pharynx Cut Longitudinally along Mid-Ventral Line (endostyle) and Open to Show Internal Structure*

a. **Prebranchial Zone**: It is a small smooth portion with a swollen horse-shoe shaped structure called dorsal tubercle.

b. **Branchial Sac**: It is posterior largest sac like portion of pharynx and fills much of space of atrial cavity. Its lateral walls are perforated with numerous elongated gill slits or stigmata. Gill slits are formed by the subdivision of larval gill slits.

These two zones of pharynx are separated by two peripharyngeal bands. Between the bands there is a narrow ciliated groove called peripharyngeal groove. The anterior band is complete and ring like while posterior band is incomplete at mid dorsal and mid ventral ends and continuous with a dorsal flap like structure called hyper-pharyngeal groove or dorsal lamina on the dorsal side and with a

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ventral glandular groove called endostylar groove or endostyle on ventral side of branchial sac.

Each wall of branchial sac contains about 200000 stigmata or gill slits. The stigmata established a communication between pharynx and the atrial cavity. The stigmata are arranged in several transverse rows. The epithelial lining of the stigmata bears long cilia called lateral cilia. They almost cover the stigmata, so that food particles do not escape through them.

Between the stigmata are external transverse and internal longitudinal vessels through which blood flows. These vessels divide the pharyngeal wall into squarish or rectangular stigmatic areas. Each area has 5-6 stigmata. Besides the transverse and longitudinal vessels there are fine inter-stigmatic transverse and longitudinal vessels.

The inner surface of each lateral wall of branchial sac is produced into crescentric longitudinal folds, on their inner surface; each wall is provided with 10 folds on its inner surface (according to S. M. Das). These folds starting from behind the posterior peripharyngeal band and extending dorsally up to the area which surround the opening of the oesophagus. The entire inner surface of branchial sac bears cilia. These cilia are shorter than frontal cilia.

On the ventral side of branchial sac, there is a mid-ventral longitudinal groove called endostyle or hypobranchial groove which has a row of median long cilia. Anteriorly the endostyle is connected with posterior peripharyngeal groove and posteriorly in front of oesophageal opening. The endostyle is lined with five longitudinal tracts of ciliated cells alternating with four longitudinal strips of non-ciliated glandular cells that secretes mucous. The cilia of the median tract are much longer than other cilia.

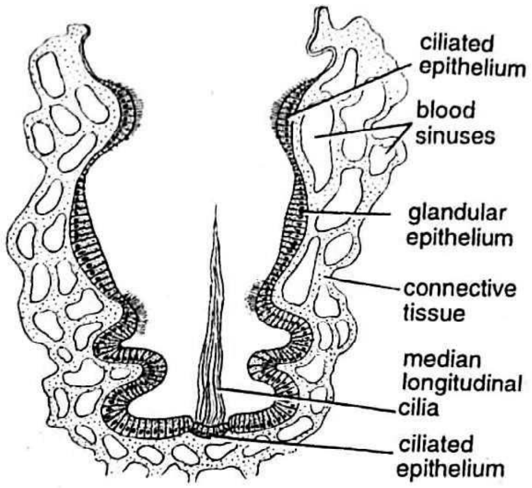

Fig. 1.21 *Herdmania: T. S. of Endostyle*

On the dorsal side of branchial sac, a thin flap like structure called hyper-pharyngeal band or dorsal lamina which runs from the posterior peripharyngeal band to right lip of oesophageal opening. It is situated in the mid-dorsal region of the branchial sac and bears 20-30 tentacles like structure called dorsal languets,

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at its free edge. These languets hang down into the cavity of branchial sac and remain curved to the right side so as to form a sort of open tube or groove or gutter for conducting mucous cord (food particles with mucous) towards the oesophagus. The languets are covered by ciliated epithelium.

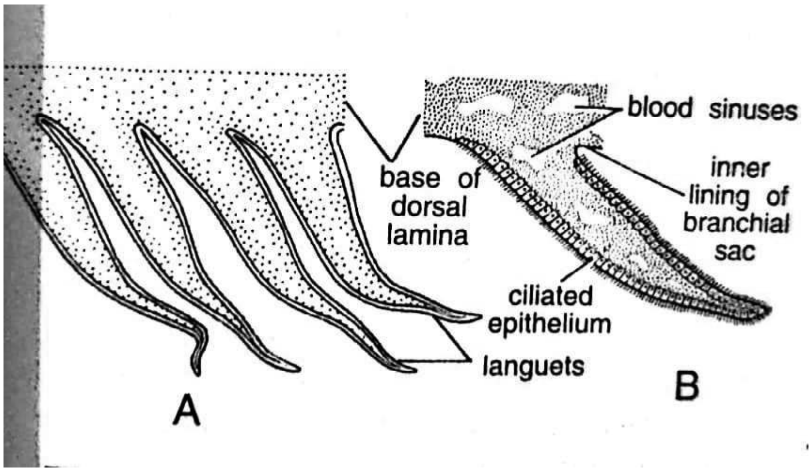

Fig. 1.22 *Herdmania: (A) Part of Dorsal Lamina; (B) One Languet in Section*

The posterior most region of branchial sac has a small circular oesophageal area made of two semicircular lips guarding the oesophageal opening. This area is devoid of blood vessels, folds and stigmata.

Oesophagus

The branchial sac posteriorly opens into the oesophagus. It is a short, thick and curved tube without stigmata. Its lumen provided into four ciliated grooves which direct the food particles into stomach.

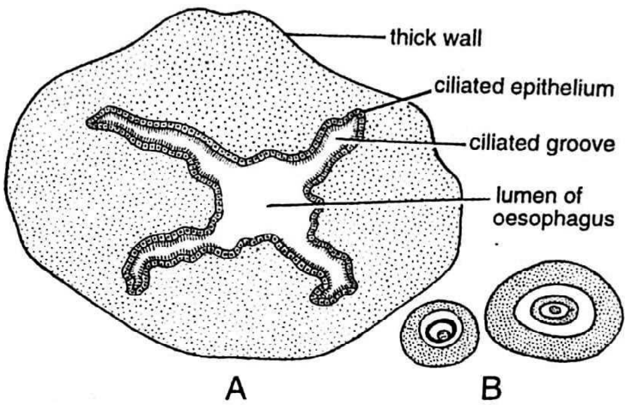

Fig. 1.23 *Herdmania: (A) T. S. of Oesophagus; (B) Starch Granules in the Wall of Oesophagus, Stomach, and Liver*

Stomach

It is a wide thin walled tube and surround by left larger and right smaller lobe of liver. Stomach receives eleven hepatic ducts appearing from both liver lobes and open separately by eleven pores in it. Inner layer of stomach wall is of gastric

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epithelium, the cells of which contain muscles at the base and 4 to 6 bladder like spaces filled with gastric secretion. There are also present a large number of starch granules in the wall of stomach which probably represent the stored food materials.

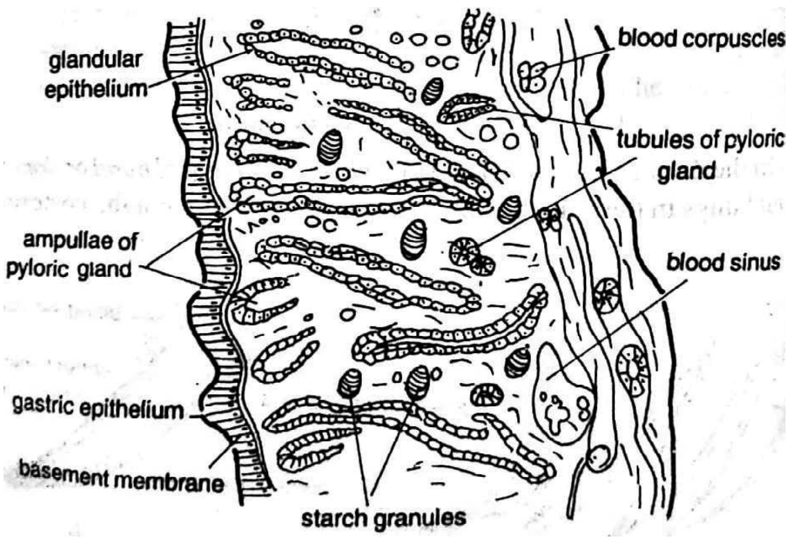

Fig. 1.24 *Herdmania: T.S. of Stomach*

Intestine

The stomach opens into intestine. It is a thin walled tube and forms a 'U' shaped loop consisting of a proximal limb and a distal limb. The proximal limb runs along the ventral margin of the branchial sac and then takes a sharp curve dorsally to become the distal limb which leads into the rectum. The loop of the intestine encloses the left gonad.

Rectum

It is a short, curved tube lined internally by flattened ciliated epithelium. It bends upward and opens near the base of atrial siphon through a four sided anus. The anal opening remains guarded by four moderately thick lips.

1.6.2 Digestive Glands

The liver and pyloric glands are the digestive glands which are associated with alimentary canal.

Liver

The liver is dark brown bilobed digestive gland made of a larger left lobe and a smaller right lobes attached on either side of the stomach. Each lobe is composed of numerous tubules or caeca which are embedded in connective tissue containing blood sinuses and starch granules. Liver secretion contains a strong amylase, a protease and a mid lipase.

Pyloric Glands

The walls of stomach and intestine contain branched pyloric glands and their tubules open into fine ducts but ultimately all of them unite to form a common single duct which opens by a small aperture into the proximal limb of intestine. The function of pyloric gland is not well understood but it is believed that it is probably pancreatic in nature and also performs excretory function.

1.6.3 Food, Feeding and Digestion

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The food, feeding and digestion are discussed below.

Food

The food of *Herdmania* is microscopic planktons such as protozoans, algae, diatoms, infusorians and fragments of decaying animals, etc.

Feeding Mechanism

Due to sedentary habit, it adopts filter-feeding methods. Continuous water current is produced by the rapid beating of cilia of stigmata. Along with this water current, food particles enter the branchial sac where they are picked up in the mucous cord by the ciliary action of endostyle. Dorsal lamina and pharyngeal bands also play important role. There are two views regarding feeding mechanism.

View of Willey and Herdman

According to them, constant water current is produced by the beating of cilia bordering the stigmata. The food particles, which enter the branchial siphon along with water current, do not reach directly into the cavity of branchial sac proper but they are entangled in the mucous cord within the groove of two peripharyngeal bands. The mucous is secreted by the glandular tracts of endostyle. They believe that by the action of endostylar cilia the mucous cord from the endostyle is carried forwards through the endostylar groove and as soon as the cord enters the peripharyngeal groove, it divides into two branches to run into the right and left sides of the groove. Here, the mucous cords entangle the food particles. Then the right and left cords entangled with food particles are carried to the mid-dorsal region by the ciliary action of peripharyngeal bands. In the mid dorsal region, they reunite and form a single cord. From mid-dorsal region, this cord passes backward through the groove or tube of dorsal lamina and then into oesophagus.

View of Orton and Das

According to them, the food particles which enter the branchial siphon along with the incurrent of water directly reach into the cavity of branchial sac. The water passes out through the gill slits but the food particles settle down against the lateral walls of the branchial sac, reach in endostyle and get embedded in mucous secreted by the glandular tract of endostyle. The mucous cord (mucous along with the food-particles) does not move forward through the endostylar groove (as it was believed by Willey and Herdman) but is thrown on the wall of branchial sac with the help of long cilia of the endostyle. Food entangled in mucous passes up against the wall, reaches in the tube of dorsal languets. The languets of the dorsal lamina help in catching the mucous cord from the branchial cavity. When the mucous passes through the way of dorsal lamina to the oesophageal opening, it rolls up. Finally the mucous is carried backwards into the oesophageal opening. From oesophagus the food passes into the stomach.

Digestion

The digestion mainly takes place in the stomach where the liver pours its secretion. The yellowish-brown secretion of liver contains a strong amylase, a protease and

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a mid lipase. Amylase hydrolyses starch into maltose, protease breaks down proteins, and lipase acts on fats. Secretion of pyloric gland probably serves as accessory digestive organ like pancreas. Digestion is completed and the digested food absorbed in the intestine. The undigested food material passes into rectum and driven out by rectal cilia into cloaca (atrial cavity) through anus and from where ultimately it passes outside the body with a great force through the atrial aperture along with the outgoing water current. The reserve food material is starch like granules and stored in the wall of stomach and intestine as well as in liver.

Check Your Progress

8. What are the zones of pharynx in herdmania into which it is divided?
9. What is the branchial sac?
10. What is the structure of oesophagus in herdmania?
11. Define stomach in herdmania.

1.7 FEEDING ORGANS AND MECHANISM OF FEEDING (DIGESTIVE SYSTEM) IN CEPHALOCHORDATA (*AMPHIOXUS*)

The digestive system of cephalochordates includes the alimentary canal and digestive glands.

1.7.1 Alimentary Canal

It is straight tube extending from mouth to anus and consists of ingressive, progressive, degressive and egressive zones – (1). The Ingressive zone includes mouth and buccal cavity; (2). The Progressive zone includes pharynx and oesophagus; (3). The Degressive zone is a part of gut where food is properly digested, absorbed and it includes intestine; (4). The Egressive zone the posterior most part of the hindgut is heavily ciliated and may be termed as rectum.

Mouth

It is a large, oval, antero-ventrally opening and leades into a spacious buccal cavity.

Buccal Cavity

The buccal cavity is bordered by filler like membrane called oral hood. It is surrounded by 22 buccal tentacles or oral cirri, bearing sensory papillae. Each oral cirrus and the edge of oral hood are internally supported by skeletal rods which are stiff and gelatinous in nature. The oral cirri form a sort of filter or sieve during feeding to prevent the entry of large particles.

The buccal cavity or vestibule is shallow cup-shaped cavity and internally lined by ectoderm (=Stomodaeum). Inside the vestibule the epithelial lining is thrown into ciliated 6-8 pair finger like processes having median grooves and collectively forms the wheel organ or rotator organ or ciliated organ of Muller's, which produces circular current of water. The median dorsal process of wheel organ is the longest and has a glandular groove called the Hatschek's groove which terminates into Hatschek's pit. Both Hatschek's groove and pit secretes mucous.

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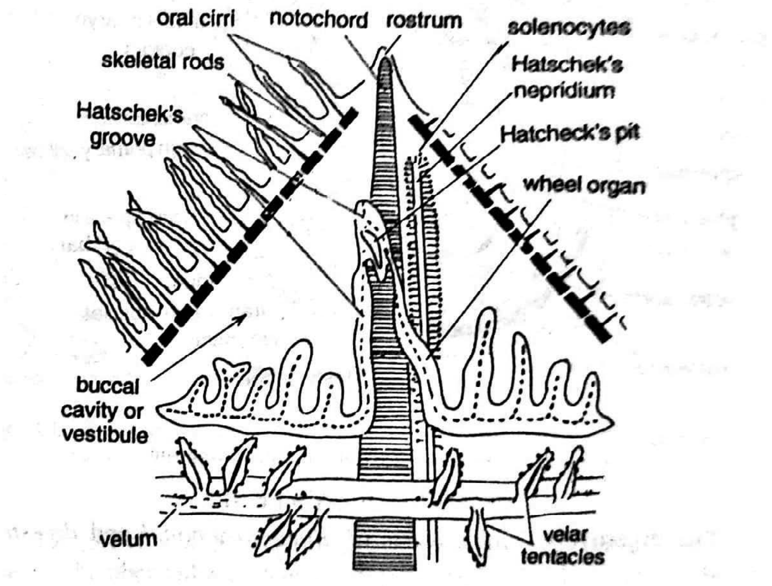

Fig. 1.25 *Amphioxus: Dorsal Wall of Oral Hood in Ventral View*

Posteriorly, the buccal cavity or vestibule is bounded by a circular membrane called velum which stands vertically between vestibule and pharynx. The velum has a circular opening, the enterostome. The posterior border of the velum around the enterostome is produced into 10-12 backwardly directed velar tentacles which bears numerous sensory papillae. The tentacles serve as strainer and prevent large food particles from entering the mouth

The enterostome has been sometimes called the mouth and is the actual opening which formed the mouth in the larva. Actually enterostome does not correspond to the mouth of chordates because it leads an endoderm-lined cavity, i.e., pharynx (in chordates, the mouth leads into an ectoderm-lined cavity, i.e., buccal cavity). Hence, the anterior opening of the oral hood is true mouth which leads into ectoderm-lined vestibule.

Pharynx

It is the largest part of alimentary canal which occupies about two-third part of the body. It is laterally compressed sac and remains suspended in the atrial or peribranchial cavity which surrounds it from all sides except on dorsal side.

The pharynx is divisible into a short pre-branchial chamber and a large branchial chamber. The lateral walls of branchial chamber are perforated by 180-250 oblique vertical gill slits or gill cleft, through which the pharyngeal cavity communicates with the atrial cavity. The gill slits are vertically separated from each other by the thin wall of the pharynx called branchial lamella or gill bar. Each gill bar is supported by skeletal rod. The gill bars are of two types, i.e., primary and secondary which differ in their structure and mode of development. The primary

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gill bars are lies between primary gill slits. The secondary gill bar arises as a growth of dorsal wall of the primary gill splits into two vertical halves. The gill slits are also divided by transverse bars called synapticulae. The gill bars are lined on their inner anterior and posterior surface by endoderm but the outer surface is lined by ectoderm. The inner surface facing the pharyngeal cavity bears cilia called pharyngeal or frontal cilia.

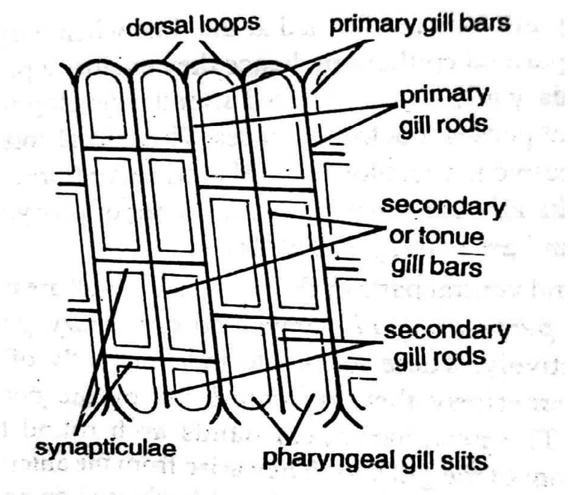

Fig. 1.26 *Amphioxus: A Part of Pharyngeal Wall to Show Gill Slits, Gill Bars and Skeletal Rods*

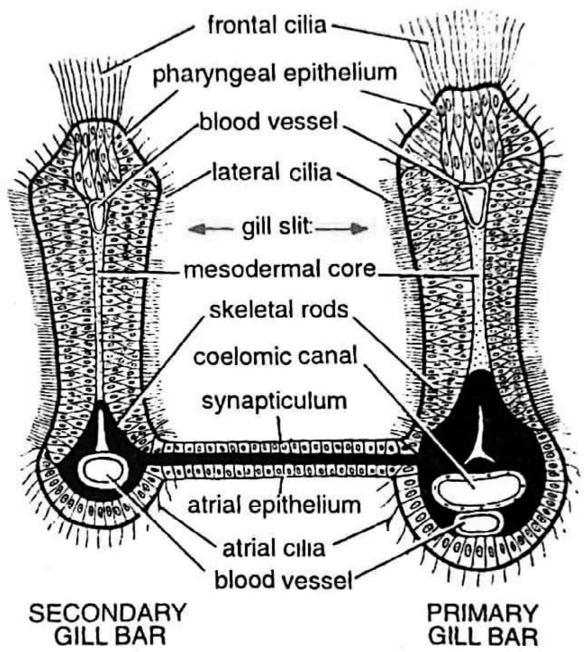

Fig. 1.27 *Amphioxus: T. S. Structure of Primary and Secondary Gill Bars*

The gill bars are supported internally by gelatinous skeletal gill rods which are united dorsally but ventrally they remain free. Ventrally, the primary gill rods are forked but secondary rods are un-forked. Primary rods are connected by

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transverse junctions called synapticulae which also contains gelatinous rods and blood vessels. The gill bars are lined with cilia all over. The cilia on the inner or pharyngeal side are especially long and are called frontal cilia.

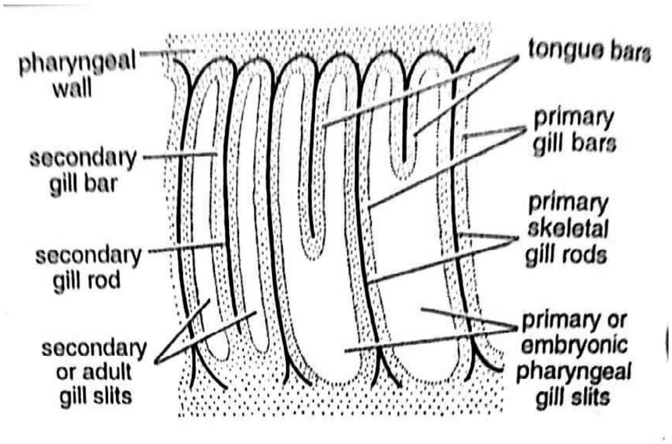

Fig. 1.28 *Amphioxus: Development of Secondary Gill Bars and Gill Slits*

The mid-dorsal and mid-ventral parts of the pharyngeal wall are not perforated and constitute ciliated hyper-pharyngeal groove or epipharyngeal groove and hypopharyngeal groove or endostyle, respectively. The endostyle is lined by four longitudinal tracts of mucous secreting gland cells. These tracts are separated by ciliated cells of which the cells of median row bear long cilia. Below the endostyle are two gelatinous skeletal plates in the sub endostylar coelom. This sub-endostylar coelomic canal contains the median longer sub-endostylar ventral aorta. Just behind the velum are two ciliated peripharyngeal bands through which the endostyle communicates with the epipharyngeal groove. The epipharyngeal groove leads posteriorly into the opening of oesophagus.

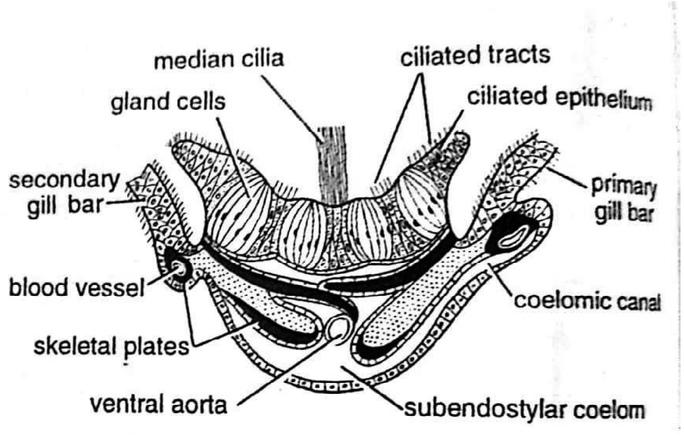

Fig. 1.29 *Amphioxus: T. S. of Endostyle*

Oesophagus

It is a short, narrow and tubular structure internally lined with ciliated epithelium.

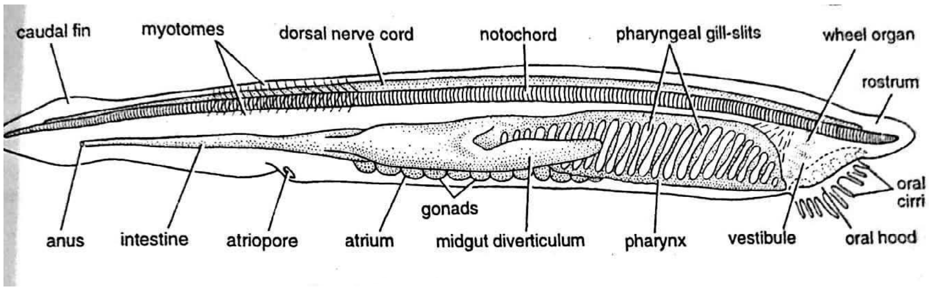

Fig. 1.30 *Amphioxus: Dissection of Alimentary Canal in Left Lateral View*

Intestine

It is a tubular organ and as long as pharynx. It remains suspended from the dorsal body wall by a dorsal mesentery into the atrial cavity. It is differentiated into three regions an anterior wide midgut, middle short ilio-colic ring and posterior tapering hindgut. A blind pouch, the mid gut diverticulum appears from the junction of oesophagus and midgut and extends anteriorly on the right side of the pharynx. The lining of midgut on the right lateral side bears a concentric lateral ciliary tract. Its cilia beat downwards directing food into the midgut diverticulum. It produces enzymes.

At the hind end of midgut is a small rounded thickening, the ileocolic ring whose ciliary action rotates mucous cord containing food or churns the food. The hindgut has a dorsal tract of cilia that starts from the ileocolic ring and extends posteriorly.

Rectum

The rectum opens out through a small circular aperture, the anus. It is situated at the base of caudal fin on ventral side. It has anal sphincter.

1.7.2 Digestive Glands

The midgut diverticulum is often referred to as liver or hepatic caecum but it does not resemble with liver in structure or junction. It is a digestive gland comparable to pancreas. Its inner zymogen cell and numerous gland cells of intestine secrete number of digestive enzyme.

1.7.3 Food, Feeding and Digestion

The food, feeding and digestion are discussed below.

Food

Amphioxus feeds on diatoms, desmids, protozoans and other pelagic microscopic organisms suspended in sea water.

Feeding Mechanism

A continuous current of water is maintained due to beating of lateral cilia of gill bars, so Amphioxus is also said to be a 'ciliary feeder'. Incurrent water with food particles enters through mouth. The water goes to the pharynx from where it passes through gill-slits into the atrial cavity and then to the exterior through atriopore.

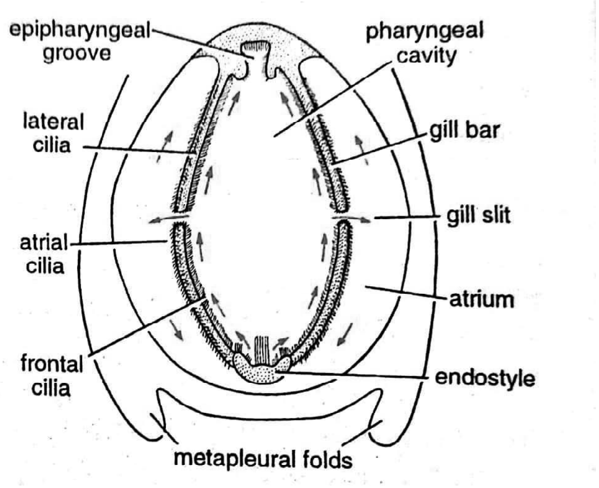

***Fig. 1.31** Amphioxus: Course of Feeding Current in Diagrammatic T.S. of Pharynx and Atrium*

During feeding, the oral cirri are turned inwards so to form a sieve which allow only minute particles to enter along with the water current. The wheel organ produces a circular current and directs the water towards the pharynx. While passing through enterostome the water current is further filtered by the velar tentacles so that only very fine food particles enter the pharynx. Thus, the whole thing forms an efficient filter and amphioxus is also said to be a 'filter feeder'. The chemoreceptors present on buccal cirri and velar tentacles probably serve to test the nature of water current and food particles.

Inside the pharynx, the food particles try to settle down on the floor but the cilia of endostyle do not allow to them to do so they entangled into mucous secreted by glandular cells of endostyle. These mucous cord are passed dorsally by the lateral branchial cilia on to the inner faces of the gill bars and then to the epipharyngeal groove by the beating of frontal branchial cilia. The cilia of epipharyngeal groove roll it into a mucous cord and gradually push back into the oesophagus. From the oesophagus the food is directed towards the lumen of midgut diverticulum which is also a ciliated structure internally. Here, digestive enzymes are mixed with the food materials. The food is returned to the midgut again. The ilio-colic ring rotates the mucous cord for mixing the enzymes in it and also for breaking the larger pieces into smaller ones. Then the food is pushed into hindgut from where the undigested food material is eliminated out through the anus.

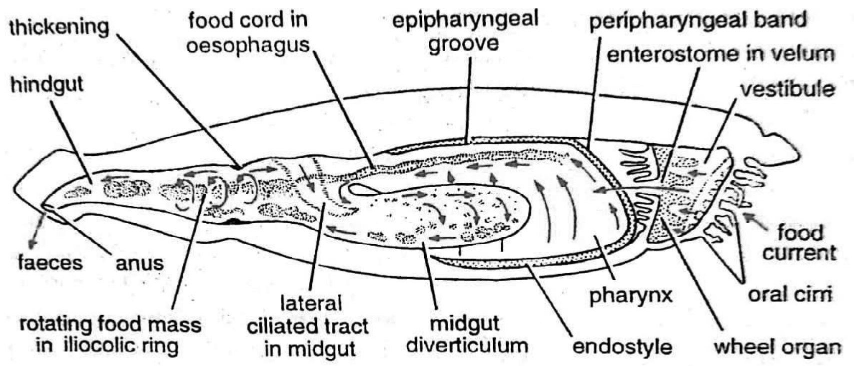

Fig. 1.32 *Amphioxus: Movements of Ciliary Currents and Food in the Alimentary Canal*

Mechanism of Digestion

Both extracellular and intracellular digestion takes place in amphioxus. Intracellular digestion takes place mainly in phagocytic cells of midgut diverticulum. The extracellular digestion takes place in the lumen of midgut diverticulum by the digestive juice secreted by zymogen cells of midgut diverticulum and glandular cells of intestine. Digestive juice contains amylase, lipase and protease enzymes which digest the carbohydrate, fat and protein, respectively. Complete digestion occurs in the absence of acid. Occasionally, some food particles may pass into atrial cavity are engulfed by phagocytic cells of renal papillae of the atrial cavity. Partially absorption occurs in midgut but mostly in hindgut. Undigested food is thrown out the anus.

Table 1.4 *Comparison of Alimentary Canals, Digestive Glands and Feeding Mechanism between Urochordates (Herdmania) and Cephalochordates (Amphioxus)*

Characters	*Herdmania*	*Amphioxus*
Alimentary Canal	Complete, curved narrow tube with intestinal and rectal loops	Complete, straight tube from mouth to anus
Mouth	Mouth or branchial aperture is four-sided and guarded by four lips, situated on branchial siphon.	Wide, antero-ventral opening bordered by free margin of oral hood and buccal cirri.
Buccal Cavity	It is a cavity of branchial siphon with branchial tentacles which act as sieve. Below the tentacles is peribranchial zone having dorsal tubercle. At the upper end of pharynx there are two thin ciliated peripharyngeal bands. Velum absent.	It is a spacious vestibule of oral hood. Its lateral margin provided with 22 oral cirri. Velum is present. It is provided with velar tentacles having sensory papillae.
Pharynx	It is divided by two peribranchial ridges into an anterior small pre-branchial region and a large posterior branchial sac with gill slits.	It is divided into a small antero-dorsal pre-branchial region and a large posterior branchial region by lateral oblique peripharyngeal bands.
Endostyle	Extends mid-ventrally along floor of pharynx.	Extends mid-ventrally along floor of pharynx.
Hyper-pharyngeal Groove	Dorsal lamina with tongue like processes called languets.	It is ciliated groove. The languets absent.
Gill Slits	About 2, 00,000 gill-slits open into atrial cavity.	Only 180-250 pairs of gill-slits are present that open into atrial cavity.

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Oesophagus	Branchial sac opens into the thick walled short tube like oesophagus, which is guarded by two large flaps. Midgut diverticulum absent.	It is short tube like. At the junction of oesophagus and midgut there is a blind midgut diverticulum.
Stomach	Demarcated from intestine and sphinctered at both the ends.	Stomach or midgut not demarcated from intestine.
Intestine	It is 'U' shaped tube enclosing the left gonad. The ilio-colic ring is absent.	It is straight tube, internally lined by cilia containing lateral ciliary tract and iliocolic ring.
Rectum	Well differentiated and internally lined with cilia.	Well demarcated and heavily ciliated.
Anus	Rectum curves dorsally to open into cloaca by anus bordered by four lips.	Rectum opens out by anus. It is a small, circular sphinctered aperture lying at the base of caudal fin.
Digestive glands	Bilobed liver. Branched pyloric gland present in the wall of stomach and intestine.	A midgut diverticulum is present which functions as liver. Pyloric gland are absent.
Atrial cavity	It is present. The gill slits and anus open here. The atrial cavity opens out through atrial aperture guarded by four lips and situated on atrial siphon.	It is present and only the gill-slits open in it. The atrial cavity opens outside through atriopore.

Check Your Progress

12. What is the food of amphioxus?
13. What is the difference between endostyle of herdmania and amphioxus?

1.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Animals with a well-defined vertebral column or back-bone are called chordates.
2. It is a stiff, elastic, longitudinal supporting rod-like skeletal or structure lying between the nerve cord and alimentary canal.
3. Urochordates are small marine animals with larvae that swim freely and adults that attach themselves to the ocean floor.
4. Cephalochordates are small, eel-like, unprepossessing animals that spend much of their time buried in sand.
5. A tunicate is a marine invertebrate animal, a member of the subphylum Tunicata.
6. Each gonad is about 3-4 cm long in herdmania.
7. In tunicates, gastrulation begins after sixth cleavage by emboly.
8. In herdmania, the pharhyx is divided into two unequal zones: pre-branchial zone and branchial zone.
9. It is posterior largest sac like portion of pharynx and fills much of space of atrial cavity. Its lateral walls are perforated with numerous elongated gill slits or stigmata.
10. It is a short, thick and curved tube without stigmata. Its lumen provided into four ciliated grooves which direct the food particles into stomach.

11. It is a wide thin walled tube and surround by left larger and right smaller lobe of liver. Stomach receives eleven hepatic ducts appearing from both liver lobes and open separately by eleven pores in it.
12. Amphioxus feeds on diatoms, desmids, protozoans, and other pelegic microscopic organisms suspended in sea-water.
13. In herdmania, endostyle extends mid-ventrally along floor of pharynx, while in amphioxus, it extends mid-ventrally along floor of pharynx.

1.9 SUMMARY

- Phylum chordata is derived from two Greek words, the chorde (a string or cord) and ata (=bearing). The phylum Chordata was created by Balfour in 1880.
- Chordates are characterized by the presence of notochord, dorsal tubular nerve cord, and pharyngeal gill slits.
- Chordates also have a closed circulatory system, and most, but not all, chordates have a heart. The blood of most chordates contains the oxygen-carrying molecule hemoglobin.
- The origin of vertebrates inevitably involves invertebrates, especially non-chordates, deuterostomes and invertebrate chordates.
- The geological records estabhished beyond doubt that the chordates originated prior to Cambrian period, as the oldest fossils of known vertebrates have been discovered in Cambrian strata.
- Most zoologist now favor the deuterostome line of chordate evolution, according to which the phyla echinodermata, hemichordate and chordate show common ancestry on embryological and biochemical evidences.
- Gutmann proposes that the earliest chordates were *amphioxus*-like animal and other groups of animals like sessile urochordates, vertebrates and burrowing hemi-chordates are developed from this group.
- The food eaten by animals has to be broken down into other substances in side body. This is called digestion. It happens in the digestive system, which begins at the mouth and ends at the anus.
- Food is any substance consumed to provide nutritional support for an organism. It is usually of plants or animals origin, and contains essential nutrients, such as carbohydrates, fats, proteins, vitamins, or minerals.
- Digestion is the breakdown of large insoluble food molecules into small water-soluble food molecules so that they can be absorbed into the watery blood plasma. In certain organisms, these smaller substances are absorbed through the small intestine into the blood stream.
- The digestive system is the group of organs that break down food in order to absorb its nutrients.

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- The human *digestive system* consists of the gastrointestinal *tract* plus the accessory organs of *digestion* (tongue, salivary glands, pancreas, liver, and gall bladder).
- The embryonic archenteron becomes the lining of the adult digestive tract and of all its derivatives. Ectodermal invagination of the head forms the stomodaeum leading into oral cavity, and a similar mid-ventral ectodermal invagination forms proctodaeum, which leads into the hindgut.
- The digestive tract differentiates for different functions into the following regions- mouth, buccal cavity, pharynx, oesophagus, stomach, small intestine, large intestine, and cloaca or anus.

1.10 KEY TERMS

- **Chordates:** Animals with a well-defined vertebral column or back-bone are called chordates.
- **Notochord:** It refers to atiff, elastic, longitudinal supporting rod-like skeletal structure lying between the nerve cord and alimentary canal.
- **Urochordates:** Urochordates are small marine animals with larvae that swim freely and adults that attach themselves to the ocean floor.
- **Cephalochordates:** Cephalochordates are small, eel-like, unprepossessing animals that spend much of their time buried in sand.
- **Tunicates:** tunicate is a marine invertebrate animal, a member of the subphylum tunicata.

1.11 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. What are the fundamental characteristics of chordata?
2. What is the relationship of cephalochordates with urochordata?
3. Briefly explain the development in tunicates cleavage.
4. What is the systemic position of Amphioxus?

Long Answer Questions

1. Discuss the ancestry of chordates in detail.
2. Describe the affinity of urochordata with cephalochordates and other deuterostomes.
3. Discuss the asexual reproduction in tunicates.
4. Explain the feeding organs and mechanism of feeding in urochordata.

1.12 FURTHER READINGS

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UNIT 2 CHORDATES: ORIGIN, EVOLUTION AND GENERAL ORGANIZATION OF VARIOUS FORMS

Structure

2.0 INTRODUCTION

In the previous unit, we discussed the concept of chordata. Here, we will discuss some organisms belonging to this phylum.

The first fossil fishes, Ostracoderms are the earliest known armored, jaw less vertebrates of the Paleozoic era and lived from the Early Silurian (about 430 million years) to the Late Devonian (about 370 million years). They are most diverse in the Early Devonian and become very rare in the Middle and Late Devonian. Osteostracans are widely distributed in North America, Europe, Siberia, and Central Asia, north of the Tian-Shan.

The cyclostomata are characterized by the presence of a circular suctorialand rounded mouth without functional jaws. They exhibit a low grade of organization and are undoubtedly the most primitive of all the existing vertebrates. The placoderms were highly specialized in many respects but these are primive gnatostomes. Colbert regards them as unsuccessful ancient 'experiments' in the evolution of jawed vertebrates. Romer stated that perhaps the greatest of all advances in vertebrate history was the development of jaws causing drastic revolutionary improvement in the mode of their life. In this unit, we will discuss the evolution, origin, and general organization of ostracoderms, cyclostomes, and placoderms, along with general account of elasmobranchii, holocephali, dipnoi, and crossopterygee. It will also focus on the integument and its derivatives along with the flight and gliding in vertebrates.

2.1 OBJECTIVES

After going through this unit, you will be able

- Describe the evolution, origin, and general organization of Ostracoderms, Cyclostomes, and Placoderms
- Evaluate the characteristics of Elasmobranchi, Holocephali, Dipnoi, and Crossopterygii
- Explain the integument and its derivatives in vertebrates
- Discuss the flight and gliding in vertebrates

2.2 OSTRACODERMS: ORIGIN, EVOLUTION, GENERAL ORGANIZATION, AND AFFINITIES

The Swiss anatomist Louis Agassiz received some fossils of bony armored fish from Scotland in the 1830s. He had a hard time classifying them as they did not resemble any living creature. He compared them at first with extant armored fish such as catfish and sturgeons but later realizing that they had no movable jaws, classified them in 1844 into a new group 'ostracoderms' which means 'shell-skinned'. Osteostracans, also known as '*cephalaspis*', played an important role in the history of vertebrate palaeontology, as they were the first fossil jawless fishes whose internal anatomy has been described in detail, thereby raising heated debates about the organization of the primitive vertebrate head.

On the dorsal surface of the head are the closely-set eyes, a pineal foramen, and a median, keyhole-shaped nasohypophyseal opening. In addition, there are peculiar 'fields' (in fact, depressions of the braincase, covered with loose platelets of dermal bone), which have been regarded as either sense organs or electric organs. The mouth and gill openings are, like in the galeaspida, situated on the ventral side of the head. Osteostracans also have large, pad-shaped paired fins. Most osteostracans are about 20 to 40 cm. in total length, but some species could be extremely small (about 4 cm in length). The largest species is about one metre in length.

Ostracoderms had separate pharyngeal gill pouches along the side of the head, which were permanently open with no protective operculum. Unlike invertebrates that use ciliated motion to move food, ostracoderms used their muscular pharynx to create a suction that pulled small and slow moving prey into their mouths.

Ostracoderms have heads covered with a bony shield. They are among the earliest creatures with bony heads. The microscopic layers of that shield appear to evolutionary biologists, 'like they are composed of little tooth-like structures.' There is a layer of enamel and even a layer of pulp. The whole shield is made up of thousands of small teeth fused together. This bony skull—one of the earliest in the fossil record—is made entirely of little teeth. Teeth originally arose to bite creatures; later a version of teeth was used in a new way to protect them.'

2.2.1 Occurrence of Ostracoderms

The earliest known vertebrates to appear in fossil record were jawless primitive fish-like animals collectively known as the ostracoderms. These were placed under the class ostracodermi. The class ostracodermi is represented by the fossil vertebrates of late Cambrian and middle Ordovician periods.

Although the fossils are frequent in the sea, there are ample reasons to believe that their progenitors were freshwater forms living near estuaries. The ostracoderms resembled the present day cyclostomes (lampreys and hagfishes) in many respects and together with them constitute a special group of jawless vertebrates, the Agnatha.

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

2.2.2 Important Features of Ostracoderms

The ostracoderms were primitive vertebrates, small to medium in size. Their body form was fish-like, usually flattened dorso-ventrally, with a huge head and gill region, a tapering but muscular trunk and some sort of tail fin. They had no jaws and no pectoral or pelvic fins but had only median fins. These earliest vertebrates were bony and heavily armoured. The bony plates and the scales of the ostracoderms were well preserved.

The head was covered in a solid shield made of broad bony dermal plates, while the rest of the body surrounded by a series of smaller plates often called dermal scales. This has led to their names 'ostracoderms' 'armoured fishes', or bony skinned animals (Gr., ostrakon = shell; derma = skin).

It has been suggested that the heavy endoskeleton served as a protection against the giant scorpion-like arthropods, the eurypterids which were the dominant predators of Cambrian, Ordovician and Silurian periods. Later, when these enemies disappeared, the jawed descendants of ostracoderms also lost their heavy armour which only hindered rapid progress.

The ostracoderm head had a pair of large lateral eyes and a median penial eye on the top. A single median nostril was located anterior to penial eye. The mouth was anteroventral, small and without jaws or teeth. The gill-slits were round and all had similar gill-pouches. Sensory fields on head were probably a part of the lateral line system.

The flattened body and feeble fins suggest that they were probably bottom dwellers and filter feeders like most of the present-day lower chordates. Very little is known about ostracoderm internal anatomy. The endoskeleton was moderately ossified. They had no axial endoskeleton or vertebrae. An internal ear with two semicircular canals was present.

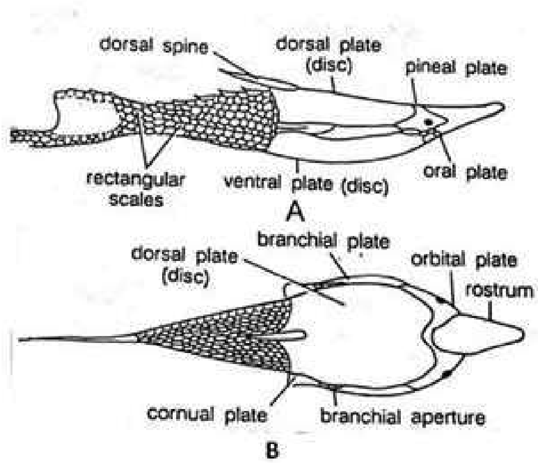

Fig. 2.1 Pteraspisrostrata, an Ostracoderm: (A) Dorsal View; (B) Ventral View

The salient characteristics of ostracoderms are:

- Ostracoderms were the first vertebrates and were popularly called armoured fishes.
- They originated about 500 million years ago, lived for about 200 million years and disappeared from the earth completely about 300 million years ago.
- They were jawless vertebrates.
- They lived in freshwater.
- They were bottom dwellers.
- Their body was fish-like and did not exceed 30 cm in size.
- Paired fins were absent.
- Median and heterocercal type caudal fins were present.

- The head and thorax were covered by heavy armour of bones. It protected ostracoderms from the giant scorpion like arthropods, eurypterids.
- Bony skull was well developed.
- Mouth was mostly present on the ventral side.
- They were having large number of gill slits.
- The nervous system had 10 pairs of cranial nerves.
- The head had a pair of lateral eyes, and a median pineal eye.
- They were filter feeders, feeding like a vaccum cleaner.
- The endoskeleton was either bony or cartilaginous.

2.2.3 Biological Significance of Ostracoderms

The ostracoderms were the primitive vertebrates recorded in the geological history. The biological significance of ostracoderms have been discussed as follows:

1. The ostracoderms are especially interesting because they represent the oldest known vertebrate fossils in the late Cambrian and Ordovician rocks dating back to nearly 500 million years. They are the remote ancestors of all the vertebrates including man.
2. The microscopic studies of their fossilized bony tissues reveals a great complexity of structure, therebyimplying that these vertebrates were far advanced and had undergone a considerable period of evolution before becoming fossilized.
3. The lack of earlier vertebrate fossils shows that they had perhaps evolved in a habitat (freshwater) which was inimical to fossilization. It is also likely that the earliest ancestors lacked hard skeletal materials as bones.
4. They developed heavy bony armour perhaps for survival against the attacks of contemporary giant arachnid predators, the eurypterids. After the disappearance of giant arachnids (eurypterids) the descendants of ostracoderms, the cyclostomes, also lost the unvented heavy armour which was a hindrance in rapid progression.
5. The cartilage of cyclostomes and sharks and skates (Chondrichthyes) was previously considered a precursor to bone and more primitive. Since the ostracoderms had bony skeletons, the bone is now considered more primitive and the cartilage is interpreted as a degenerate condition.

2.2.4 Affinities of Ostracoderms

The fossil ostracoderms, as we find them, were specialized and products of a long evolutionary past. They probably evolved from unarmoured ancestral forms such as *Jamoytius* and became diverged to various modes of life. Now the question arises whether the ostracoderms should be placed in the direct line of descent of vertebrates. There is evidence to believe that ostracoderms were not all equally related and at least two distinct major groups are recognized: cephalaspids and the pteraspids. According to Lankester, pteraspids were related to cephalaspids because both are jawless, have a large cephalic shield and occur in the same beds.

On the other hand Prof. Eric Stensio (1927) believes that the pteraspids have given rise to myxinoids and the cephalaspids to lampreys. There is indeed little in common among the ostracoderm fossils except for the absence of jaws.

It is certain that the group shows many structural similarities with the cyclostomes (the most primitive surviving vertebrates) are the degenerated descendants of some forms of ostracoderms. The ostracoderms closely resemble the modern cyclostomes in:

- Absence of biting jaws, i.e., absence of jawless mouth.
- Absence of paired fins.
- Structure of brain and cranial nerves.
- Similar auditory capsules.
- Unpaired olfactory organs, and
- Pouch-like branchial sacs.

Hence, the two classes, i.e., ostracodermi and cyclostomata are placed together in the superclass Agnata. But the relationship of ostracoderms with gnathostomes is still obscure. The gnathostomes (jawed vertebrates) evolved simultaneously with the ostracoderms during the Devonian period and no fossil link is so far discovered depicting the line of transformation.

The ostracoderms could not compete with the jawed fish that evolved in such diversity during Devonian and became extinct. Before extinction the ostracoderms gave rise to the first bony fishes, the placoderms, and the cartilaginous chondrichthyes.

The Osteostraci include a major clade, the Cornuata, characterized by pointed lateral processes of the headshield, in front of the paired fins (homoplastic with the cornual processes of the Galeaspida and Pituriaspida), and a few primitive genera (*Ateleaspis, Aceraspis, Hirella, Hemicyclaspis*) which represent 'basal' osteostracans. The early Silurian Ateleaspis is regarded as the most generalized osteostracan.

The Cornuata comprise five major taxa: the Cephalaspidida, Zenaspidida, Benneviaspidida, Kiaeraspidida, and Tyestiida. There are a few other minor taxa of uncertain affinities, such as the Tannuaspidida from Central Asia (Tuva).

The Cephalaspidida are characterized by broad and flattened cornual processes, onto which extend the lateral fields. Cephalaspis is the classical representative of this group which, however, includes many other forms, such as, the large Parameteoraspis, whose headshield can reach 45 cm in breadth.

The Zenaspidida have a more massive headshield, often bearing a posterior median crest or spinal process. They have a characteristic ornamentation of large tubercles, surrounded by smaller ones.

The Benneviaspidida have a flattened headshield and their exoskeleton has lost the polygonal pattern of the platelets, to form a continuous layer. Some benneviaspidids, such as, the Boreaspididae, develop a long rostral process, like some galeaspids and pituriaspids. One of them, Tauraspis, is unique in having a pair of forward pointing 'horns'.

The Kiearaspidida are small osteostracans whose headshield extends posteriorly into a long abdominal division and whose cornual processes are extremely reduced or lost. Some of them, the Acrotomaspididae, are very specialized forms, with extremely reduced cephalic fields and their mouth opens antero-dorsally.

The Thyestiida are also small osteostracans, characterized by the special structure of their sensory-line canals. They include forms, the Tremataspididae, which have lost the paired fins and cornual process, their headshield becoming olive-shaped. This may represent an adaptation to burrowing habits.

Among all 'ostracoderms', osteostracans (possibly along with pituriaspids) share the largest number of uniquely derived characteristics with the gnathostomes: cellular bone, sclerotic ring in eyes, paired fins containing musculature, and epicercal caudal fin.

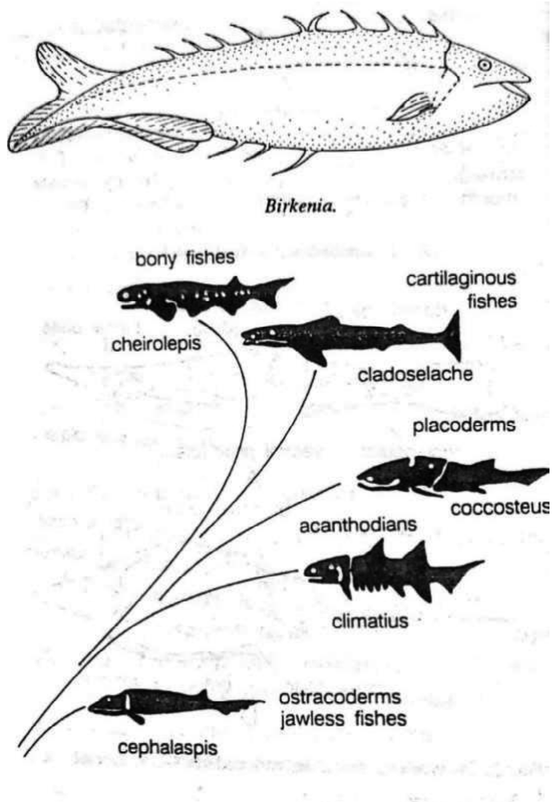

***Fig. 2.2** Phylogenetic Tree of Agnatha and Evolution of the Primitive Fishes*

Check Your Progress

1. How did Osteostracans play an important role in the history of vertebrate palaeontology?
2. Where were the fossils of Ostracoderms preserved?
3. Why are Ostracoderms biologically significant? Give any two reasons.

NOTES

2.3 GENERAL ORGANIZATION OF CYCLOSTOMES

The Cyclostomata (Gr. *Kyklos* = circular + *Stoma* = mouth) are characterized by the presence of a circular suctorial and rounded mouth without functional jaws. They exhibit a low grade of organization and are undoubtedly the most primitive of all the existing vertebrates. The Cyclostomata are the living agnathans, they are primitive in many respects, but specialized in others. They include lampreys, hagfishes and slime eels. They are commonly known as round mouthed eels as they superficially look like eels. However, they are not to be confused with true eels which are highly developed bony fishes.

2.3.1 Origin of Cyclostomes

They are a modified and degenerate offshoot of the primitive vertebrate stalk, arose in the Devonian. In the adult state they are parasitic or scavengers on fishes. They have round bodies with laterally compressed or diphycercal tail. Its buccal cavity has a muscular tongue bearing epidermal teeth by which they rasp the flesh of fishes. They are the only living vertebrates without jaws. They have 6-14 pairs of internal gills in different species. Gill-chambers are round pouches (hence, Marsipobranchii). Its two orders are not closely related, because they have evolved from different orders of ostracoderms.

2.3.2 Classification of Cyclostomes

About 50 species of cyclostomes are recognized. They belong to two major divisions (Petromyzontiformes and Myxiniformes). They are termed variously as subclasses, orders or families. Because they possess a round jawless mouth, they are combined in the class Cyclostomata.The similarity of these two groups is probably the result of convergent evolution. However, they show important and basic morphological differences which can be attributed to their long phylogenetic separation and different habits and habitats.

Order 1: Petromyzontiformes (Gr., petros = stone; myzon = suck):

Members of this order are called lampreys or lamper eels or lamperns or sand pride, etc.

1. Mouth ventral, suctorial with rasping tongue beset with many horny teeth
2. Nostril dorsal. Nasohypophyseal sac terminates posteriorly in a blind sac, i.e., it does not communicate with the pharynx
3. Seven pairs of gill-pouches and gill-slits which open into a separate respiratory pharynx below the esophagus
4. Dorsal finis well-developed
5. Branchial basket is complete
6. Dorsal and ventral roots of spinal nerves remain separate
7. Ear with 2 semicircular canals

8. Eggs are numerous and small.
9. Development indirect with a long larval stage and metamorphosis.
10. Both marine and freshwater forms.

Examples: Lampreys – Over 30 species – *Petromyzon, Lampetra, Ichthyomyzon*.

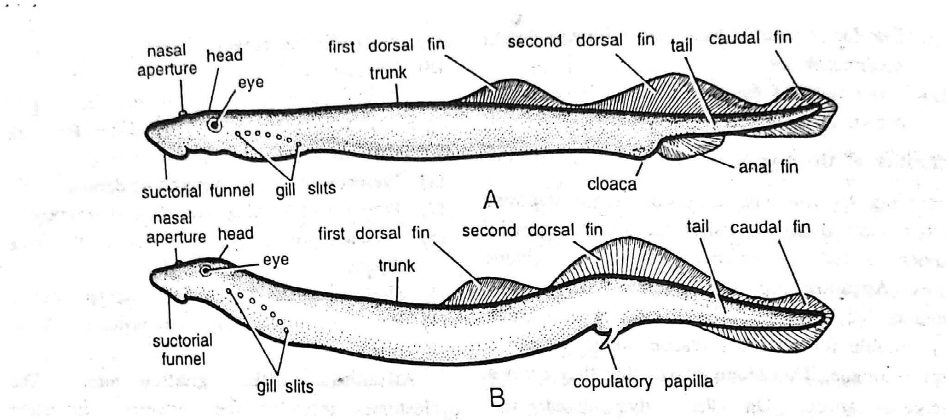

Fig. 2.3 *Petromyzon, A: Female; B: Male*

Order 2: Myxiniformes (Gr., myxa = slime; oidea = type of):

Representatives of order are called hagfishes. They are exclusively marine.

1. Mouth terminal and surrounded by 8 small tentades. Teeth few. No buccal funnel.
2. Nostril terminal. Nasohypophyseal sac opens posteriorly in the pharynx.
3. Gill-pouches and gill-slits 6 to 14 pairs.
4. Dorsal fin feeble or absent.
5. Branchial basket poorly developed.
6. Dorsal and ventral roots of spinal newes united.
7. Ear with only one semicircular canal.
8. Eggs few and large. Development dark.
9. Hagfishes are all marine species.

Examples: Hagfishes – About 15 species – *Myxine, Eptatretus* (= *Bdellostoma*), *Paramyxine*.

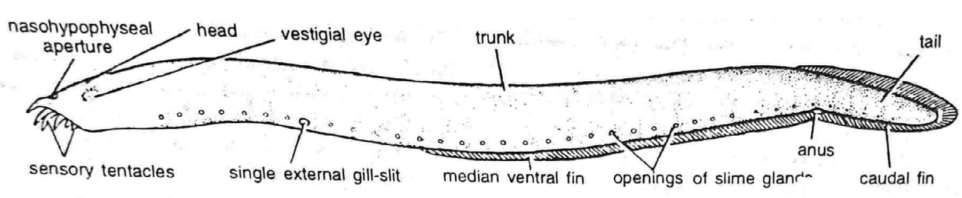

Fig. 2.4 *Myxine*

2.3.3 Affinities of Cyclostomes with *Amphioxus*

Cyclostomes are evidently chordate. They are primitive vertebrates. Their ammocoete larva resembles in most characters with that of branchiostoma, which shows primitive relationship. Whereas, adult cyclostomes possess specialized as well as degenerate characteristics.

Characteristics Resembling Those of Amphioxus are:

The similarity involves:

- Absence of jaws, exoskeleton and paired fins.
- Continuous notochord (but with an added sheath).
- Segmental musculature (myotomes) but little modified from head to tail.
- Ciliated alimentary tract straight and without much regional specialization.
- Relatively large numbers of gill-slits.
- Endostyle in lamprey larva.
- Gonads without gonoducts.

Besides these, the ammocoete larva of lampreys resembles amphioxus as follows:

- Fish-like body.
- Oral hood anterior to mouth.
- Continuous dorsal and caudal fins.
- Ciliated digestive tract.
- Filter feeding habit and
- Endostyle functions in feeding.

Characteristics of Cyclostomes more Primitive than Fishes (Differences from Fishes)

The differences are:

- No hinged jaw.
- No paired fins.
- No true teeth.
- Continuous or nearly continuous median fin fold (in hag fishes).
- Diphycercal caudal fin.
- Fin rays without muscular attachment.
- Cranium incomplete.
- No vertebrae, or poorly developed.
- Rudimentary pancreas.
- No spiral valve, or only slightly developed spiral valve in intestine.
- Single median nostril.
- Brain relatively small and generalized.
- Heart is rather loosely twisted S-shaped tube.

- Lateral line organs poorly developed and in isolated pits.
- Hypophysial duct rather large, open to the exterior and not connected with pituitary body.
- IX and X cranial nerves not enclosed in cranium.
- Absence of modulated nerves.
- Sympathetic nervous system is very primitive and poorly developed.

2.3.4 Affinities of Cyclostomes with Ostracoderms

Cephalaspids and anaspids are fossil agnathans that show similarity to the modern cyclostomes than pteraspids (Neterostraci or Pteraspida). Ostracoderms belonging to Ordovician are the oldest fossil vertebrates. They were abundant in Silurian period and become extinct in Devonian. Probably they were the fore-runners of higher fishes.

The fossil ostracoderms and present cyclostomes are kept in agnatha due to the following similarities:

- Presence of a median pineal eye
- Presence of velar pump-like lamprey
- Endostyle sac-like
- Single nasal opening though nasal sacs are paired
- Brain is like that of lamprey
- Two semicircular canals in the ear
- Dorsal and ventral nerve roots separate up to 15
- Pairs of branchial pouches surrounded by a branchial basket
- Continuous unconstructed notochord
- Absence of jaws

Stensio holds that the pteraspids have given rise to the myxinoids, and the cephalaspids to the lampreys. The agnatha were the first animals of the chordate type to become large. They feed on detritus on the bottom. The lampreys and hagfishes have been derived from early agnatha by the evolution of a sucking mouth, perhaps with loss of the bony skeleton and paired limbs.

2.3.5 Generalized Characteristics of Cyclostomata

The general features of cyclostomata are:

- Body is cylindrical, elongated and eel-like.
- Skin is soft, smooth, slimy, containing unicellular mucous glands and without scales.
- Paired appendages are absent, though median fins are present and supported by cartilaginous fin rays.Tail diphycercal.
- Trunk and tail muscles segmented into myotomes separated by myocommata.

- Exoskeleton is lacking. Endoskeleton fibrous and cartilaginous with no bones. Notochord persists throughout life. Imperfect neural arches (arcualia) over notochord represent rudimentary vertebrate.
- Mouth is ventral, circular, suctorial and without jaws (group agnatha). A few horny teeth and a rasping tongue are present.
- Digestive system lacks a stomach. Alimentary canal is straight. Intestine with a fold typhlosole. No cloaca is found.
- Respiratory organs are 5 to 16 pairs in lateral sac like pouches of pharynx, hence another name of class, marsipobranchii.
- Heart two chambered with one auricle and one ventricle, with a conusarteriosus anteriorly. Heart is enclosed in cartilage derived from the hinder visceral arch. Many aortic arches in gill region. Renal portal system absent but hepatic portal system present. Blood with leucocytes and nucleated circular erythrocytes. They have no spleen.
- Body temperature variable, i.e., poikilothermic animals.
- Two mesonephric kidneys with ducts to urinogenital papilla.
- Dorsal nerve cord with differentiated brain. Brain has a very small cerebellum. 8 to 10 pairs of cranial nerves.
- Single median nasal aperture or nostril and only one or two semicircular canals are present in each auditory organ and a median olfactory sac like organ is present.
- Membranous labyrinth has one or two semi-circular canals.
- Uni or bisexual. Gonad single, large, without gonoduct.
- Fertilization external. Development is direct or with a prolonged larval stage.
- They may be external parasite or internal scavangers on fishes.

2.3.6 Specialized Characteristics of Cyclostomata

Cyclostomes possess some peculiar specialized characters in many respects. It is probable that many adult characteristics are adaptations for parasitic mode of feeding. Some of their specialized features are listed below:

- A distinct head.
- A suctorial/sucking mouth, buccal funnel. Powerful tongue armed with sharp horny teeth which serve as a rasping organ while feeding.
- Secretion of anticoagulants in saliva to feed on blood and body fluids of prey.
- Peculiar sac-like gill chambers or pouches located far behind head, probably an adaption to burrowing.
- Complete separation of ventral sac like respiratory pharynx from dorsal upper digestive pharynx (oesophagus).
- The respiratory current of water sucked and ejected through the same way i.e. Water entering gill-pouches and also leaving them through external gill openings and not through mouth.

- Respiratory water current entering gill pouches as well as leaving them through external gill opening and not through moth while mostly remains attached to rocks or fishes for feeding.
- Large mucous glands secreting enormous quantities of mucus in hagfishes.
- Single dorsal median nostril.
- Large pituitary sac.
- The roof of the brain is mainly non-nervous.
- Large thyroid gland.
- Large, heavy-yolked egg, with meroblastic cleavage and no larval stage in hags.

2.3.7 Degenerated Characteristics of Cyclostomata

The cyclostomes have the following degenerate characters:

- Simple, elongated, cylindrical eel-like body form compared to broad fish-like shape of ostracoderms
- Lack of bony armour or exoskeleton
- Lack of bony endoskeleton which is cartilaginous
- Rudimentary paired eyes covered by thick skin in hags
- Reduced liver and lack of gall bladder, and bile duct in adult lamprey
- Absence of paired fins and girdles
- Vestigial eyes covered by thick skin and muscle in hag fishes
- Tongue apparatus
- Sucking mouth and horny teeth (in Lamprey)
- Sac like gill pouches
- Separate branchial sac with branchial basket (in Lampreys)
- The dorsal position of nostril (in Lampreys)
- Presence of large, large, heavy, yolked eggs with meroblastic cleavage and no larval stage in hag fishes
- The large slime glands especially in hags

The cyclostomes may be described as the modified and degenerate survivors of some of the first vertebrates that lived in the world. They are regarded as 'the specialized survivors of the group ostracodermi'. They are believed to have arisen from a common craniates group from which fishes and other vertebrates have evolved. They have branched off from the common stem earlier than the formation of jaws. They are more highly organized than the Amphioxus but not so when compared to the jawed vertebrates. The ostracoderms in which there has been a tendency for the reduction of the bone, appear to be the closest relatives of the cyclostomes.

2.4 GENERAL ORGANIZATION OF EARLY GNATHOSTOMES: "PLACODERMS"

The 'Placoderms' (placo=plates, derm=skin) were the earliest jawed vertebrates of fossil record. They appeared during the Silurian, flourished or dominant in Devonian and Carboniferous but all of them become extinct by the end of the Permian period. Thus, they lived during the Paleozoic era only and are sometimes referred to as the Palaeozoic fishes. All of them were well protected by heavy, bony plates and are, therefore, called 'Placoderms'. During the brief period of their existence, the placoderms become adapted to different modes of life and, therefore, form a very heterogenous group, possessing only a few common features as given below:

- All of them had a primitive type of jaw. The upper jaw was strong and fused with the skull.
- The hyoid arch did not support the jaws as in modern fishes, so that the jaw suspension was of a primitive type. This is called the aphetohyoidean condition.
- Hyoid gill slits were present and spiracles were not formed.
- Paired fins were present but were quite variable in different members of the group.

2.4.1 Origin and Evolution of Placoderms

Placoderms originated about 400 million years ago in the Devonian period of Paleozoic era. They flourished through Devonian and Carboniferous and became extinct by Permian about 280 million years ago. During Devonian, they underwent great evolutionary radiation when two types (the cartilaginous and bony fishes) evolved in early carboniferous times. Placoderms originated and lived in the freshwater. But later forms involved the seas as well (Romer, 1959).

It is believed that some primitive ostracoderms were probably the ancestors of placoderms. Smith (1960) stated that placoderms may be the derivatives of ostracoderms. However, their fossil record does not show any connecting link between the jawless and jawed fishes. Like ostracoderms before them, the jawed fishes also appear fully formed without intermediates. Fossil evidence for the ancestry of placodermi simply does not exist.

2.4.2 Salient Features of Placoderms

The salient features are:

- Placoderms were regarded as the first true fishes.
- They were called plate-skinned fishes and they had a bony armour like that of ostracoderms.
- They were mostly the bottom dwellers and lived on invertebrates like their agnathan (ancestors) counterparts.

- They were closer to the cartilaginous fishes.
- The shape and the size of body widely varied but had a dorsoventrally flattened body (an adaptation for bottom living habit). Their size ranged from few centimeters to 10 meters (*Dunkleosteus, Dinichthyes*).
- Body was divisible into head, trunk and tail.
- The head and trunk were covered by bony shields while the tail remained mostly naked. In few forms the tail also had a covering of small thin scales.
- They had paired fins and heterocercal tail.
- Jaw suspension was primitively autostylic or aphetohyoidean type.
- Platoquadrate and mandibular bones remained unossified and fused rigidly to the head shield or to the inner part of the cranium.
- The hyoid arch was relatively unspecialized and did not participate in jaw suspension.
- Jaw consisted of bony plates, formed by modification of dermal bones linning the jaw cartilage. Similar plates on palatoquadrate, probably assisted them in crushing shelled molluscs and arthropods.
- They developed an internal ear with semicircular canals
- Spiracle probably a typical gill-slit between the mandibular and hyoid arch.
- The fins in general were similar to those of early sharks. These were represented by a pair of pectoral and pelvic fins and often by large pectoral spines attached to the bony plates on the trunk.
- Males had pelvic claspers.

2.4.3 Classification of Placoderms

All the extinct earliest jawed fishes were once believed to be generally related and therefore placed in a single group or class, the placodermi. But the spiny sharks are now placed in a separate class acanthodii. The class placodermi includes following two subclasses or orders:

1. **Subclass: Arthrodira** (Gr. Arthros= a joint + dira=neck) **and Order: Arthrodiriformes:** Earliest placoderms. Resembled ostracoderms in appearance and habitat. Heavy bony armour shield of head and trunk meeting in a movable joint (Gr., arthros, joint). Powerful gaping jaws with sharp shearing blades, violently predaceous, and devonian. For Example: *Coccosteus, Dunkleosteus, Dinichthyes, etc.*
2. **Subclass: Antiarchi** (L. Ante=before) (Gr. Archeion= ancient) **and Order: Antiarchiformes:** Bottom-dwellers and mud-feeders in fresh water. Ecologically similar to and competing with flat agnathas. Head and fore part of trunk covered by a depressed bony shield. These cephalic plates had a different arrangement and the mode of attachment of head with body shield was also different. Pectoral fin long. Devonian. For Example: *Bothriolepis, Pterichthyodes, etc.*

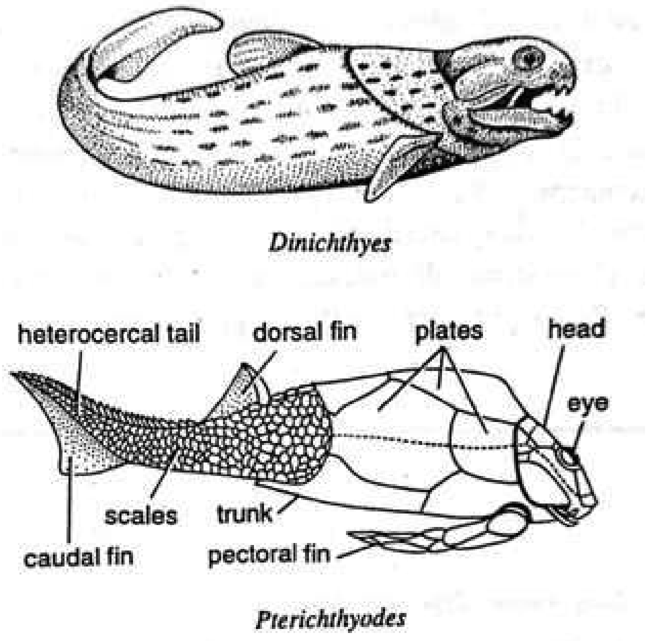

Fig. 2.5 *Placoderms*

2.4.4 Biological Significance of Placoderms

Placoderms were the earliest of the known fossil vertebrates with jaws, mostly creatures of the Devonian. Their bony armour links them genetically with their predecessors, the ostracoderms. With bony jaws and paired fins, they were more specialized than ostracoderms. A new era in the history of fishes opened with the advent of jaws. As Prof. A. S. Romer recalls in his book, *The Vertebrate Body,* that: 'Perhaps the greatest of all advances in vertebrate history was the development of jaws and the consequent revolution in the mode of life of early fishes'. There is no fossil evidence for the ancestry of placoderms. Some primitive ostracoderms were probably their ancestors. According to one view, the placoderms all become extinct by the end of the palaeozic era, without giving rise to any surviving forms. According to another view, the cartilaginous fishes or chondrichthyes and the bony fishes or osteichthyes, both arose in early Devonian from some primitive group of the placoderms. Contrary to the former belief, the cartilaginous fishes did not give rise to bony fishes. Thus, bone, rather than cartilage, is to be considered a primitive characteristic.

2.4.5 Comparison of Ostracoderms and Placoderms

Ostracoderms were the first jawless vertebrates but the placoderms were the first jaw bearing vertebrates. They had similarities as well as dissimilarities.

Table: 2.1 *Comparative Accounts of Ostracoderms and Placoderms*

S.N.	Ostracoderms	Placoderms
1	Originated in the Cambrian period about 500 million years ago.	Originated in the Devonian period about 400 million years ago.
2	Jawless vertebrates and included in Superclass Agnathostomata.	Jawed vertebrates and included in Superclass Gnathostomata.
3	First vertebrates.	Originated possibly from ostracoderms (plausibly)
4	Shell-skinned vertebrates	Plate-skined vertebrates.
5	Freshwater forms	Later invaded sea.
6	Terminal mouth without teeth.	Ventral mouth with teeth.
7	Gill slits 8-10 pairs.	5 pairs gill slits.
8	Eyes dorsally and not surrounded by bony plates.	Eyes ventro-laterally and surrounded by bony plates.
9	Pineal opening was present behind the hair.	Pineal opening was present between the eyes.
10	Paired fins were absent except *Cephalaspis*.	Paired fins were present.
11	Vertebral column was absent.	Primitive vertebral column was present
12	Nerve cord was present.	Nerve cord was surrounded by vertebral column.
13	They gave origin to placoderms.	They gave origin to bony as well as cartilaginous fishes.
14	**Examples**: *Jamoytius, Pteraspis, Cephalaspis, Birkenia, Anglaspis, Drepanaspis, Lanarkia, Thelodus,* etc.	**Examples**: *Coccosteus, Bothrolepis, Macropetalicthyes, Phyllolepis, Rhamphodopsis* ,etc.

Check Your Progress

4. State the characteristic features of cyclostomes.
5. How many species of cyclostomes are recognized?
6. Who were the earliest jawed vertebrates of fossil record?
7. When did placoderms originate?

2.5 CHONDRICHTHYES: THE CARTILAGINOUS FISHES

The Class Chondrichthyes (Gr. Chondros, cartilage + ichthys, fish) is divided into two subclasses: Elasmobranchii and Holocephali.

2.5.1 General Account of Elasmobranchii

Elasmobranchii (Gr. Elasmos, plate + branchia, gill), i.e., plated gill fishes, which include a large number of marine fishes commonly called the sharks and rays, comprises more than 1000 living species of cartilaginous fishes. The elasmobranchii are mostly predaceous fishes and are most abundant in the tropical and subtropical areas. Some of them are very larger in size and the biggest of all the fishes was probably *Carcharodon*, reaching about 80 feet in length. The whale shark, *Rhinodon*, is the largest of the living fishes and reaches about 70 feet. The basking shark, *Cetorhinus* grows to a length of 40 feet. Both these giant sharks are plankton feeders and are harmless to man. However, a number of species like the *Carcharodon carcharius* (the white shark), *Carcharinus glaucus* (the blue shark) and 'Tiger-shark' are maneaters.

General Characteristics of Elasmobranchii

The characteristics include:

- Mostly marine and predaceous
- Body fusiform or spindle shaped
- Fins both median and paired, all supported by fin rays. Pelvic fins bear claspers in male. Tail heterocercal
- Tough skin containing minute dermal dentacles or placoid scale and mucous glands
- One pair of external nostrils
- Endoskeleton entirely cartilaginous, without true bones
- Notochord persistent
- Vertebrae complete and separate. Pectoral and pelvic girdles present
- The skull is hyostylic or amphistylic and without sutures
- Mouth ventral. Jaws present. Teeth are modified placoid scales. Stomach J-shaped. Intestine with spiral valve or scroll valve
- Respiration by 5-7 pairs of gills. Gill-slits separate and uncovered. Operculum absent. The first pair of gill slits modified into the spiracles
- No air bladder and lungs
- Heart 2 chambered (1 auricle and 1 ventricle). Sinus venosus and conusarteriosus present. The contractile conus has several valves arranged in transverse rows. Veins enlarged at several places to form the sinuses. Both renal and hepatic portal system present. Blood with high concentration of urea and trimethylamine oxide
- Temperature variable (poikilothermous)
- Kidneys opisthonephric. Excretion ureotelic. Cloaca present
- Brain with large olfactory lobes and cerebellum. Cranial nerves 10 pairs. The size of the brain is large in relation to the size of the body
- Olfactory sacs do not open into pharynx. Membranous labyrinth has 3 semicircular canals. Lateral line system is present
- Sexes are separate. The males generally possess a pair of claspers on the pelvic fins
- Gonads are paired. Gonoducts open into cloaca. Fertilization is internal
- Oviparous or Ovoviviparous. Eggs large, yolky. Cleavage meroblastic
- Development is direct, without metamorphosis.

Classification of Elasmobranchii

The class Elasmobranchii is divided into three subclasses Cladoselachii, Xenacanthii and Selachii.

1. **Sub-Class: Cladoselachii (Pleuropterygh) (Gr. *Klados*= branch + *selakhe*= shark):** This includes extinct shark like fishes represented by the Palaeozoic genus *Cladoselache*. The characteristic feature was the primitive structure of the pectoral fins which had wide bases, with no anterior and posterior constriction to separate the fin from the body wall. The body was elongated with terminal mouth and heterocercal tail. The fish had two dorsal fins but no anal fin. The notochord was persistent throughout life. The body was covered with small denticles. Claspers were absent.
2. **Sub-Class: Xenacanthii (Ichthyotomi):** These were more specialized than the cladoselachii and possessed pectoral fins of the biserialarchipterygial type consisting of an elongated axis extending out from the body and bearing pre-and post-axial rays. The tail was diphycercal. A long dorsal fin and two small anal fins were present. A long serrated dorsal spine was present on the head. Skull was amphistylic, notochord persistent and claspers were present in the male. Scales were probably absent. The group is typically represented by the genus *Xenacanthus* (*Pleurocanthus*).
3. **Sub-Class: Selachii (Pleuropterygh):** This group is composed of sharks and rays, characterized by elongated or fusiform body, amphi-or hyostylic skull and heterocercal tail. The paired fins are not of the archipterygial type. Males possess claspers. This subclass is divided into two orders: Pleurotremata and Hypotremata.

Table 2.2 *Differences between Pleurotremata and Hypotremata*

S.N.	Pleurotremata	Hypotremata (Batoides)
1.	Lateral gill slits, i.e., on each side of the gill	Ventral gill slits
2.	Body more or less cylindrical	Body depressed; flat or disc-like.
3.	Anterior margin of the pectoral fins free.	Anterior margins of the pectorals fused with sides of the body and head.
4.	The pectoral radials are simple and of few segments. Only the anterior ones reach the edge of the fin.	The pectoral radials are numerous, multisegmented and bifurcated at the end. All of them reach the free edge of the fin.
5.	In the skull, cartilage is not attached to the olfactory capsule	Paired preorbital cartilage is attached to the olfactory capsules.
6.	Two halves of pecroral girdle are separate.	Two halves of pectoral girdle are joined with each other or with vertebral column.
7.	Both hyomandibular and ceratohyal bear cartilaginous rays and support the first gill.	Hyomandibular without rays and does not support the gill.
	Ex. Sharks viz; *Scoliodon, Sphyma*.	Ex. *Dasyatis* (Sting ray), *Torpedo* (Electric rag), *Raja*.

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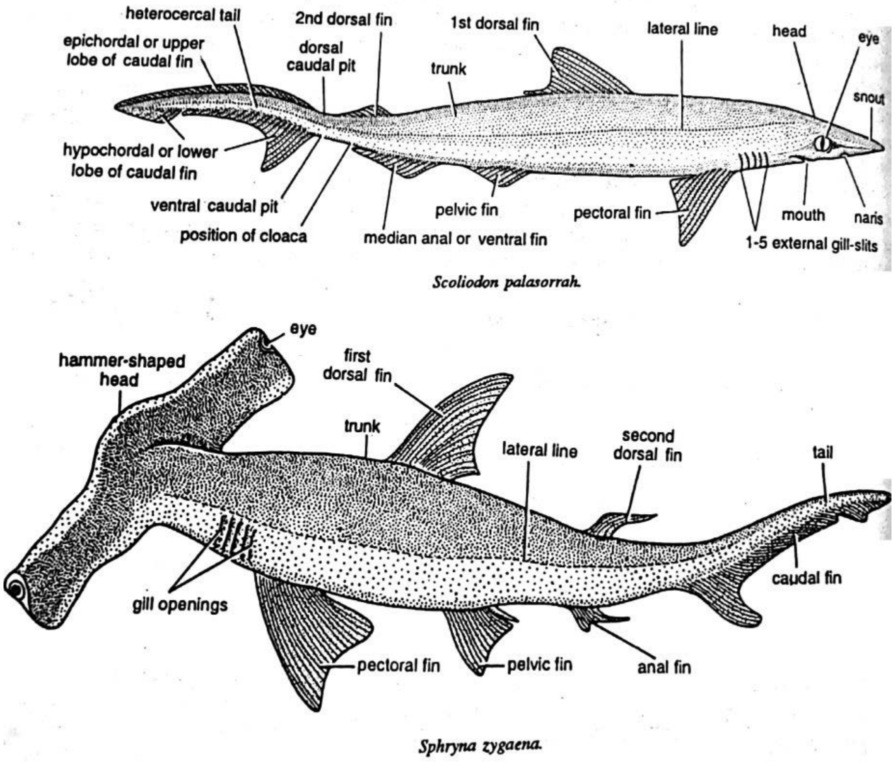

Fig. 2.6 Pleurotrematas (Sharks)

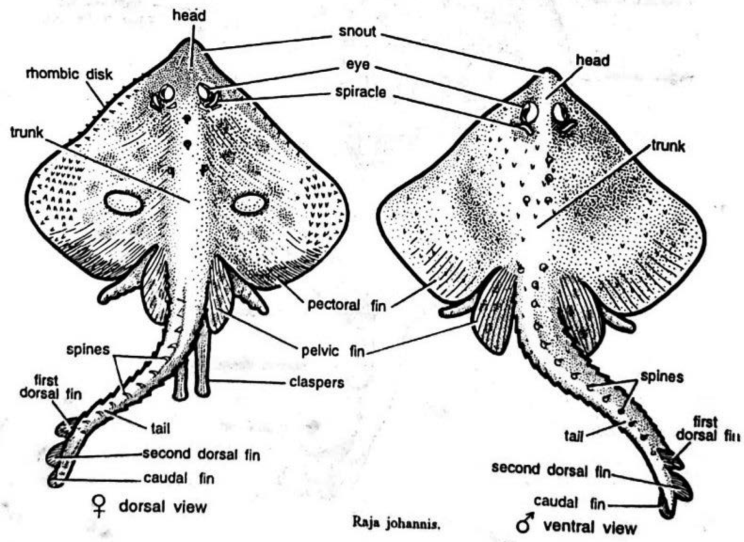

Fig. 2.7 Hypotremata (Batoides): Raja

2.5.2 Holocephali

Holocephali (Gr. *Holos* = entire + *kephale* = head), is a very small ancient group of highly specialized marine fishes. It comprises of rat-tailed fishes. They appeared first in the lower Jurassic and at present, are represented by a few marine genera only. It includes the only cartilaginous fishes having fleshy opercular covering of

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the gills. Like the Acanthodians, they seem to represent divergent and specialized descendants of some primitive elasmobranch ancestor.

General Characteristics of Holocephali

The characteristics are:

- Endoskeleton cartilaginous, often calcified.
- Persistent (unconstructed) notochord; poorly developed vertebrae.
- Holostylic jaw suspension, i.e., the upper jaw is immovably united with cranium, hence the name holocephali.
- Teeth united to form crushing plates, devoid of enamel. This is an adaptation for crushing molluscs, crustaceans and sea urchins.
- The occipital condyles are well developed and are marked better than that of the sharks.
- The gill openings are only four in number and the spiracular cleft is absent. A fleshy operculum, supported by branchial rays, is attached to the hyoid arch and forms covering of the gill openings on each side.
- Median and paired fins are well developed.
- No spiracle; no air bladder; no cloaca.
- Absence of stomach and presence of spiral valve in the intestine.
- Kidney is opisthonephric corresponding fundamental pattern of other fishes.
- Sexual dimorphism is well marked. Females attain larger size than the males.
- Mature male with cephalic or frontal clasper on forehead, a pair of pelvic claspers and a pair of prepelvictenacula.
- Oviparous.Fertilization internal and cleavage holoblastic.

General Organization of Holocephalians

This section describes the general organization of holocephalians.

External Features of Holocephali

The external features are:

- Body appearance is shark-like but the head is large and compressed, having a small mouth.
- Operculum is formed by a fold of skin to cover the gill slits so that a single branchial aperture is found.
- Spiracle and cloaca are absent. Two dorsal and a ventral fin present.
- Tail appears to be heterocercal, but in chimaera, it is whip-like. The pectoral as well as pelvic fins are large in size.
- The anal fin is small. The urinogenital aperture is distinct from the anus.
- Sexes are separate and sexual dimorphism well mark. Females are larger than the males.
- Males having cephalic or frontal clasper on forehead covered with denticles. Skin is smooth and silvery.

- Lateral line system has open grooves, with many branches on head.
- The hyomandibular does not participate in the suspension of the jaw.
- Such suspension is often called holostylic, to emphasize, that it probably evolved independently of that in dipnoans and the tetrapods.
- There are 5 gill arches with four gill openings protected by cover.
- The spiracular cleft is completely closed.
- All the pterygiophores of the first dorsal fin are fused into a single plate, the remaining fins and the pectoral girdle are on elasmobranch pattern.
- Each pelvic half consists of a narrow iliac region and a broad pubo-ischial region.
- A fleshy operculum, supported by branchial rays is attached to the hyoid arch and forms covering of the gill openings on each side.

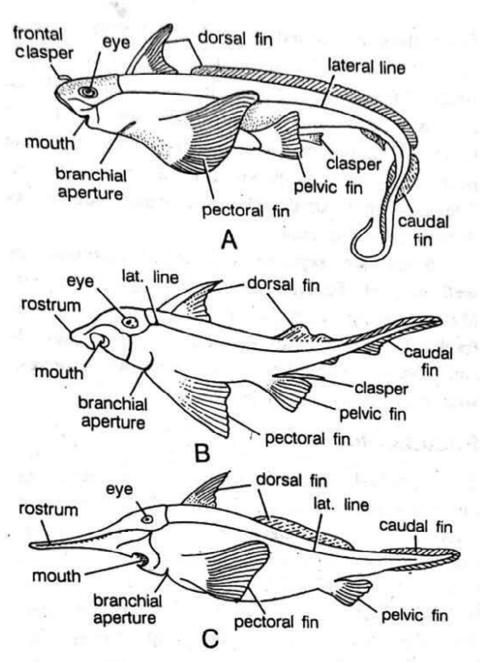

Fig. 2.8 *A. Chimaera B. Callorhynchus C. Harriota*

Fins and Locomotion of Holocephali

- There are two dorsal fins. Usually, the first dorsal has strong spines as in *Chimaera*. Anal fin is small.
- Tail is of ordinary heterocercal type but in *Chimaera* and *Hydrolagus*, it is of isocercal type.
- The paired fins are represented by a set of large pectoral and smaller pelvic fins. Pelvics are abdominal in position.
- The graceful flapping movement of large sized pectoral fins enables the holocephalians to swim by sculling the body in contrast to the swimming of the sharks.

Digestive System of Holocephali

- The mouth in holocephali is small as compared to the wide mouth of elasmobranch.
- It is bounded by three lips-like folds and equipped with the tooth plates having irregular surfaces and sharp cutting edges.
- The tooth plates have reduced pulp cavities and the layer of enamel, replaced by vasodentine.
- Vomarine, palatine and mandibular teeth are present. The gut is straight and a simple tube.
- A short oesophagus opens behind directly into a broad intestine and the latter into a short rectum, opening to the exterior by an anal aperture.
- The true stomach is altogether absent and the intestine has a well-developed spiral valve.

Respiratory System of Holocephali

- A mandibular pseudo branch is absent and the hyoid bears only a posterior hemibranch.
- The first, second, and third branchial arches have holobranchs but the fourth has a hemibranch.
- The fifth arch is gill less and lacks a cleft between it and its predecessor.

Circulatory System of Holocephali

- Heart is built upon the pattern, similar to other fishes.
- The heart consists of a sinus venosus, atrium, ventricle and conus with three rows of valves.
- The holocepalians retain urea in the blood for osmoregulation as in sharks.

Nervous System of Holocephali

- Cerebellum is small. Medulla oblongata is produced laterally into restiform bodies.
- The cerebral hemispheres are small and each is connected with an olfactory bulb by means of a narrow peduncle.
- Diencephalon is long and trough shaped.
- The small rounded pineal body is present at the end of a pineal stalk.

Urinogenital System of Holocephali

- The kidney of holocephalians is opisthonephric having a large number of uriniferoustubules and built upon the basic pattern of other fishes.
- The peritoneal funnels are absent in holocephalians but the abdominal pores are present.
- Unisexual. Clasping organs are remarkable in males only.
- Females attain larger size than the males.
- The male reproductive system consists of testes, vas deferens, epididymis and vesicular seminalis.

- The testes are large oval bodies but contain only immature sperms.
- The sperms become mature in the epididymis and form spermatophores.
- Vesiculaseminalis is divided internally into several chambers by means of transverse septa.

  •The spermatophores are stored in these compartments and are finally released into the urinogenital sinus.
- The female reproductive organs resemble those of the elasmobranchs and consist of apair of ovaries, shell glands and uteri.

Fertilization and Development of Holocephali

- The fertilization is internal and the cleavage holoblastic type.
- The incubation period is fairly long, for example, in *Callorhynchus*, it extends from 9-12 months.
- The holocephalians are oviparous.
- Their eggs are characteristically spindle shaped and are surrounded by horny egg capsules secreted by the shell glands.
- The capsules of Hydrolagus measure about 15 cm and those of Callorhynchuscollei, about 25 cm, in length.
- The eggs are laid in pairs, and contain three compartments.

Sensory Organs of Holocephali

- Holocephalian's eyes are large in relation to the body size, presumably as an adaptation to their total, dark habitat in the deep sea.
- The lateral-line canals are open and are speciallydeveloped on the head and on the underside of snout.
- They differ from those of the elasmobranchs possibly because of a change in the snout's structure or the style of their food detection.
- The membranous labyrinth typically consists of three semicircularcanals.
- The vertical canals forming the crus, also receive the horizontal canal.
- The endolymphatic duct opens externally by a pore.

Affinities of Holocephali

Holocephali occupies a position in between the cartilaginous and bony fishes and have conserved certain of the primitive characteristics from their so-called placoderm ancestors. They show resemblances with the elasmobranchs on one hand and teleosts on the other. They also possess a number of well-defined characters that are peculiar to the group and entitle them to be a separate class.

Resemblances with the Elasmobranchs

Holocephalians show both, the characters of palaeozoic elasmobranchs as well as those of modern living sharks.

a. Primitive Shark's Features of Holocephali:

- The tail is heterocercal.

- A stiff spine along the anterior edge of the first dorsal spine is retained from the ancient sharks.
- Mouth placed ventrally as also in the modern sharks.

b. Modern Shark's Features of Holocephali:

- Skin smooth and silvery.
- Cartilaginous endoskeleton, devoid of any replacing or dermal bones.
- The vertebral column is ancestrous and ribless consisting of a persistent notochord with cartilaginous arches.
- Lack of bony jaws.
- Simplified brain (Diencephalon only elongated due to large sized eyes).
- The general development of chondrocranium.
- A pair of claspers present posterior to the pelvic fins in the male, as in elasmobranchs. Besides these, anterior claspers and the frontal claspers are also present in holocephali.
- The paired fins and girdles are built upon the elasmobranch pattern.
- The tail is heterocercal.
- The nasal and labial cartilages along with the orbital margins of cartilages are present.
- Air bladder is absent.
- A spiral valve is present in the intestine.
- A separate posterior superficial ophthalmic foramen is present.
- The reproductive organs on the elasmobranch pattern.
- The conusarteriosus is present in the heart and contains three rows of valves.
- Urea is retained in the blood for osmoregulation.
- Presence of egg capsule.
- The lateral line canals are distinct and suggestive of the sharks.
- Excretory system on the elasmobranch pattern

Differences from Elasmobranchs

- Holostylic jaw suspension.
- No spiracle.
- Presence of skinny operculum.
- Extra pelvic clasper and cephalic clasper in male.

Resemblances with Dipnoi

- Nature of skull.
- Unconstricted notochord.
- Presence of crushing tooth plates.

Resemblances with Teleosts

- An operculum is present so that the gills do not open directly to the exterior but into a common chamber situated beneath the operculum.
- Single external branchial chamber is present.
- Reduced interbranchial septum, allowing gill filament to project beyond it.
- Spiracle is absent.
- Cloaca absent.
- Four complete aortic arches serving the four gill openings.
- The urinogenitalaperature lies behind the anus so that there is no cloaca.

Resemblances with Placoderms

Holocephalians show close relationship with some placoderms like- *Rhamphodopsis* and Ctenurella in the following points:

- Presence of a large labial cartilage.
- Presence of large tooth plates.
- Presence of long tail.
- Presence of a pair of rostral process to support fleshy snout.
- Presence of pre-pelvic claspers in male.
- Presence of short and deep platoquadrate.

a. Primitive Characteristics:

- Cartilaginous endoskeleton.
- Persistent notochord with cartilaginous arches.
- Separate external openings for each gill slit.
- Large opercular covering of the gill slits.

b. Specialized Features:

The Holocephaliposses some characters that are peculiar to the groups. These are:

- The skull is holostylic, the palatoquadrate is fused with the cranium. Neither the skull nor the Jawsare attached to the hyoid arch. This is probably an adaptation due to large size of the dental plates.
- The dentition is peculiar consisting of large plates. Teeth are not covered by enamel but a layer of vasodentine is present. The pulp cavity is reduced. The dental plates form a parrot like beak.
- The gill opening is covered by an opercular flap, and there is no spiracle.
- Presence of unusual frontal claspers on the head and in front of the pelvic fins.
- Absence of scales.
- A rostrum is present.

Thus, it may be concluded that the holocephali are the descendants of some primitive form of shark with unconstructed notochord. They gradually become specialized by the loss of scales, spiracles and the cloaca, and acquired extra claspers in the male. A fixed upper jaw with strong dental plates and the presence of an operculum may also be considered as specialized features of this group.

Check Your Progress

8. Name two main classes of condricthyes.
9. Define holocephali.
10. What kind of fertilization and cleavage does holocephalic organisms possess?

2.6 OSTEICHTHYES: DIPNOI AND CROSSOPTERYGII

Osteichthyes, generally known as the bony fish, is a diverse taxonomic group of fish with skeletons predominantly made of bone tissue. They differ from the chondrichthyes, which have skeletons made primarily of cartilage. The overwhelming majority of fish are members of the osteichthyes order, which includes 45 orders, 435 families, and 28,000 species. It is the most diverse group of vertebrates on the planet today. The ray-finned fish (*Actinopterygii*) and lobe-finned fish (*Sarcopterygii*) are two types of osteichthyes. Bony fish fossils date back to around 420 million years ago, and they're transitional fossils with a tooth pattern that's halfway between shark and bony fish tooth rows.

2.6.1 General Account of Dipnoi

Dipnoi (Greek: di-two, pnoe-breathing) is a small order of freshwater bony fishes. They breathe through their gills and lungs. During the Devonian epoch, Dipnoi evolved. Narrow jaws, crushing plate-like teeth, internal nares, a shortened exo- and endo-skeleton, and a diphycercal tail distinguish them. There are one or two functional air bladders, also known as 'lungs'. As a result, there are changes in the circulatory system and the heart.

Dipnoi Distribution

The distribution of modern lung fishes is discontinuous. Neoceratodus (=Epiceratodus), Protopterus, and Lepidosiren are the three lung fish genera that have survived. All of them are river dwellers.

- Neoceratodus is the sole extant genus in the ceratodontidae family, with ceratodus being extinct. It is known as 'Burnett Salmon' or Australian lungfish since it is only found in the Burnett and Mary rivers of Queensland, Australia.
- Protopterus can be found in tropical Africa's huge lakes and rivers. It's also known as the 'Nile lungfish' or the 'African lungfish.'
- Lepidosiren can be found in South America, in the Amazon River and the Paraguay River Basin. It's also known as the 'Amazon lungfish' or the 'South American lungfish.'

Dipnoi's Primitive Characteristics

Its primitive characteristics include:

- A notochord that is not constrained.
- Cloaca is present.
- Spiral valves in intestine.
- Valves in the conus.
- Diphycercal tail
- The inferior nostril on the ventral side.
- A persistent notochord that is not constricted in any way.
- Autostylic cartilaginous skull

2.6.2 General Account of Crossopterygii

Crossopterygii is one of the two primary divisions of the lobe-finned fishes is the infraclass of bony fishes (class Osteichthyes), often known as fringe-finned fishes (Sarcopterygii). The group initially appears as fossils in the Early Devonian period, and they were generally small to medium-sized predatory fish that lived in shallow tropical seas, estuaries, and fresh waters during the Palaeozoic period. There were two principal groups: a diverse set of fishes, Rhipidista and the Coelacanthini. Their main radiations occurred in the Devonian period, and they were rapidly declining by the Mississippian period. By the Middle Permian, the Rhipidista had been extinct, but the coelacanths had undergone a second, lesser Mesozoic radiation, and one of the most famous lobe-fins of all, Latimeria chalumnae, had survived to the current day. The skull of crossopterygii has a unique hinge that allows the front half of the skull to be lifted and lowered during feeding and breathing motions.

The Crossopterygii have paired fins that act as support against the water's floor and are made up of muscular paddles with a skeletal axis of multiple penicillate segments that resemble the bones of quadrupeds' extremities. Two small dorsal fins are present. The body axis continues into a short third lobe of the caudal fin in several crossopterygii. The anterior and posterior sections of the inner cranium are more or less moveable in relation to one another. The brain takes up a small portion of the cranial cavity (around 1/100 of the volume in Latimeria). The notochord is preserved and reaches the posterior end of the anterior part of the cranium, but the vertebrae are normally in the shape of a ring or half-ring. Extinct creatures have bodies up to 5 metres long. All of the group's members are predators.

2.7 INTEGUMENTS AND ITS DERIVATIVES IN THE VERTEBRATES

Integument is the means of identifying the organism, and it also defines the boundary of its body. The integument consists primarily of the skin and its derivatives. Skin is also the primary means through which an organism interacts with its environment.Because of its importance as the primary interface between an organism and its environment, the skin is designed to perform many functions. These functions include:

- Support and protect soft tissues against abrasion, microbe
- Reception and transduction of external stimuli, i.e., heat, chemical, tactile
- Transport of materials involved in excretion, secretion, absorption, dehydration, rehydration
- Heat regulation
- Respiration
- Nutrition/nutrient storage, i.e., storage of vitamins, synthesis of Vitamin D
- Locomotion
- Coloration - cryptic or display

2.7.1 Basic Structure of the Integument

Skin is a functional unit composed layers of fairly distinct epidermis (derived from ectoderm) and dermis (derived from the dermatome of somites) that are separated by the basement membrane

Epidermis

The characteristics of epidermis are:

- It is relatively thin in most animals.
- The upper layer composed of mostly dead, differentiated cells (stratum corneum) with a lot of keratins which helps the skin maintain some protection against water loss and bacteria.
- Continually produced by the most basal layer of the epidermis (stratum germinativum) and consists of cuboidal cells that are generalized and move toward the upper layer as they differentiate.
- As the cells move outward, most synthesize keratin, a water-insoluble protein, the cells become flattened, die, and are sloughed off. Other epidermal cells form multicellular glands or isolated glandular cells.

Dermis

The features of dermis are:

- It is more of a connective tissue than protective.
- Irregularly-shaped connective tissue cells that produce the extracellular matrix, including collagen and elastic fibers.
- The upper layer (stratum laxum) lies directly below the basement membrane and is mostly loosely-packed cells.
- The stratum compactum lies below and contains more tightly-packed cells.
- The presence of elastin in the dermis is a synapomorphy of gnathostomata - in part, the dermis anchors the skin to the underlying musculature.
- Also includes dermal scales, blood vessels, nerves, pigment cells, the bases of feathers and hairs, and their associated erector muscles.

Both layers of integument have given rise to various types of derivatives. The epidermis gives rise to integumentary glands, epidermal scales, horns, digital structures, different corneal structures, feathers, and hairs. The dermis forms dermal scales of fishes and of some reptiles, plates or scutes in reptiles, fin rays in fishes and antlers in mammals.

2.7.2 Epidermal Derivatives

Epidermal derivatives are epidermal glands (unicellular and multicellular), epidermal scales and scutes, horns, digital structures (claws, nails and hoofs), feathers and hairs.

Epidermal Glands

These are formed from the malpighian layer of the epidermis. They arise from the epidermis and often penetrate the dermis. These are lined by cuboidal or columnar cells. According to their structure they are unicellular or multicellular:

(a) Unicellular Glands:

These are single modified cells found among other epithelial cells and are found in amphioxus, cyclostomes, fishes and larvae of amphibians. Unicellular glands are known as mucous cells or goblet cells that secrete mucus (protein mucin with water) which lubricates the body surface. Other unicellular glands are granular cells and large beaker cells of cyclostomes and fishes, they also secrete mucus.

(b) Multicellular Glands:

These are of two types:

- **Tubular Glands**: These are multicellular tubes of uniform diameter formed as ingrowths of the malpighian layer into the dermis, e.g., glands of Moll on the margin of the human eyelids. Tubular glands may become coiled at the base deep in the dermis, e.g., sweat or sudoriferous glands of mammals, or they may divide into many tubules which are then called compound (branched) tubular glands, e.g., mammary glands of females and of males in monotremes and primates, etc., and gastric glands in stomach.
- **Alveolar or Saccular Glands**: These are multicellular down growths of the malpighian layer into the dermis, having a tubular duct whose terminal end become flask-shaped, e.g., mucous and poison glands of amphibians. Alveolar glands may branch into many lobules which finally open into a common duct, they are then called compound alveolar glands, e.g., mammary glands of eutherians, and salivary glands.

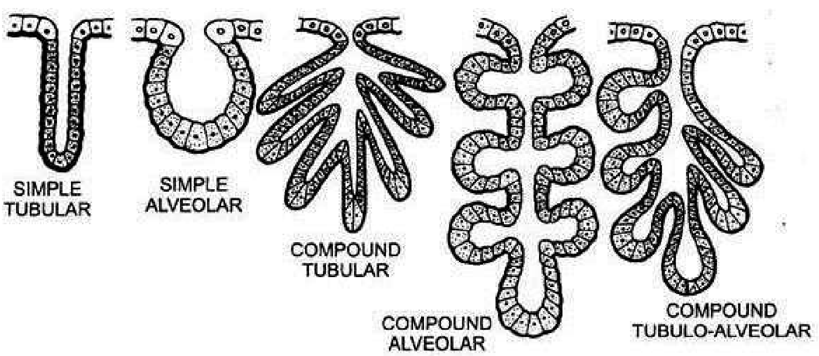

***Fig. 2.9** Different Types of Epidermal glands*

According to function, the epidermal glands of vertebrates are of the following types:

(a) Mucous Glands: They may be unicellular or multicellular. The unicellular glands are mucous gland cells, granular cells and beaker cells of amphioxus, cyclostomes and fishes. They secrete mucus which keeps the skin moist and slippery, and also affords protection against bacteria and fungi. Mucous cells and granular cells lie near the surface, but the beaker cells lie more deeply and extend from the malpighian layer to the surface. Multicellular mucous glands are alveolar and found all over the body surface of some fishes and amphibians. They produce mucus for lubricating the skin and in amphibians they keep the skin moist to help in respiration.

(b) Poison Glands: Amphibians also have alveolar poison glands which are larger but less than mucous glands. In toads, parotoid salivary glands (present behind the head) modified into poison glands. The secretion of poison glands has a burning taste and is used as a defence. Caecilians have giant poison glands. Some tubular glands are found on the feet and suctorial discs of tree frogs which help in climbing. Tubular glands are also found on the swollen glandular thumb parts of male frogs and toads during the breeding season. They help in clasping the female during copulation.

(c) Luminescent Organs or Photophores: They are found in longitudinal rows near the ventral side of the body in those fishes which live in deep sea where light do not penetrate. Each photophore is a group of epidermal cells lying in the dermis and has a lower layer of luminous cells below which is a layer of reflecting pigment cells, and the upper layer of mucous cells forms a lens. The glandular cells produce phosphorescent light which is transmitted to the outside by other cells. The light helps to attract the prey of deep-sea fishes.

(d) Femoral Glands: Femoral glands are found in male lizards (e.g., Uromastix) below the thighs in a row from the knee to the cloaca. They secrete a sticky substance which hardens into short spines that are used for holding the female during copulation.

(e) Uropygial Glands: These are the only glands in birds, and they are best developed in aquatic birds. Uropygial glands are branched alveolar glands located on the dorsal side at the base of the tail or uropygium in the form of swelling. They secrete an oil which is odoriferous and attracts the opposite sex. The oil contains pomatum which is picked up with the beak and used for preening and water-proofing the feathers.

(f) Sweat Glands: The largest number and variety of epidermal glands are found in the skin of mammals. They are tubular or alveolar and multicellular. Sudorific or sweat glands are long, coiled tubular glands embedded deep in the dermis. Their upper part forms a duct which opens on the surface by a pore and the lower coiled part lies in the dermis surrounded by a network of blood capillaries.

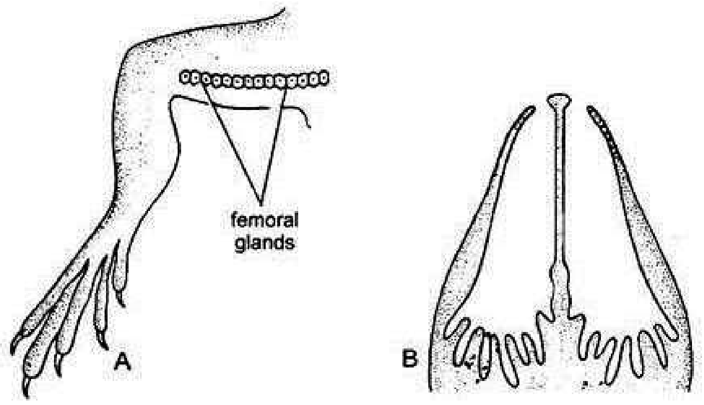

Fig. 2.10 *Epidermal Glands:* ***A.*** *Femoral Glands of Lizard* ***B.*** *Uropygial Glands of Bird*

Sweat is secreted by sweat glands continuously, may or may not be visible. Sweat contains a large amount of water having dissolved salts of sodium, potassium and urea. Sweat removes some metabolic wastes and regulates the body temperature by evaporation. Sweat glands are not uniformly distributed. In man they are more numerous on palms, soles, and arm pits. In cats, rats, and mice they are confined to the soles of the feet. In rabbit they are around the lips; in bats on the sides of head; in ruminants on the muzzle and the skin between the digits and in hippopotamus they are found only on the pinnae. Sweat glands are absent in Tachyglossus, Sirenia, and Cetacean's mammals. In some mammals the secretion of sudorific glands is red coloured. In hippopotamus it is red and spreads on the head and back. The male giant kangaroo, *Macropusrufus* secretes red sweat. Modified sudorific glands form glands of Moll in the margins of the human eye in connection with eye-lashes.

Ceruminous glands of external ear of mammals are modified sweat glands and secrete a waxy substance which combines with the secretion of sebaceous glands to form earwax which catches dust. Oil glands form ceruminous glands in the external ears of some gallinaceous birds.

(g) Sebaceous Glands: Sebaceous glands are alveolar glands opening in hair follicles containing hairs. They also independently open at the skin surface around the genital organs, tip of the nose, and edges of the lips. Sebaceous glands secrete an oil (sebum) to lubricate the hairs and also cover the skin with a film of oily coating. The oily secretion of sebaceous glands contains waxes, fatty acids, and cholesterol, which makes the skin pliable. Sebaceous glands are absent in *Manis* (pangolin), and Sirenia, and Cetacea which practically have no hairs. Modified sebaceous glands form Meibomian glands in the eyelids, each has a long straight duct into which separate alveoli open. They produce an oily secretion which forms a film over the lacrimal fluid or tears holding them evenly on the surface of the eyeball for keeping the eye moist, in weeping the oily film are broken and tears flow out. Ceruminous glands of external auditory meatus are modified sebaceous glands. Their greasy or waxy secretion, called the cerumen traps the insects and dust particles.

(h) **Scent Glands:** Scent glands are modified sebaceous glands or sweat glands andtheir secretion act as attractant to the opposite sex. These are found in head near eyes in deer, around anus in Skunks and carnivores and pigs and between their toes in goats.

(i) **Preputial Glands:** These are found in many kinds of mammals. In beaver (a rodent of North America), large sacs containing a secretion known as castoreum lie beneath the skin on either side of penis and open by ducts into the prepuce.

(j) **Mammary Glands:** These are characteristic of mammals. They secrete milk generally in the females for nourishment of the young. In monotremes both sexes may secrete milk, this condition is called gynaecomastism which is not a normal condition. Mammary glands of monotremes are compound tubular glands, while in other mammals they are compound alveolar. Mammary glands of monotremes have no nipples, they open into pits on the surface of the skin, and the young ones obtain milk by licking tufts of hairs. In others the mammary glands open by their ducts separately into a nipple. Mammary glands along with fat form integumentary swellings called mammae or breasts. The number and location of mammae varies in different mammals. The number ranges from two in many mammals to 25 in opossum. Mammae may run along two ventral milk lines from the arm pits to the groin, or they may be axillary, thoracic, abdominal or inguinal in position.

Epidermal Scales and Scutes

The skin of vertebrates is rarely naked, and it is usually provided with protective scales, bony plates, feathers or hairs. There are no epidermal scales in fishes and amphibians. They appear for the first time in reptiles. They are cornified derivatives of the malpighian layer and are generally shed and replaced. The scleroprotein called the keratin is continually accumulated in the permanently growing layer of the epidermis called the stratum germinativum.

The stratum corneum cells become dead, cornified and form hard horny structures, such as scales and scutes in reptiles, beaks, claws, horns, nails, hoofs, feathers and hairs in different vertebrates. Scales are most noticeable on lizards and snakes. They are continually being produced by the permanently growing layer of the stratum germinativum and are generally folded so as to overlap one another. When they are fully grown, they become separated from the stratum germinativum and appear as non-living, cornified structures.

The epidermal scales form a protective covering (armour) of the body. The scales in snakes and lizards are continuous and undergo ecdysis periodically. Before ecdysis, the new scales that will replace the old ones are formed. The entire corneal layer of scales is shed as whole in snakes. The old epidermal covering becomes loosened first in the head region.

This skin, including even the transparent plates over the eyes, is turned back and the snake finally crawls out of the old covering, leaving the old covering inside out. The scales on the ventral side in most snakes differ from their other scales in being long and transversely arranged, they help in locomotion.

Turtles and crocodiles have different kinds of scales which do not overlap, nor undergo periodic ecdysis, but the scales are gradually worn off and replaced. Large epidermal scales, such as those on the shell of turtles and on the head of snakes, are generally called scutes. In birds the scales are confined to the shanks and feet and some at the base of the beak.

They generally overlap as in snakes and lizards. In mammals epidermal scales are found on the tail and paws of rats, mice, beavers, musk rats and shrews. These scales are not much cornified, nor do they undergo ecdysis; hairs project from beneath the scales. In scaly ant-eaters large epidermal scales cover the entire body, except the ventral side, the scales are reptilian and undergo ecdysis singly.

In armadillos there are large scales which fuse to form plates on the head, shoulders and hips; in the middle of the body, except mid-ventrally, the scales fuse to form ring-like bands; these scales do not undergo ecdysis but are gradually worn off and replaced.

Some epidermal scales of the tail of a rattle-snake are modified to form a rattle. It consists of a series of old dried scales. Rattles of rattle snakes represent horny remnants of the skin which adhere to the base of the tail and are not lost during ecdysis.

During ecdysis the scale at the tip of the tail is not shed and it forms a ring. Thus, after several ecdysis a series of rings form a rattle, each new ring being larger than its predecessor. In older rattle snakes the terminal rattles are often lost. In tortoises and turtles, the dermal plates forming the carapace and plastron are covered externally with cornified epidermal scales.

These are not shed regularly like lizards and snakes. A few turtles lack scales and have a leathery skin. The bodies of alligators and their relatives are also covered with epidermal scales which gradually wear off and are replaced.

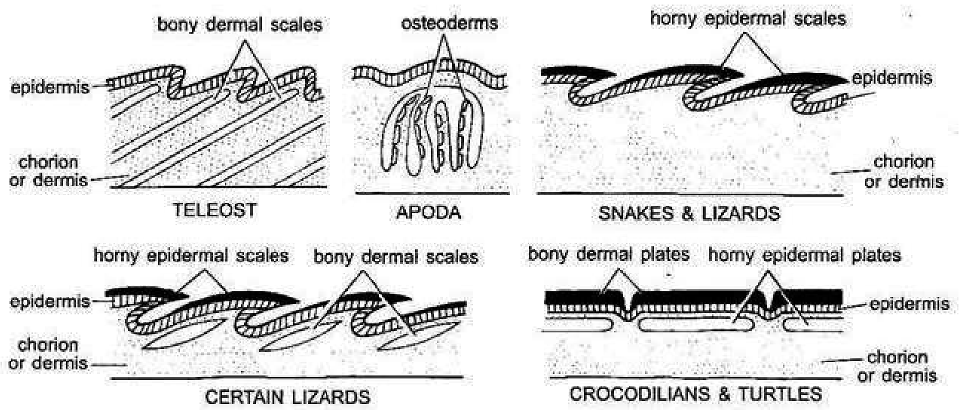

Fig. 2.11 *V.S. of Skin of various Vertebrates showing relationship between various types of scales*

In turtles, tortoises and modern birds there are no teeth. Each jaw bone being covered with horny sheath formed of several fused plates or scales which form a beak. In monotremes, there is a soft bill which differs from the beak of birds is not being covered with modified epidermal scales.

Horns

Horns are found in ungulate (even-toed hoofed) mammals only. True horns are hollow and are found in pronghorn, cattle, antelope, sheep and goats that consist of an inner core of bone, an outgrowth of the frontal bone. It is encased in a keratinized, epidermal covering. True horns continuously grow throughout life and are not shed. The types of horns are:

(a) Rhinoceros or keratin fibre horn has no skeletal element. It is made by keratinized cells of the epidermis and consists of matted keratin fibres bound together, but its fibres are not true hair. It is a permanent epidermal structure and if broken it grows again. There is one horn in the Indian rhinoceros and two in the African species.

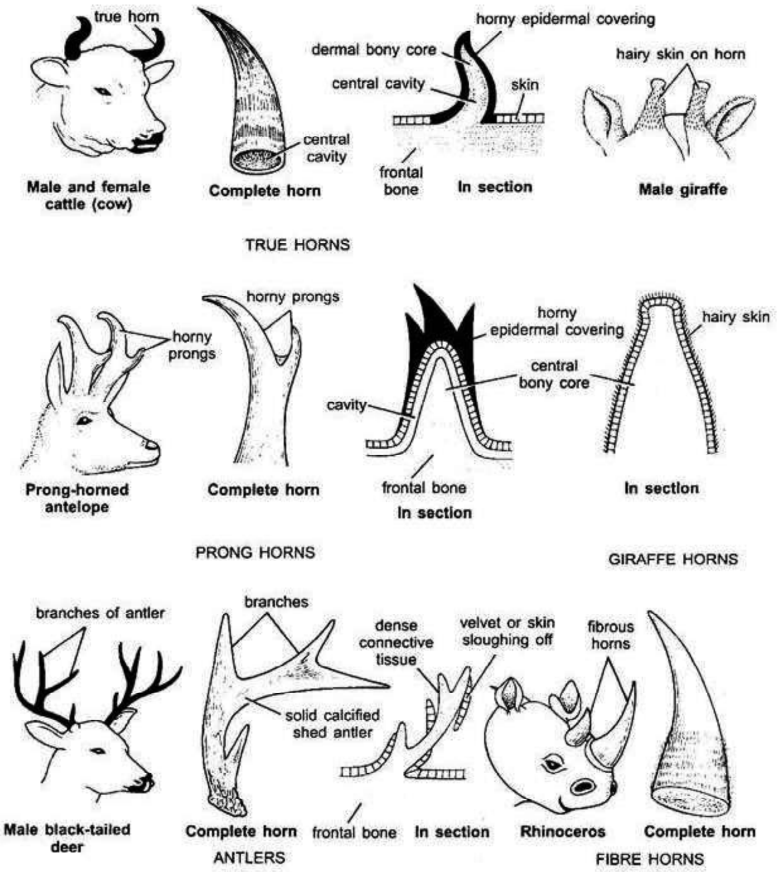

Fig. 2.12 *Types of Mammalian Horns and Antlers*

(b) Pronghorn is a true horn, consists of a permanent projection of the frontal bone covered by a hard, horny epidermal sheath. The sheath is forked bearing one to three prongs made only of horny sheath. The horny sheath is shed annually and is replaced by another which grows from the skin that surrounds the core. It is found in Russian antelope *Antilocapra*.

(c) Giraffe horns develop from cartilaginous protrusions which are present at birth. They ossify and fuse at the top of the skull, where they appear as knobs permanently covered with living skin and hair. Giraffe possesses three knobs, of these three knobs, one is median and anterior to the other two knobs. These horns are short, unbranched and are permanent, and are present in both sexes.

(d) Antlers are found in the male antelopes (deer family), but they are present in both sexes in reindeer and caribou. Antlers are solid mesodermal bone, but they are formed under the influence of the integument. It consists of a branching solid outgrowth of frontal bone formed of dense connective tissue. It is covered during growth by hairy, vascular skin called 'velvet'. The velvet is shed exposing the antler naked when the antler reaches full growth. Thus, the antler consists only of dermal bone. The bony antler is also shed annually after the breeding season, and a new antler develops. Formation of antlers is controlled by the hormones of testes and anterior lobe of the pituitary.

Table. 2.3 *Difference between Antlers and Horns*

Antlers	Horns
• Antlers are outgrowths over the head of artiodactyls.	• Same
• Antlers are found only in Cervidae, but absent Asiatic genera *Moschus* and *Hydropotes.*	• Horns (hollow) are found in Bovidae and in Antilocapridae in modified form
• Normally present in males except *Rangifer*.	• Commonly occur in both sexes but generally larger in males.
• Shed annually.	• No shedding and if it occurs only outer sheath is shed.
• Antler is made up of bone and covered by velvet (Skin + hair).	• Horn consists of inner core of bone, an outgrowth of frontal bone covered over by keratinized epidermal covering.

Digital Structures

In amniota the distal ends of digits have claws, nails or hoofs formed from the horny layer of the epidermis. They grow parallel to the surface of the skin and are built on the same plan.

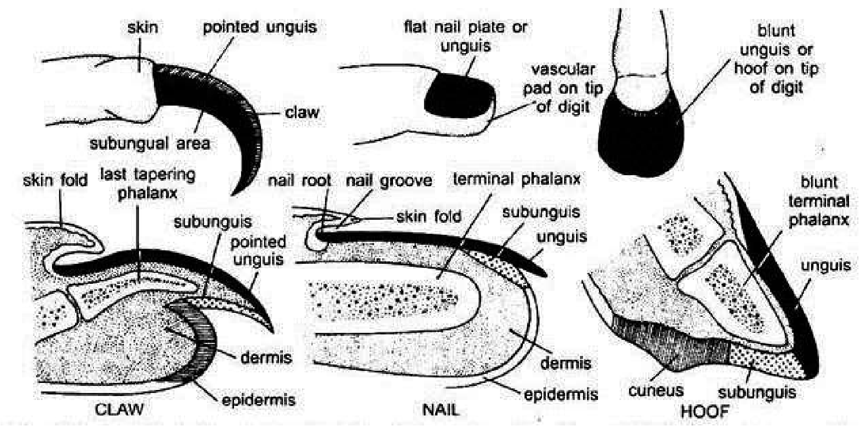

Fig. 2.13 *Relation between Claw (eagle), nail (human) and hoof (horse). Digital Tips Show Complete above and in Sagittal Section Below*

(a) Claws: Claws were first appear in the reptiles. It is made of a hard horny dorsal scale like plate called unguis and a relatively soft ventral subunguis, both converge terminally and cover the terminal part of the last phalanx.

Claws of reptiles and birds are similar but in mammals the subunguis is much reduced and is continuous with a pad at the end of a digit. In cat family claws are retractile.

(b) Nails: They are found in primates. The dorsal unguis is large and flat and subunguis is soft and much reduced. Tip of the digit forms a sensitive and vascular pad over which the nail groove is present. It is formed by the invagination of epidermis. Growth of the unguis takes place from the nail root lying below the skin in the nail groove.

(c) Hoofs: They are found in ungulates. The horny unguis is thick and around the end of the digit, and encloses the thickened subunguis which touches the ground. Subunguis surrounds the soft, horny cuneus. Tip of digit, thus, forms a pad containing a blunt phalanx. Nails and hoofs of mammals are modified claws. Whalebone plates of toothless whales are also the modification of stratum corneum.

Feathers

Feathers are found only in birds and are formed from the epidermis in which the stratum corneum is highly specialized. Feathers are light, strong, elastic, waterproof and show many colours due to pigments (carotenoids and melanins) and structural arrangement. Carotenoids (zooerythrin- animal red; zooxanthin- animal yellow) are frequently called lipochromes which are soluble in fat solvents like methanol, ether or carbon disulphide, and insoluble in water. Melanins are soluble only in acids. Eumelanin granules vary from black to dark brown and phaeomelanin granules may be almost colourless to reddish brown.

Many of the feather colours are the product of both carotenoids and melanin. They form a protective covering (conserve body heat), provide buoyancy to the water birds during swimming and at rest, regulate body temperature and support the body in flight. Three types of feathers (contour feathers, down feathers, and filoplumes) are found in birds. The development of feather is like that of scales.

Shedding and replacement of feathers is known as moulting which takes place gradually, one moulting usually takes an average time of six weeks. At the base of each feather follicle a dermal papilla persists from which new feathers will form, so that there is a continuous replacement of feathers throughout life. The replacement in some birds is seasonal, while in others it is gradual throughout the year. Feathers of birds show varied and often brilliant colourations.

Hair

Hair is found only in mammals. It projects from the skin and covers the entire integument in most (furred mammals), but in others only traces are left, such as, whales have only a few core hairs on the snout. During development the body of the embryos of all mammals is covered with a coating of fine hair called lanugo which is usually shed before birth and replaced by a new one. Hair is entirely epidermal in origin.

Structure of Hair

Hairs are not modified scales but are new outgrowths of the epidermis only. A hair has an upper projecting shaft and a lower root lying in a hair follicle which is a sunken pit in the dermis. The shaft is made of only dead, keratinized cells. The part of the hair protruding above the skin is dead.

At the base of the follicle the root is expanded into a bulb and growth of the hair takes place only in the root where the cells of the malpighian layer divided actively. Below the bulb is a dermal papilla having connective tissue and blood vessels, which nourishes the hair. Beyond the bulb the cells gradually die so that the shaft is made of dead cornified cells.

The hair shaft has an external cuticle of transparent overlapping cells which have lost their nuclei, inside the cuticle is a cortex (middle part of hair) containing shrivelled cells and pigments, and a central core or medulla having air spaces. In the follicle the hair root is surrounded by two layers of hair sheath cells forming an outer and inner root sheath. They do not extend beyond the follicle. A sebaceous gland opens into the upper part of the hair follicle for oiling the hair.

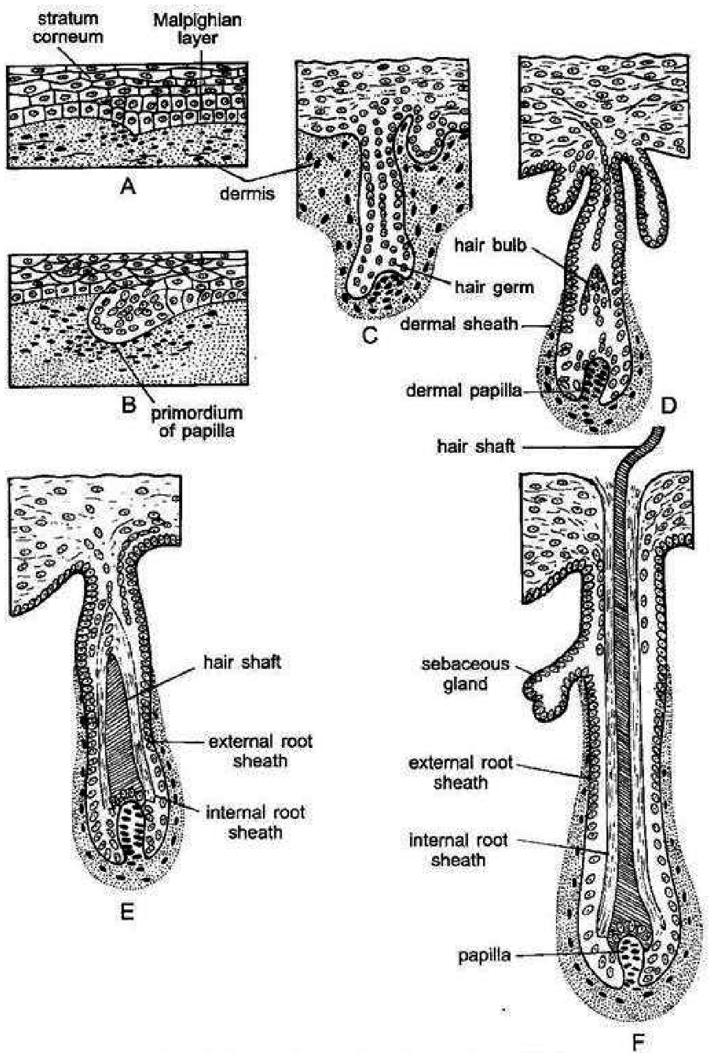

Fig. 2.14 *Developmental Stages and Structure of Hair.*

An arrector pili muscle composed of smooth fibres extends from the upper part of the dermis to the basal part of the hair follicle on the side towards which the hair slopes. It pulls the hair base causing the hair to stand when an animal is confronted with danger. Hair does not project vertically but at an acute angle from the skin.

Development of Hair

A thickening of the epidermis (stratum germinativum) pushes into the dermis and becomes cup-shaped at its lower end. The dermis extends into the cup forming a hair papilla which has blood vessels for supplying nourishment. The epidermal down growth which at first is a solid cord of cells now splits to form a central shaft of cornified keratinized cells, and a space around it.

The epidermal cells around the space form the hair follicle. The lower part of the hair follicle becomes swollen and is known as a bulb. The cells of the follicle thickened and bud off a sebaceous gland. The central shaft by addition of new keratinised cells from the root grows in length and pushes through the solid epidermal cells to emerge outside the skin.Thus, the development of hair differs from that of a feather. It is formed entirely from the solid column of epidermis, while in the feather there is a mesodermal feather pulp extending into the hollow quill.

The hairs trap air which does not transmit body heat and, thus, act as insulators for the body. In some animals the colours of hair are protective. Hair in nostrils and ears prevent entry of dust, eyebrows and eyelashes protect the eyes, vibrissae are delicate organs of touch (act as tactile organs), hairs on the tail are used to drive away insects. In some animals, such as lions and some monkeys the mane distinguishes the male. Hairs are also modified in spines, scales, horns, etc., in some mammals.

2.7.3 Dermal Derivatives

In this section we will discuss some of the dermal derivatives.

Scales

The scales arise from the dermis and are, thus, mesodermal in origin, they are found only in fishes, some reptiles and a few mammals. Ostracoderm fishes, the earliest known vertebrates, had an armour of large bony plates. These bony plates became very small in placoderms to give rise to cosmoid scales which are not found in any living forms today (except in Latimeria).

Cosmoid scales were also present in primitive choanichthyes and composed of four distinct layers, the lowest layer is of isopedine or dentine resembled compact bone, the next layer was a spongy bone with vascular spaces consisting of pulp cavities having odontoblasts, the third layer was of hard compact cosmine with canaliculi and the outermost layer was thin but hard vitrodentine or enamel.

Ganoid scales are the other type of scales found in earliest primitive bony fishes. This implies that two different lines of evolution with regard to scales appeared very early in the history of fishes. A ganoid scale has a basal layer of isopedine, above which there may be a reduced cosmine layer or it may be absent and the uppermost layer is made of a hard, translucent substance called ganoin. Ganoid scales with a reduced cosmine layer are found in *Polypterus*, and with no cosmine in *Lepidosteus*.

NOTES

The evolution of the ganoid scale by the loss of its upper layer of ganoin gave rise to a thinner leptoid scale which are two types: cycloid and ctenoid scales. In the other line of evolution, the cosmoid scale lost its three lower layers, only the fourth enamel like dentine layer was retained and somewhat elaborated to form the placoid scale. Thus, in the present fishes there are four types of dermal scales:placoid, ganoid, ctenoid and cycloid scales.

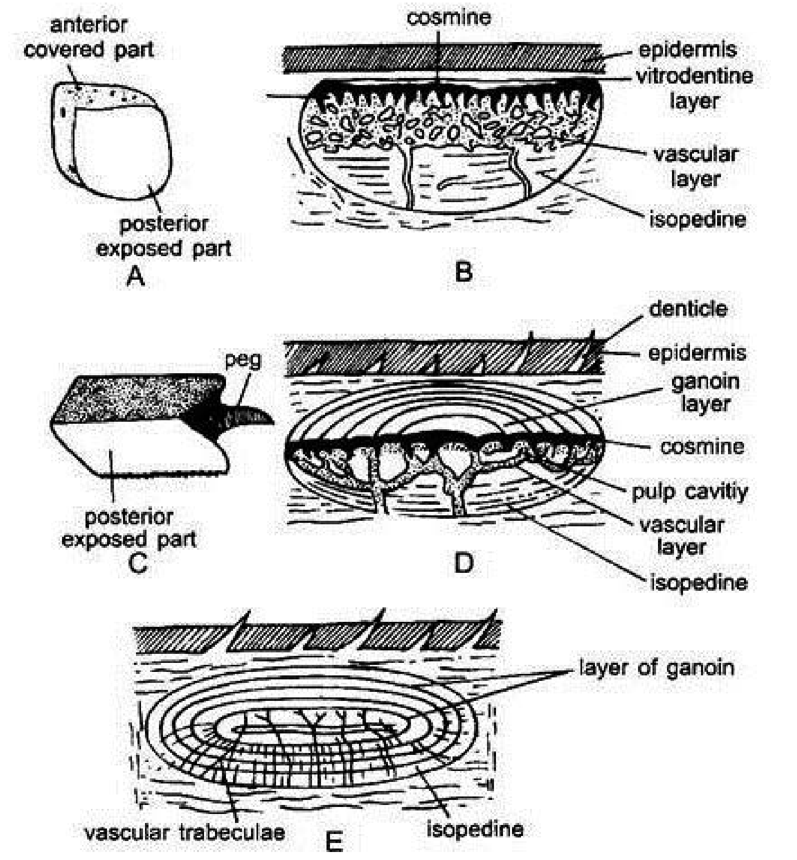

Fig. 2.15 *Structure of Scales of Fishes. A: An Isolated Scale; B: T.S. of Cosmoid Scale; C: An Isolated Ganoid Scale; D: T.S. of Palaeoniscoid Scale; E:T.S. of Lepidostoid Scale*

Embedded in the dermis of elasmobranchs in oblique rows and projecting from the epidermis are dermal denticles of placoid scales forming an exoskeleton. The placoid scales were evolved by loss of some layers from the cosmoid scales. Placoid scales are found only in elasmobranchs, in sharks they are very small and give the skin a rough texture, but in skates they are large.

Structure of Scales

A placoid scale has a flat bony basal plate bearing a trident spine which projects above the epidermis and points backwards. Inside the spine is a pulp cavity containing pulp made of connective tissue, blood vessels, and a layer of odontoblast cells. The basal plate is made of calcified dentine, and the spine has mostly dentine which is covered with a cap of hard modified dentine called vitrodentine and not enamel. The basal plate and spine are both of mesodermal origin. The cured skin of sharks containing placoid scales is called shagreen which is used for polishing and for handle covers. In bony fishes there are two kinds of leptoid scales- cycloid and ctenoid scales. They have a thin layer of bony isopedine below which is a thin layer of connective tissue.

Cycloid scales are round, thick in the centre and thin towards the margins. They have a lower layer of fibrous connective tissue and an upper layer of bone-like isopedine which is elaborated to form dentine. They show concentric lines of growth which indicate the age of the fish. The scales lie embedded in the dermis diagonally overlapping each other.

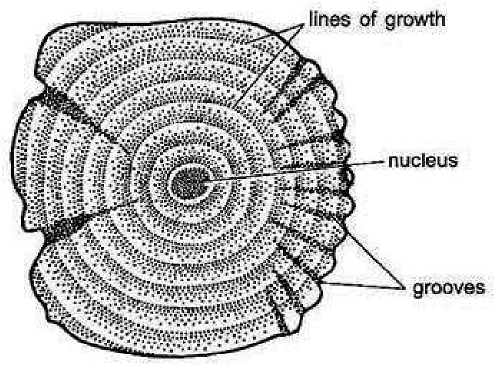

Fig. 2.16 *Cycloid Scale*

The posterior part of each scale overlapping the anterior part of the scale behind, thus, covering the body with a double layer of scales. The exposed part (posterior) has a smooth edge, while the concealed part may have a wavy margin. Cycloid scales form a dermal exoskeleton in many bony fishes.

Ctenoid scales probably arose from the simpler cycloid scales. They have the same shape, structure and concentric lines as the cycloid scales, but they differ in having small teeth or cteni on their free posterior part. Their anterior concealed part may have notched or scalloped margin. Ctenoid scales form a dermal exoskeleton of most bony fishes.

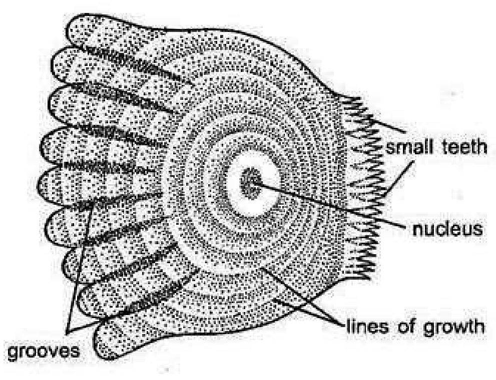

Fig. 2.17 *Ctenoid Scale*

The cycloid or ctenoid scales covering the lateral line canals are perforated by a vertical tube of the lateral line opening on the surface. In some flat fishes' grooves both cycloid and ctenoid scales are present. In some catfishes there are no scales, in eels' scales are very small and embedded in the dermis. In sea-horses scales form a continuous armour covering the body. Scales of bony fishes arise only from dermis; they form a protective exoskeleton but do not hamper movement.

The earliest tetrapod's had dermal scales are known as bony plates or osteoderms which probably functioned as armor. In living amphibians (Apoda)have only tiny dermal scales or vestiges of osteoderms are present. They are found in pockets below the epidermis and are not visible externally. Their homology with dermal armor is not clear.

Amphibians mark the transition between the aquatic and terrestrial environment. Skin remains similar to its aquatic roots and resembles the skin of the fish however, scales are not present.

Two most ancient groups of reptiles, the turtles and crocodiles, have retained bony dermal plates. Turtles have continuous osteoderms below the epidermal plates of the carapace and plastron. These osteoderms form a rigid dermal skeleton which becomes connected with the endoskeleton. In crocodiles there are osteoderms below the epidermal plates only on the back and the throat.

In birds and mammals there is a tendency for elaborating epidermal structures with an accompanied reduction or loss of dermal derivatives. In mammals, osteoderms are found in armadillos lying below the epidermal scales. They are bony plates of spongy texture. Extinct glyptodons had rigid bony armour of osteoderms. In some whales bony osteoderms may be present on the back and the dorsal fin.

Check Your Progress

11. Define integument.
12. What is epidermis?
13. Define epidermal derivatives.
14. What do you understand by unicellular glands?
15. Define sebaceous glands.
16. What is a pronghorn?

2.8 FLIGHT AND GLIDING IN THE VERTEBRATE

A number of vertebrates are capable of aerial mode of locomotion, either by flight or by gliding. This character has been originated many times during evolution without any single ancestor. Flight has evolved at least three times in separate vertebrates: pterosaurs (Pterosauria), birds (Aves), and bats (Chiroptera). Gliding has evolved on many more occasions.

Animal aerial locomotion can be divided into two categories-powered and unpowered. In unpowered modes of locomotion, the animal uses aerodynamics forces exerted on the body due to wind or falling through the air. In powered flight, the animal uses muscular power to generate aerodynamic forces to climb or to maintain steady, level flight. Those who can find air that is rising faster than they are falling can gain altitude by soaring or gilding.

2.8.1 Unpowered flight

In this type of mode of aerial locomotion animals converting the potential energy into kinetic energy and using aerodynamic forces to control trajectory and angle of descent. Energy is continually lost to drag without being replaced, thus these methods of locomotion have limited range and duration. It includes parachuting and gliding flight.

Parachuting

Parachuting falling at an angle greater than 45° from the horizontal with adaptations to increase drag forces. Very small animals may be carried up by the wind. Some gliding animals may use their gliding membranes for drag rather than lift, to safely descend.

Gliding flight

Gliding flight falling at an angle less than 45° from the horizontal with lift from adapted aerofoil membranes. This allows slowly falling directed horizontal movement, with streamlining to decrease drag forces for aerofoil efficiency and often with some maneuverability in air. Gliding animals have a lower aspect ratio (wing length/breadth) than true flyers.

2.8.2 Powered Flight

Powered flight uses muscles to generate aerodynamic force, which allows the animal to produce lift and thrust. The animal may ascend without the aid of rising air.

Externally powered

Soaring is not powered by muscle, but rather by external aerodynamic sources of energy: the wind and rising thermals, respectively. Both can continue as long as the source of external power is present. It is typically seen only in those species that are capable to powered flight, as it requires extremely large wings. Soaring or moving in air requires specific physiological and morphological adaptations that can sustain the animal aloft without flapping its wings. Under the right conditions, soaring creates a gain of altitude without expending energy. Large wingspans are needed for efficient soaring. Many species will use multiple of these modes at various times; a hawk will use powered flight to rise, then soar on thermals, then descend via free-fall to catch its prey.

Gliding and parachuting

Gliding is the simplest form of flight. It is a very energy-efficient way of travelling from tree to tree. During a free-fall with no aerodynamic forces, the object accelerates due to gravity, resulting in increasing velocity as the object descends. During parachuting, animals use the aerodynamic forces on their body to counteract the force of gravity. Any object moving through air experiences a drag force that is proportion to surface area and to velocity squared, and this force will partially counter the force of gravity, slowing the animal's descent to a safer speed. If this drag is oriented at an angle to the vertical, the animal's trajectory will gradually become more horizontal, and it will cover horizontal as well as vertical distance.

Smaller adjustments can allow turning or other maneuvers. This can allow a parachuting animal to move from a high location on one tree to a lower location on another tree nearby. Specifically in gliding mammals, there are three types of gliding paths respectively being S glide, J glide, and 'straight-shaped' glides where species either gain altitude post launch then descend, rapidly decrease height before gliding, and maintaining a constant angled descent.

During gliding, lift plays an important role. Like drag, lift is proportional to velocity squared. Gliding animals will drop from high locations such as trees or buildings, just as in parachuting, and as gravitational acceleration increases their speed, the aerodynamic forces also increase. Because the animal can utilize lift and drag to generate greater aerodynamic force, it can glide at a shallower angle than parachuting animals, allowing it to cover greater horizontal distance in the same loss of altitude, and reach trees further away. Successful flights for gliding animals are achieved through five steps: preparation, launch, glide, breking, and landing. Gliding species are better able to control themselves in mid-air, with the tail acting as a rudder, making it capable to pull off banking movements or U-turns during flight. During landing, arboreal mammals will extend their fore and hind limbs in front of itself to brace for landing and to trap air in order to maximize air resistance and lower impact speed.

2.8.3 Flight and Gliding

Unlike most air vehicles, in which the objects that generate lift (wings) and thrust (engine or propeller) are separate and the wings remain fixed, flying animals use their wings to generate both lift and thrust by moving them relative to the body. This has made the flight of organisms considerably harder to understand than that of vehicles, as it involves varying speeds, angles, orientations, areas, and flow patterns over the wings.

A bird or bat flying through the air at a constant speed moves its wings up and down. Because the animal is in motion, there is some airflow relative to its body which, combined with the velocity of its wings, generates a faster airflow moving over the wing. This will generate lift force vector pointing forwards and upwards, and a drag force vector pointing rearwards and upwards. The upwards components of these counteract gravity, keeping the body in the air, while the forward component provides thrust to counteract both the drag from the wing and from the body as a whole.

Usually, the development of glide help to the vertebrates live on tree, although there are other possibilities. Gliding, in particular, has evolved among rainforest vertebrates, especially in the rainforests in Asia (most especially Borneo) where the trees are tall and widely spaced. Several species of aquatic animals, and a few amphibians and reptiles have also evolved to acquire this gliding ability to save themselves from predators.

Flying is something that is done by birds and planes. They have purpose, direction and control over their movements. They can go where they want or where they are supposed to go, i.e., from point A to point B. They usually have a power source: an airplane has an engine to propel it forward, birds use their wings.

Gliding, on the other hand, is something that is done without any effort. It does not require propulsion or any engine. Think of a paper airplane, it does not have any source of power. When we throw it in the air, it slowly crosses the length of the room and then lands or rather falls to the floor. This is gliding. To glide animal is to use the air currents and gravity to move over short distances.

Flying and gliding are two different words that often denote something that is in movement, usually in the sky. The main difference between flying and gliding is that while flying is mainly associated with air, gliding can refer to gliding in the air, or on water, or even on land, in some instances.

While, almost all birds fly, there are many that glide from one place to another over short distances, usually from one tree to another. They do this by just extending their wings and allowing the air current to carry them. There are also some mammals that glide from one tree to another. A prime example of this is the flying squirrel, wrongly named as it does not fly but glides.

The only vertebrates that can truly fly are birds and bats. Other vertebrates manage to travel through the air by gliding. Following are the few examples of gliding or flying vertebrates of different groups.

Flight or Gliding in Fishes

The flight or gliding in fishes is described below:

a. **Devil Rays (Fish):** The devil rays, in the genus *Mobula*, are related to manta rays. Their wing span can grow up to 17 feet wide, making them the second-largest group of rays after the mantas. These muscular fish can leap several feet out of the water.

b. **Flying Fishes:** There are about 50 different species of flying fish belonging to family Exocoetidae. They are mostly marine fishes of small to medium size. The maximum size of these fishes is 45 cm (18 inch) but most of species are less than 30 cm (12 inch) in length. They can be divided into two-winged varieties and four-winged varieties. They glide usually up to 30–50 meters (100-160 feet) in length, but few species glide up to 100 meters using the updraft on the leading edges of waves. *Exocoetus* glide up to 650 feet in the air as long as 45 second by using its large powerful pectoral fins. Scientists suspect that flying fish glide for escape predators. It has been suggested that the genus *Exocoetus* is on an evolutionary borderline between flight and gliding.

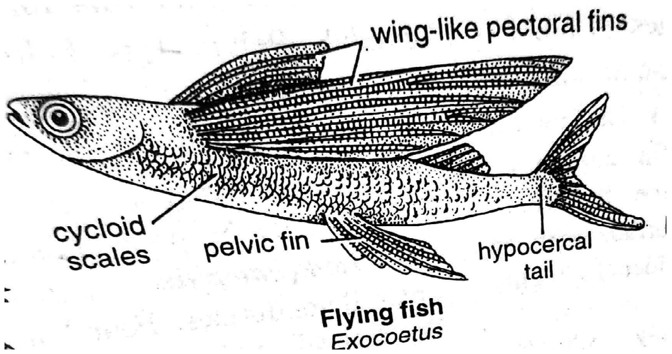

Fig. 2.18 *Exocoetus (Flying Fish)*

c. **Halfbeaks:** A group related to the exocoetidae, one or two hemirhamphid species possess enlarged pectoral fins and show true gliding flight rather than simple leaps. *Euleptorhamphus viridis* can glide up to 50 meters (160 feet) in two separate hops.

d. **Freshwater Butterfly Fish:** *Pantodon buchholzi* has the ability to jump not to glide a short distance. It can move through the air several times the length of its body. While it does this, the fish flaps its large pectoral fins, giving it its common.

Flight or Gliding in Amphibians

The flight or gliding in amphibians is described below:

a. **Wallace's Flying Frog:** *Rhacophorus nigropalmatus* is found in Malaysia and Indonesia. This frog has long webbed toes and a skin flap between its limbs which allows it to parachute float downward at a steep angle from the treetops. Although Wallace's flying frogs prefer to live in the forest canopy, they must descend to ground level to mate and lay eggs.

b. **Malayan Flying Frog:** *Rhacophorus prominanus* glides by using the membranes between the toes of its limbs, and small membranes located at the heel, the base of the leg, and the forearm.

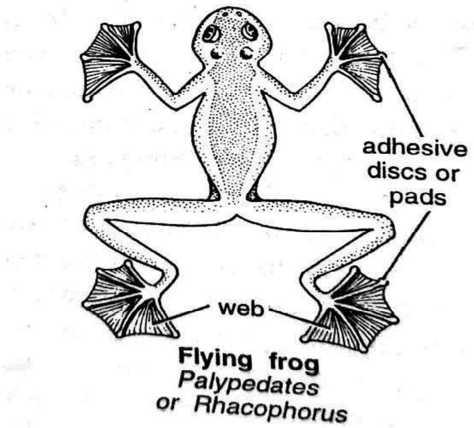

Fig. 2.19 *Flying Frog, Rhacophorus prominanus*

c. **Chinese Flying Frog:** *Rhacophorus dennysi* can maneuver in the air, making two kinds of turn, either rolling into the turn (a banked turn) or yawing into the turn (a crabbed turn).

Flight or Gliding in Reptiles

The flight or gliding in reptiles is described below:

a. **Paradise Tree Snake (Reptile):** *Chrysopelea paradise, a tree snake* found in rain forests of Southeast Asia, Melanesia and India. It glides by stretching out its body sideways and opening its ribs so the belly is concave, and by making lateral slithering movements. It glides from the treetops by flattening its body out to maximize surface area, wiggling from side to side to go in the desired direction. It can remarkably glide up to 100 meters (330 feet) and make 90 degree turns.

b. **Flying/Gliding Geckos (Reptile):** It is a group of Gekko (Genus Ptychozoon, Lupersaurus, Cosymbotus and Thecadactylus) which live in the wet forests of Southeast Asia. In addition to patagia that let them parachute from tree branches, the geckos have remarkably mutable skin that camouflages them against tree trunks extremely well. These lizards have small flaps of skin along their limbs, torso, tail, and head that catch the air and enable them to glide.

c. **Draco (Flying lizard):** There are 28 species of lizard of the genus *Draco*, found in Sril Lanka, India, and Southeast Asia. They live in trees, feeding on tree ants, but nest on the forest floor. They can glide for up to 60 meters (200 feet) and over this distance they lose only 10 meters (30 feet) in height. Unusually, their patagium (gliding membrane) is supported on elongated ribs rather than the more common situation among gliding vertebrates of having the patagium attached to the limbs. When extended, the ribs form a semicircle on either side the lizard's body and can be folded to the body like a folding fan.

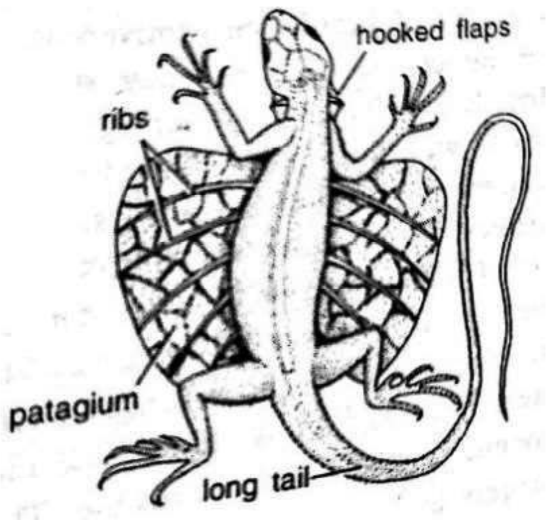

Fig. 2.20 *Draco (Flying Lizard)*

d. **Gliding Lacertids:** There are two species of gliding lacertids, of the genus *Holaspis*, found in Africa. They have fringed toes and tail sides and can flatten their bodies for gliding or parachuting.

e. **Pterosaura (Reptile):** *Pterosaurs* were the first flying as well as largest known flying extinct vertebrates. They had large wings formed by a patagium stretching from the torso to a dramatically lengthened fourth finger.

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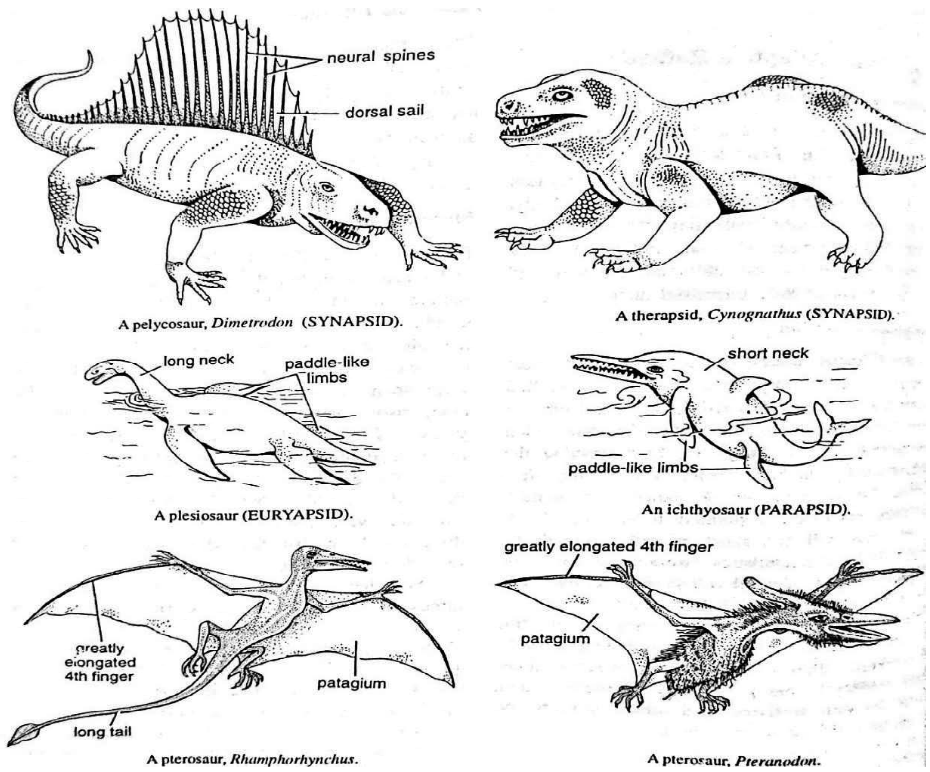

Fig. 2.21 *A. Pterosaurs, Rhamphorhynchus; B. Pterosaurs, Pteranodon*

Flight or Gliding in Aves

Approximately 10,000 living species of birds can fly (except flightless birds). Bird flight is one of the most studied forms of aerial locomotion in animals. The mechanism of flying is balance between two sets of forces such as lift and weight, and thrust and drag. The weight is the result of gravity along the mass of body and lift is generated by flow of air over wings through the mechanism of aerodynamics. The forelimbs of birds have been modified into inimitable and powerful propelling organs; the wings suited solely to flight. These organs have intricated structural preparation and consisting framework of bones, muscles, nerves, blood vessels, feathers, etc. During the resting period of birds, the wings remain folded along sides of body, but become expanded during the flight. The surface area of wings is amplified multifold by the development of elongated flight-feathers called remiges. The vane of every remix forms a flexible and uninterrupted surface for striking air in flight and may also form a broad surface for supporting bird in air.

Most contemporary aerial birds are 'heavier-than-air' machines and almost every part of their organization has been modified for aerial life. To fly in air, birds have to possess following necessary specializations in their organizations like morphology, anatomy and physiology: (i) development of organs for flight, (ii) modifications in exo and endoskeleton for lightness and rigidity, (iii) evolution of extra energy with provision for high power, and (iv) acquiring speed and balance control.

Birds as a Flying Machine

The flight is a consecutive action in birds. During take-off bird has to get hold of sufficient forward momentum to afford lift. In many birds' jump is provided by legs, which is sufficient for takeoff. While larger or heavier birds such as peacock run or swim rapidly to gather enough forward momentum for a take-off. Several large birds' nest on a cliff or tree which allows them an up-current for take-off. The small-sized birds such as pigeons usually take a quick jump by means of their legs followed by beating of their wings. The birds fly on the principle of aeroplane or heavier than air machine. Therefore, body of birds is well adapted for aerial mode of life. Such flight adaptations attain by following ways:

i. **Centralization:** The visceral organs of birds are well centralized and suited its aerial mode of life. For example, the occurrence of light horny beak without teeth, muscular gizzard, short tail with tail feathers, compact short streamlined body with perfectly balanced axis, centre of gravity well below wings, smaller lighter head, and longer neck which can be retracted during flight.

ii. **Lightness and Rigidity:** The bones are light, strong and pneumatic built on principle of girder.

iii. **Wings for Support:** The large, broad wings and tail provide support during fight. Birds are able to adjust their wings and tail during flight in fast flowing air.

iv. **Sustained Power:** Birds have a great sustained power or energy of flight. This is attained by well developed flight muscles and large heart allows a greater stroke output as well as large-sized red blood corpuscles which carry a large amount of hemoglobin that supply higher oxygen for oxidation and metabolism.

v. **Steering and Balancing:** This is done by using wings and tail in birds. The wings are chief component of flight and support body weight in air. Depression of wing elevates and propels the bird through air. Thus, wings act as balancing and flying organs. The tail with tail feathers acts as a rudder for steering during flight, it suddenly checks flight and as a counter balance in perching.

Types of Flight in Birds

The modes of flight reported in birds are broadly grouped in to three to four categories based on the habit, habitat, and times. All these kinds of flight may be used by same birds at different times and circumstances. During flight in birds, the tail helps to support and balance the body, serving as a rudder for vertical and lateral steering. The elevation of tail during flight produces an upward skew, however the lowering of tail a downward turning. The landing of bird is achieved by lowering and fanning out tail feathers that act as a break, meanwhile legs are lowered and birds drops on a perch.

i. **Non-Flapping Flight or Skimming or Gliding**: Many soaring or gliding birds like vultures hang in the air and gain height without moving the wings. Essentially this means that their wings generate a lot of lift without producing much drag. Large birds have evolved to be gliders partly because gliding becomes easier with larger wings while mechanical flapping flight become harder with larger wings. All birds glide to some extent when flying except Hummingbirds. As a rule, smaller the bird, shorter the distance it can glide and faster it sinks. Gliding can be observed in game birds. A pheasant ascends from ground like a rocket with fast wing beats and then glides for some distance down to nearby woods.

ii. **Flapping Flight**: The flapping flight is a more complex process in which bird's wing changes shape and angle of attack during both up and down stroke. It is usually a rowing in the air with the added effort to generate lift as well. If a Blue Tit stop flapping its wings, it better be about to land on a branch or will fall to the ground. The flapping flight comprising two distinct movements: the power stroke (wings move forward and down) and the back stroke (returns the wings to the position from which the next power stroke will commence).

iii. **Soaring or Sailing Flight**: Soaring differs from gliding flight in that bird does not lose altitude and sometimes even climbs up in air. When soaring, a bird uses no energy of its own; instead, it depends on external forces called thermal currents, which are raising masses of air that form over areas where the ground warms up rapidly. Obstruction currents are produced when wind currents are deflected by mountains, cliffs, or tall buildings. The resulting upward rise of air lifts birds to high altitudes, providing a base for further gliding. Soaring birds always have large and broad wings, and the ratio of their body weight to the size of the airfoils is low.

iv. **Hovering Flight**: During this type of flight, a bird propagates its own lift by rapid beating of wings which is firmly flexed at the elbow joint and holding body nearly vertical by the movement of its wing surfaces forward and back in a horizontal plane. The wings of hummingbirds are prepared in such a way that when in motion they act like lifting rotors and their pointed wings do not flap and glide as other bird wings do, but propel them through the air by moving up and down at higher rate about 70 times per second. After feeding at a flower they can fly backward, climb vertically, turn at lightning speed, and come to a sudden standstill in midair.

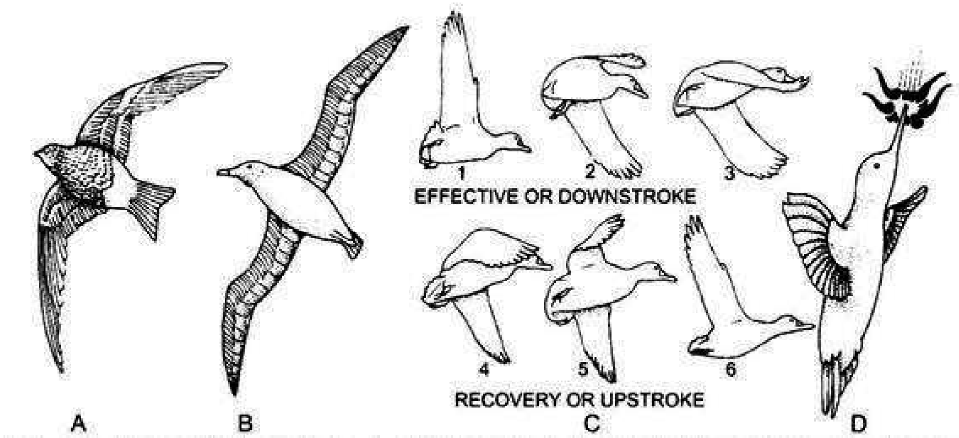

Fig. 2.22 Diversity in Types of Flight in Birds: Skimming (A); Soaring (B); Flapping (C); Hovering (D)

Morphological and Anatomical Flight Adaptation

The birds are only amniotes whose bodies are highly specialized for aerial mode of life. However, during their evolutionary period, a noticeable adaptive radiation has occurred in them, as certain birds either became exclusively terrestrial and flightless (e.g., ostrich, kiwi etc.), few adapted for amphibious life (e.g., ducks) and many more adapted for flying and terrestrial mode of life. Here, the discussion is mainly concerned with aerial or volant adaptations of birds. All requisites for volant life of birds can be studied under the following headings

i. **Body Shape:** The birds have comparatively shorter, light and compact body as than other animals. The body plan and visceral organs are centralized by the placement of most organs and large muscles near the center of gravity that is partially underneath and behind wings to provide superior balance during flight.

ii. **Feathers**: The covering of body by contour feathers result the streamlined posture with decline drag. The down feathers are soft and meant for insulation, however the primary feathers are remiges forms the size and shape of wings which assist flight in birds. The tail feathers are rectrices which stretch sideways so that tail can be used like a rudder for steering and balancing.

iii. **Skeleton:** The evolution of flight has endowed birds with way to reduce weight in birds. This type of aerial adaptation is attained by the amalgamation and elimination of some unnecessary bones and pneumatization of remaining ones as well as their connections to air sacs to makes skeleton comparatively lighter and stronger. The coracoid, furcula, and scapula form a sturdy tripod for supporting wings and broad surfaces for attachment of large flight muscles. The foremost key adaptation is fusion of caudal bones into single **pygostyle** to supports tail feathers, lack teeth or even a true jaw instead having evolved a beak, far lighter weight. The birds have uncinate processes on the ribs which assist and strengthen the rib cage by overlapping with ribs behind them. The skull of birds is composed of thin, hollow bones, which is extremely lighter (<1% of total body weight) than remaining body weight due to abolition of a heavy jaw, jaw muscles, and teeth.

iv. **Limbs**: The forelimbs (wings) are attached closer to the center of gravity and farther from head than in other animals. The natural movement of wings is up and down, rather than back and forth. Forelimb's fold into a Z-shape and along as well as vicinity to body. Hand bones are small, fused, flattened and specialized to manipulate the flight feathers. Aerodynamic shape of forelimb provides lift and propulsive force.

v. **Muscles**: There are about 175 different muscles in bird which mainly control the wings, the tail, neck and legs during flight and perching. Flight muscles are enormous as they have to generate thrust and vigorous movement of wings during flight. The largest muscles in birds that control the wings are called pectorals or breast muscles, and contribute 15–25% of a bird's body weight. They make the birds' wing stroke very powerful to fly, and also provide most of the movements needs for its down stroke. The muscle below pectorals is supracoracoideus which raises wing during flying. The leg muscles are massive for bipedal locomotion but are tight and close to body. Legs are tucked next to body in flight to reduce drag.

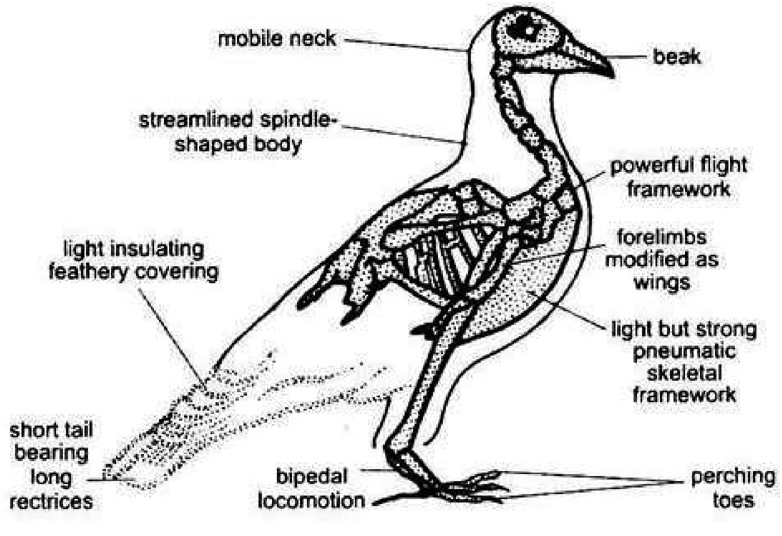

Fig. 2.23 *Schematic Diagram of a Bird Showing Key Features for Adaptation to Flight*

vi. **Digestive System**: The birds consume high-energy foods such as insects, seeds, fruits, meat, and nectar for its active aerial life. The digestive system of birds is tremendously efficient in absorbing high nutrition from small amounts of food at a rapid rate. The birds possess a gizzard having four muscular bands which act to rotate and crush food by shifting from one area to next within gizzard. In some species, the gizzard may provide some small pieces of grit or stone which are the swallowed by birds to aid in grinding process. There are many birds possess a muscular pouch along the esophagus called a crop that functions for both to soften food and regulate its flow through the system by temporary storage.

vii. **Respiratory System**: The respiratory system of birds is adapted to the cope up the energy demands of flight. The respiratory system of birds is proportionately larger (one-fifth of body volume) and much more efficient than other animals (one-twentieth of body volume), because flight is a more energy demanding activity than walking or running. The lungs of birds are less flexible, and relatively small, but these are interconnected with a system of large, thin-walled air sacs in anterior to posterior portions of body which further connected with air spaces in bones. The inhaled air at the outset passes into posterior air sacs and, on exhalation into lungs. When a second breathe is inhaled into posterior sacs, the air of first breathe moves from lungs into the anterior air sacs. When second exhalation occurs, the airs from first breathe moves from anterior air sacs to out of lungs, while inhaled air moves into the lungs. The air thus moves in one direction through the lungs in most of the birds but some also have two-way flow system. The birds' respiration creates a 'crosscurrent circulation' of air and blood, which provides greater capacity for gaseous exchange across permeable respiratory membrane. The exchange of oxygen takes place during both inhalation and exhalation. Air enters lungs via trachea. Half of inhaled air enters posterior air sacs, while other half passes through lungs and anterior air sacs. The anterior air sacs empty directly into trachea, while the posterior air sacs empty via lungs into trachea and to outside. The avian lungs do not have alveoli, but instead contain millions of tiny passages known as parabronchi, connected to air capillaries, where oxygen and carbon dioxide are exchanged with cross-flowing blood capillaries by diffusion. A diaphragm is absent in birds.

viii. **Heart**: The avian heart is comparatively muscular, larger, powerful, four-chambered and identical in its design to mammals. The segregation of two kinds of blood makes a bird's circulatory system well outfitted to handle rigors of flight. The flight muscles of most birds are red in color because of the presence of myoglobin, cytochrome and rich supply of blood for sustained flight. Light-colored muscles are found in pheasants, grouse, quail, and other galliformes birds which are also well supplied with blood. These are apparently capable of carrying a heavy work load for a short time with rapid fatigue. A Ruby-throated Hummingbird's heart beats up to a rate of 1200 beats per minute however the house Sparrow's heart by averages 460 beats per minute.

ix. **Blood**: The blood of birds has higher blood pressure and sugar level, which is almost twice to that of mammalian glucose level. The swift flying and migratory birds have smaller red blood cells with greater surface-to-volume ratios for greater oxygen-absorbing potential.

x. **Brain:** The brain is large with enormous cerebral hemispheres with white matter and greatly reduced olfactory lobes, however, the optic lobes are excessively enlarged. The cerebellum is fully furnished with a median lobe, vermis and later lobes flocculi for coordination of muscular activity and balance during flight.

xi. **Eyes**: The eyes are large, with wide field of view and binocular vision. The nictitating membrane is transparent or translucent and covers entire eye ball during flight. The sclerotic ring of bony plates protects eye ball and increases distance between lens and retina for sharp distant vision, acute eyesight in raptors which having eight times sharper vision than humans. An indented fovea on retina magnifies the central part of visual field with one or two fovea's (hummingbirds and albatrosses) in each eye. The birds also having a common potential to identify polarized light.

xii. **Metabolism**: The birds have high metabolism and endothermy for quick generation of power and for maintenance of high body temperature (38^0C to 42^0C or 100.4^0F-107.6^0F). The birds require large amounts of energy for flight, and need efficient oxygen circulation in high altitudes.

xiii. **Reproductive System**: Ovaries and testes are reduced in size except during breeding season. Usually only one functional ovary is present in most of birds and second or right ovary is greatly reduced to decrease body weight, therefore in female liver is displaced to right to compensate weight difference. But in predator birds both ovaries and oviducts are present. This is because during hunting these birds have to pounce on prey with great force and meanwhile struggling prey can kick and break eggs in reproductive system. Therefore, eggs developing in two ovaries can compensate for this loss.

Mechanism of Aerodynamics During Flying

The bird wings are not flat but are concave below and convex above. The air that passes over top of wing has more distance to travel and thus it speeds up, resulting in drop of pressure above the wing than below. This effectively sucks the wing up. Meanwhile air moving below the wing has opposite effect, generates more pressure and effectively pushes wings up. Hence, a bird with air moving over its wings is pulled up from above and pushed up from below. The low pressure of air on top of the wings represents a sink that high pressure air under the wing tries to fill. This happens most along thin trailing edges of wing and causes a spiraling vortex of disturbance at wing tip that increase drag. Therefore, the most efficient wings are those which provide lift but reduce drag, such as crescent shaped wings of swallows and swifts. The aerodynamic potential is calculated by aspect ratio, which is the ratio of wing length divided by wing breadth. The longer wings are better for gliding but harder to flap quickly, therefore not much good at quick acceleration. However, the wing loading is the relationship between total body-mass measured in grams versus total wing area measured in cm^2.

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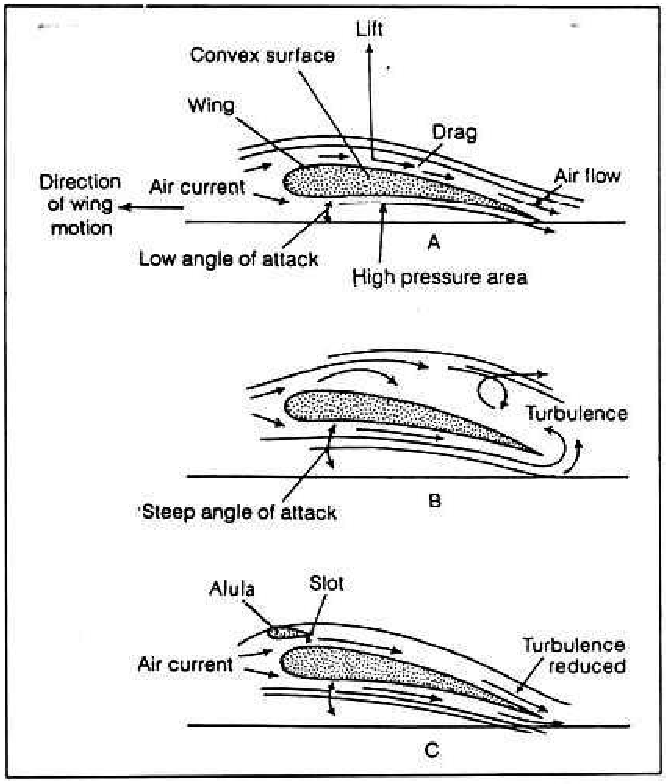

Fig. 2.24 *Aerodynamics During Flying of a Bird*

Evolution of Flight Adaptation in Birds

The evolution of flight has endowed birds with many physical characteristics in addition to wings and feathers. One most important requirement for heavier-than-air flying machines, birds acquire structure that comprises strength and lighter weight. This is accomplished by the fusion and elimination of some bones and pneumatization (hollowing) of remaining ones led to belief that birds had skeletons that weighed proportionately less than other vertebrates. The bird must be able to support itself either entirely by its forelimbs or hind limbs and requires a deep, solid breastbone (sternum) to anchor wing muscles. There is variable degree of pneumatization reported in birds so that to decrease their buoyancy and make diving easier, some diving birds (loons and auklets) have relatively solid bones. The birds have found some other ways to lighten the load in addition to hollowing out their bones, keeping their reproductive organs (testes, ovaries and oviducts) tiny for most of the year.

The respiratory system of birds is also adapted to demands of flight by acquiring one-fifth of its body volume. On contrary to mammalian lungs, the lungs of birds are less flexible, and relatively small, but these are interconnected with a system of large, thin-walled air sacs in front (anterior) and back (posterior) portions of body which thereafter connected with the air spaces in bones also. The evolution has created an ingenious system that passes the air in a one-way or two-stage flow through the bird's lungs.

The heart acquired by birds is comparatively larger, powerful, than other and of the same basic design as of mammals. The separation of two different types of blood provides a bird's circulatory system, well outfitted to handle the rigors of flight. Even though birds have found several ways to adopted for flight by streamline posture, lighten body weight, or totally eliminate unnecessary parts (like urinary bladders). The birds have brain that is proportionately much larger and connected to sharp eyes, and has ample processing centers for coordinating information received from them.

Flight or Gliding in Mammals

Bats are the only freely flying mammals. A few other mammals can glide or parachute; the best known are flying squirrels and flying lemurs.

a. **Flying Squirrels (Mammal):** There are about 40 different species of flying sqirrels belonging to family Sciurinae and subfamily Petauristinae. Flying squirrels are found in Asia (most species), North America (genus *Glaucomys*) and Europe (Siberian flying squirrel). They inhabit tropical, temperate, and Subarctic environments, with the *Glaucomys* preferring boreal and montane coniferous forests, specifically landing on red spruce (*Picearubens*) trees as landing sites; they are known to rapidly climb trees, but take some time to locate a good landing spot. They are nocturnal and highly sensitive to light and noise. During flight they can spread its patagium which looks like a kite or parachute. It can steer by moving its adjusting the tautness of its skin. When a flying squirrel wishes to cross to a tree that is further away than the distance possible by jumping, it extends the cartilage spur on its elbow or wrist. This opens out the flap of furry skin (the patagium) that stretches from its wrist to its ankle. It glides spread-eagle and with its tail fluffed out like a parachute, and grips the tree with its claws when it lands. Flying squirrels have been reported to glide over 200 meters (660 feet).

b. **Anomalures (Scaly-Tailed Flying Squirrels):** Anomalures belongs to family Anomaluridae. These brightly coloured African rodents are not squirrels but have evolved to a resemble flying squirrels by convergent evolution. There are seven species, divided in three genera. All but one species has gliding membranes between their front and hind legs. The genus *Idiurus* contains two particularly small species known as flying mice, but similarly they are not true mice.

c. **Cynocephalus (Mammal):** *Cynocephalus* are tree dweller of Southeast Asia and sometimes called flying lumber. Although they are not true lemurs (true lemurs are primates) nor truly fly and are about the size of a house cat. They can glide up to 200 feet between trees with the help of their patagium (a flaps of skin between their front and hind legs that extend to their tail and neck) and webbed present between their toes. In the air, they can soar gracefully through the forest, but on the ground, they look like an animated pancake.

d. **Colugos (Flying Lemurs):** Colugos belonging to order dermoptera. There are two species of colugo. Despite their common name, colugos are not lemurs. Molecular evidence suggests that colugos are a sister group to primates; however, some mammologists suggest they are a sister group to bats. Found in Southeast Asia, the colugo is probably the mammal most adapted for gliding, with a patagium that is as large as geometrically possible.

They can glide as far as 70 meters (230 feet) with minimal loss of height. They have the most developed propatagium out of any gliding mammal with a mean launch velocity of approximately 3.7 m/s. The Mayan Colugo can initiate glides without jumping.

e. **Sifaka (Gliding/Parachuting Mammal):** Sifaka, a type of lemur, and possibly primates have thick hairs on its forearms and a small membrane under its arms that has been suggested to provide lift by having aerofoil properties. A number of primates (sifakas, indris, galagos and saki monkeys) have adaptations that allow them to limited gliding or parachuting.

f. **Possums (Flying Phalangers or Wrist-Winged Gliders)**: They are belonging to subfamily Petaurinae and found in Australia, and New Guinea. The gliding membranes are hardly noticeable until they jump. On jumping, the animal extends all four legs and stretches the loose folds of skin. The subfamily contains seven species. Of the six species in the genus *Petaurus*, the sugar glider and the Biak glider are the most common species. The lone species in the genus *Gymnobelideus*, Leadbeater's possum has only a vestigial gliding membrane.

g. **Feather-Tailed Possums:** It belongs to family Acrobatidae. This family of marsupials contains two genera, each with one species. The featheritail glider (*Acrobates pygmaeus*), found in Australia is the size of a very small mouse and is the smallest mammalian glider. The feather-tail possum, *Distoechurus pennatus* is found in New Guinea, but does not glide. Both species have a stiff-haired feather-like tail.

h. **Greater Glider (*Petauroidesvolans*)**: The only species of the genus *Petauroids* of the family Pseudocheiridae. This marsupial is found in Australia, and was originally classed with the flying phalangers, but is now recognized as separate. Its flying membrane only extends to the elbow, rather than to the wrist as in Petaurinae. It has elongated limbs compared to its non-gliding relatives.

i. **Bats (Mammal):** There are approximately 1,240 bat species, representing about 20% of all classified mammal species. Most bats are nocturnal and many feed on insects while flying at night, using echolocation to home in on their prey.

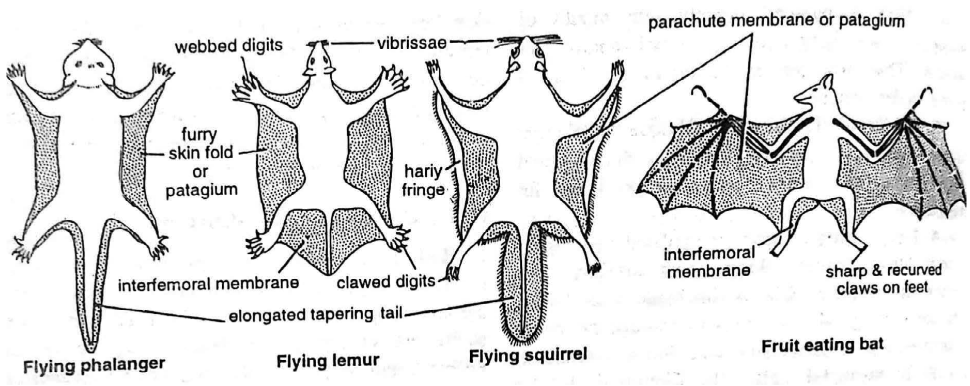

Fig. 2.25 *Gliding and Flying Mammals (Diagrammatic Representation).*

Check Your Progress

17. Define unpowered flight.
18. Name the only freely flying mammal.

2.9 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Osteostracans, also known as *cephalaspis*, played an important role in the history of vertebrate palaeontology, as they were the first fossil jawless fishes whose internal anatomy has been described in detail, thereby raising heated debates about the organization of the primitive vertebrate head.
2. Most of fossils of ostracoderms were preserved in the bottom sediments of freshwater streams. However, the opinion is sharply divided as to whether their habitat was freshwater or marine.
3. Ostracoderms are biologically significant because:
   a. The ostracoderms are especially interesting because they represent the oldest known vertebrate fossils in the late Cambrian and Ordovician rocks dating back to nearly 500 million years. They are the remote ancestors of all the vertebrates including man.
   b. The lack of earlier vertebrate fossils shows that they had perhaps evolved in a habitat (freshwater) which was inimical to fossilization. It is also likely that the earliest ancestors lacked hard skeletal materials as bones.
4. The cyclostomes are characterized by the presence of a circular suctorial and rounded mouth without functional jaws.
5. About 50 species of cyclostomes are currently recognized.
6. The placoderms were the earliest jawed vertebrates of fossil record.
7. Placoderms originated about 400 million years ago in the Devonian period of Paleozoic era.
8. The class Chondrichthyes is divided into two subclasses: Elasmobranchii and Holocephali.
9. Holocephali is a very small ancient group of highly specialized marine fishes. It comprises of rat-tailed fishes.
10. The fertilization is internal and the cleavage holoblastic type in holocephalic organisms.
11. Integument is the means of identifying the organism, and it also defines the boundary of its body. The integument consists primarily of the skin and its derivatives.
12. The upper layer composed of mostly dead, differentiated cells (stratum corneum) with a lot of keratins which helps the skin maintain some protection against water loss and bacteria is called epidermis.

13. Epidermal derivatives are epidermal glands (unicellular and multicellular), epidermal scales and scutes, horns, digital structures (claws, nails and hoofs), feathers and hairs.
14. These are single modified cells found among other epithelial cells and are found in amphioxus, cyclostomes, fishes and larvae of amphibians.
15. Sebaceous glands are alveolar glands opening in hair follicles containing hairs. They also independently open at the skin surface around the genital organs, tip of the nose, and edges of the lips.
16. Pronghorn is a true horn, consists of a permanent projection of the frontal bone covered by a hard, horny epidermal sheath.
17. In this type of mode of aerial locomotion animals converting the potential energy into kinetic energy and using aerodynamic forces to control trajectory and angle of descent.
18. Bat is the only freely flying mammal.

2.10 SUMMARY

- The earliest known vertebrates to appear in fossil record were jawless primitive fish-like animals collectively known as the ostracoderms.
- Ostracoderms had separate pharyngeal gill pouches along the side of the head, which were permanently open with no protective operculum.
- Ostracoderms have heads covered with a bony shield. They are among the earliest creatures with bony heads.
- The ostracoderms were primitive vertebrates, small to medium in size. Their body form was fish-like, usually flattened dorso-ventrally, with a huge head and gill region, a tapering but muscular trunk and some sort of tail fin.
- The Cephalaspidida are characterized by broad and flattened cornual processes, onto which extend the lateral fields.
- Cephalaspis is the classical representative of this group which, however, includes many other forms, such as the large Parameteoraspis, whose headshield can reach 45 cm in breadth.
- The Zenaspidida have a more massive headshield, often bearing a posterior median crest or spinal process. They have a characteristic ornamentation of large tubercles, surrounded by smaller ones.
- The Benneviaspidida have a flattened headshield and their exoskeleton has lost the polygonal pattern of the platelets, to form a continuous layer.
- Among all ostracoderms, osteostracans (possibly along with pituriaspids) share the largest number of uniquely derived characteristics with the gnathostomes: cellular bone, sclerotic ring in eyes, paired fins containing musculature, and epicercal caudal fin.
- The Cyclostomata are characterized by the presence of a circular suctorial and rounded mouth without functional jaws. They exhibit a low grade of

organization and are undoubtedly the most primitive of all the existing vertebrates.

- Cephalaspids and anaspids are fossil agnathans that show similarity to the modem cyclostomes than pteraspids (Neterostraci or Pteraspida). Ostracoderms belonging to Ordovician are the oldest fossil vertebrates.
- The agnatha were the first animals of the chordate type to become large. They feed on detritus on the bottom. The lampreys and hagfishes have been derived from early agnatha by the evolution of a sucking mouth, perhaps with loss of the bony skeleton and paired limbs.
- The 'Placoderms' were the earliest jawed vertebrates of fossil record. They appeared during the Silurian, flourished or dominant in Devonian and Carboniferous but all of them become extinct by the end of the Permian period.
- Ostracoderms were the first jawless vertebrates but the Placoderms were the first jaw bearing vertebrates. They had similarities as well as dissimilarities.
- The elasmobranchii are mostly predaceous fishes and are most abundant in the tropical and subtropical areas.
- Holocephali, is a very small ancient group of highly specialized marine fishes. It comprises of rat-tailed fishes.
- Holocephali occupies a position in between the cartilaginous and bony fishes and have conserved certain of the primitive characteristics from their so-called placoderm ancestors.
- Integument is the means of identifying the organism, and it also defines the boundary of its body. The integument consists primarily of the skin and its derivatives.
- Both layers of integument have given rise to various types of derivatives. The epidermis gives rise to integumentary glands, epidermal scales, horns, digital structures, different corneal structures, feathers, and hairs.
- Sebaceous glands are alveolar glands opening in hair follicles containing hairs. They also independently open at the skin surface around the genital organs, tip of the nose, and edges of the lips.
- The skin of vertebrates is rarely naked, and it is usually provided with protective scales, bony plates, feathers or hairs. There are no epidermal scales in fishes and amphibians. They appear for the first time in reptiles.
- Scales are most noticeable on lizards and snakes. They are continually being produced by the permanently growing layer of the stratum germinativum and are generally folded so as to overlap one another.
- Horns are found in ungulate (even-toed hoofed) mammals only. True horns are hollow and are found in pronghorn, cattle, antelope, sheep and goats that consist of an inner core of bone, an outgrowth of the frontal bone.

- In amniota the distal ends of digits have claws, nails or hoofs formed from the horny layer of the epidermis. They grow parallel to the surface of the skin and are built on the same plan.
- Feathers are found only in birds and are formed from the epidermis in which the stratum corneum is highly specialized.
- Hair is found only in mammals. It projects from the skin and covers the entire integument in most (furred mammals), but in others only traces are left, such as whales have only a few core hairs on the snout.
- A placoid scale has a flat bony basal plate bearing a trident spine which projects above the epidermis and points backwards.
- The earliest tetrapod's had dermal scales are known as bony plates or osteoderms which probably functioned as armor.
- Animal aerial locomotion can be divided into two categories-powered and unpowered. In unpowered modes of locomotion, the animal uses aerodynamics forces exerted on the body due to wind or falling through the air. In powered flight, the animal uses muscular power to generate aerodynamic forces to climb or to maintain steady, level flight.
- The surface area of wings is amplified multifold by the development of elongated flight-feathers called remiges.

2.11 KEY TERMS

- **Ostracoderms:** The earliest known vertebrates to appear in fossil record were jawless primitive fish-like animals collectively known as the ostracoderms.
- **Placoderms:** These are the earliest jawed vertebrates of fossil record.
- **Integument:** It is the means of identifying the organism, and it also defines the boundary of its body. The integument consists primarily of the skin and its derivatives.
- **Epidermis:** The upper layer composed of mostly dead, differentiated cells (stratum corneum) with a lot of keratins which helps the skin maintain some protection against water loss and bacteria is called epidermis.
- **Epidermal Derivatives:** Epidermal derivatives are epidermal glands (unicellular and multicellular), epidermal scales and scutes, horns, digital structures (claws, nails and hoofs), feathers and hairs.
- **Sebaceous Glands:** Sebaceous glands are alveolar glands opening in hair follicles containing hairs. They also independently open at the skin surface around the genital organs, tip of the nose, and edges of the lips.
- **Pronghorn:** It refers to a true horn, consists of a permanent projection of the frontal bone covered by a hard, horny epidermal sheath.

2.12 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. What are the features of Ostracoderms?
2. Write a short note on the affinity of Cyclostomes with *Amphioxus*.
3. What are the subclasses of the class Placodermi?
4. Give a brief account of Dipnoi and Crossopterygii.
5. Briefly explain the structure and development of hair.
6. What is the difference between powered and unpowered flight?

Long Answer Questions

1. Discuss the affinities of Ostracoderms in detail.
2. Describe the generalized, specialized, and degenerated characteristics of cyclostomes.
3. Explain the features of Placoderms.
4. Discuss the general organization of Holocephali.
5. Describe the different kinds of epidermal glands.
6. Evaluate the morphological and anatomical flight adaptation of birds.

2.13 FURTHER READING

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UNIT 3 CIRCULATORY, RESPIRATORY, AND SKELETAL SYSTEM IN VERTEBRATES

NOTES

Structure

3.0 INTRODUCTION

The cardio-vascular system is in some cases known as the blood-vascular, or basically the circulatory system. It comprises of the heart that is an internal muscular siphoning/ pumping organ with a closed system of vessels called arteries, veins, and capillaries. These tubular /siphoning networks are running to the entire human body and supply blood to every corner of the body. The blood component includes oxygen, nutrients, wastes, immune and additional functional cells which assists to homeostasis and fundamental working of human cells and organs. Thus, the cardiovascular system is the organ system that conveys blood through tubular system to every cell and from every single one parts of the body to heart, transporting nutrients and oxygen to tissues and eliminating carbon dioxide and other wastes as well.

The respiratory system is the network of organs and tissues that helps in breathing. It comprises tubular airways, soft contractile lungs and numerous blood

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vessels. All these essential sections work mutually in a coordinated pattern to transport oxygen all over the body and each cell as well as trap and eliminate out waste gases like carbon dioxide.

The vertebrates having a median vertebral column or backbone comprising vertebrae, and internal frame work centered on a prominent spine. This entire frame work of vertebrates called skeletal system comprising the bones; cartilage; ligaments; tendons and sharing about 20% of the entire body weight.

In this unit, we will discuss the circulatory system, respiratory system, and the skeletal system.

3.1 OBJECTIVES

After going through this unit, you will be able to:

- Discuss the fundamentals of circulatory system
- Describe the basic concepts of respiratory system
- Analyse the various structural components of skeleton system

3.2 GENERAL PLAN OF CIRCULATION IN VARIOUS GROUPS

The circulatory system, also known as the cardiovascular or vascular system, is an organ system that allows blood to circulate and transport nutrients, oxygen, carbon dioxide, hormones, and blood cells to and from the body's cells in order to provide nourishment, aid in disease prevention, and maintain homeostasis. The lymphatic system, which circulates lymph, is part of the circulatory system. The cardiovascular (from Latin words meaning 'heart' and 'vessel') system includes the blood, heart, and blood vessels. The lymphatic system is made up of lymph, lymph nodes, and lymph arteries, and it returns filtered blood plasma from the interstitial fluid (between cells) as lymph. A systemic circulation and a pulmonary circulation are two parts of the blood circulatory system. Some invertebrate groups have an open cardiovascular system, whereas humans and other vertebrates have a closed cardiovascular system (meaning blood never leaves the network of arteries, veins, and capillaries). The lymphatic system, on the other hand, is an open system that serves as an additional pathway for surplus interstitial fluid to be returned to the bloodstream. The diploblastic animal phyla, which are more primitive, lack circulatory systems.

3.2.1 Blood

Blood is continually moving or circulating liquid connective tissue in the body. It offers nutrition, oxygen to body cells and removes the wastes as well. It comprises plentiful cells and proteins found suspended in it to making blood more viscous than water. The average person has about more than 4.5 liters of blood with pH 7.4 and normally contributes for 8 percent of the total body weight. The plasma is noncellular part of blood makes up about half part (53.3%) of the blood content. The plasma comprises glucose and other dissolved nutrients along with the proteins that assist blood clotting, transport of material via blood, and execute allied functions as well. The other half part (about 46.7%) of blood volume is composed of blood cells: (i) Red Blood Corpuscles/ Cells (RBCs) or Erythrocytes which constitutes 45% of whole blood and carry oxygen to the tissues; (ii) White Blood Cells (WBCs) or Leukocytes which constitutes about 1% and fight against infections; and (iii) Platelets or Thrombocytes (smaller cells) that constitutes about 0.7% and help blood to clot.

The blood seems to be red in color due to the high quantity of hemoglobin occurs in RBCs. Each molecule of hemoglobin has four heme groups to interact with different molecules. The hemoglobin bound with oxygen in arterial circulation give rise distinctive red color. However, the deoxygenated blood in venous circulation is comparatively dark red in shade. During carbon monoxide and cyanide poisoning the blood appears more bright red in color. Under standard body conditions, blood can't be truly blue. Even though most visible veins come into view blue since only blue light can go through acutely enough to illuminate veins underneath the skin.

For the maintenance of homeostasis, the blood volume and blood pressure have to be high adequately for its supply to all body's tissues through a process called tissue perfusion. In comparison to other tissues brain requires a continuous supply of oxygen and glucose to stay alive. The conditions of low blood volume during injury, dehydration, or internal bleeding, the body will go into a status of hypovolemic shock because of low tissue perfusion. On contrary, the augmented blood volume than normal may lead hypertension, heart failure, and aneurysms as well.

Erythrocytes (RBCs)

Erythrocytes or RBCs are small, flexible cells like biconcave flattened discs measuring about 7-8μm in diameter. RBCs comprise hemoglobin (an iron-bearing protein) which binds to oxygen so that can be transported to tissues. Fully developed red blood cells (RBCs) are without nucleus, and organelles. The ratio of RBCs to blood plasma is called hematocrit and normally sharing about 45%. The collective surface area of all RBCs of the human body would be roughly two thousand times larger in comparison to the body's exterior surface. There are about 5 million RBCs/mm^3 of blood and outnumber WBCs by about 1000 to 1. These are the major factors contributing to blood viscosity. Clinically, the normal human blood contains 12-18 grams of hemoglobin per 100ml. The hemoglobin content is somewhat higher in men (13-18 g/dl) than women (12-16 g/dl).

Fig. 3.1 *Shape and Appearance of Normal Erythrocytes (RBCs)*

Leukocytes (WBCs)

Leukocytes are frequently larger than RBCs and ranged between 10–14 µm in diameter. There is no hemoglobin in leukocytes but comprising organelles and nucleus with DNA. These are the major functional constituent of the immune system. These destroy and remove older, anomalous cells and cellular debris. These attack to infectious agents (pathogens) and foreign substances as well. Therefore, leukocytes constitute a protective, movable army which assists in defense of the body against damage caused by foreign particles, bacteria, viruses, parasites, and tumor cells. There are numerous kinds of leukocytes or white blood cells (WBCs): basophils, eosinophils, neutrophils, monocytes, natural killer cells, B and T cell lymphocytes, macrophages, and dendritic cells, all of which carry out distinct functions. There are 4000-11000 WBCs/mm^3 human blood and share about 1% of the total body volume. The slipping of WBCs in and out of the blood vessels called diapedesis. On the other hand, the areas of tissue damage and infection in the body can be recognized or located by WBCs through positive chemotaxis. The leukocytosis is a condition, when the Total Leukocyte Counts (TLC) higher than the 11000 cells/mm^3 of blood. On the contrary, abnormally lower WBCs count is diagnosed as leukopenia.

The WBCs or leukocytes like neutrophils, eosinophils, and basophils are called granulocytes due to lobed nuclei which characteristically connected by thin strands of nuclear material. The neutrophils are the most frequent WBCs with multilobed granules which respond to both acidic and basic stains. However, the eosinophils encompass a blue-red nucleus and look like an old-fashioned telephone receiver with brick-red cytoplasmic granules. The number of eosinophils rises quickly during allergies, entry of foreign particle via skin and infections by parasites. While basophils are the rarest WBCs and consisting large, histamine-containing granules that stain dark blue. The histamine is an inflammatory material that makes blood vessels permeable and attracts other WBCs to the inflammatory site.

The second group of WBCs is known as agranulocytes due to the lack of observable cytoplasmic granules. It includes lymphocytes and monocytes. The lymphocytes comprise a large, dark purple nucleus and tend to take up residence in lymphatic tissues to play an imperative function in the immune response. However, monocytes are the largest WBCs. These travel into the tissues to transform into macrophages with huge appetites. The macrophages are very important in fighting against chronic infections.

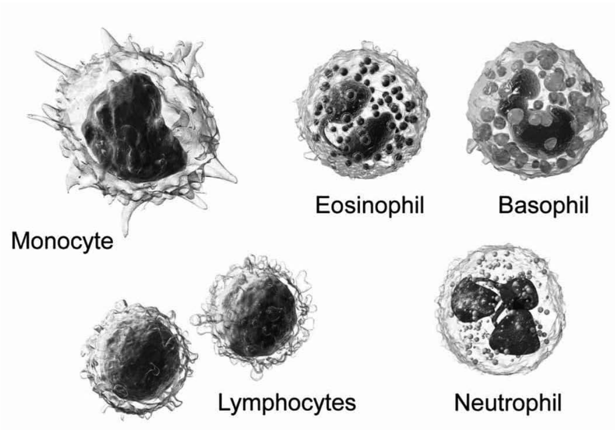

Fig. 3.2 *Shape and Appearance of Normal Leukocytes (WBCs)*

Thrombocytes (Platelets)

Platelets are not cells in the firm sense, but these are trash of bizarre multinucleated cells called megakaryocytes, which pinch off thousands of anucleate platelet 'pieces'. The platelets are desirable for the blood clotting (coagulation) process that take in plasma after rupture or breakage of blood vessels. Thrombocytes ranged between 1-2 µm in diameter, and lacking nuclei. Platelets comprise mitochondrial DNA but not nuclear DNA. These are generated at the rate of 200 billion per day. The production of thrombocytes is regulated by a hormone thrombopoietin. The sticky surface of platelets permits these to gather at the place of broken blood vessels to figure a clot. This process is called hemostasis. The platelets secrete factors that augment local platelet aggregation (e.g., thromboxane A), improve vasoconstriction (e.g., serotonin), and encourage blood coagulation (e.g., thromboplastin, fibrinogen). Platelets are significantly imperative for wound healing through clot formation and complete ceasing of bleeding. All the synthesized elements commence from a common type of stem cell, the hemocytoblast that results to two types of descendants: the lymphoid stem cell (produces lymphocytes), and the myeloid stem cell (produce all other group of formed elements).

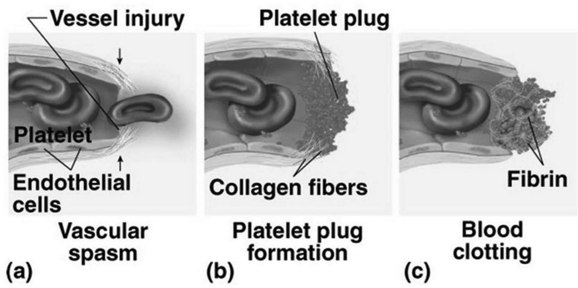

Fig. 3.3 *Mechanism of Hemostasis and Blood Clotting*

Blood Group Determination

An antigen is a material identified as a foreign particle and stimulates the immune system to secrete antibodies for defence against it. The antibodies are the RBC proteins which are helpful in recognition of foreign substance if transfused into body as antigens. Therefore, these 'recognizers' are called antibodies which are found in the blood plasma. The binding activities of the antibodies results to foreign RBCs to clump through an incident called agglutination. The blood groups typing are based on two antigens: type A or type B. When a person inherits absence of both these types of antigens results into type 'O' blood. However, the presence of both antigens leads to type 'AB'. While, the occurrence of either A or B antigen gives rise type 'A' or type 'B' blood groups.

The Rh blood groups are named after one of the eight Rh antigens (agglutinogen D) that were originally recognized in Rhesus monkeys. Later on, the identical antigen was recovered in human beings as well. The study showed that most of the Americans are Rh^+ (Rh-positive), because their RBCs bear the Rh antigen. On contrary not like the antibodies of the ABO system, anti-Rh antibodies do not automatically synthesize and occur in the blood of Rh^- (Rh-negative) individuals. During the blood transfusion, the Rh factors playing a key function and their unmatching may result to hemolysis (rupture of RBCs). But it has noticed that, the hemolysis does not occur during the first transfusion because it needs some time for the body to react and initiate antibodies formation. The blood group determination for both the donor and the recipient prior to blood transfusion is of utmost significance.

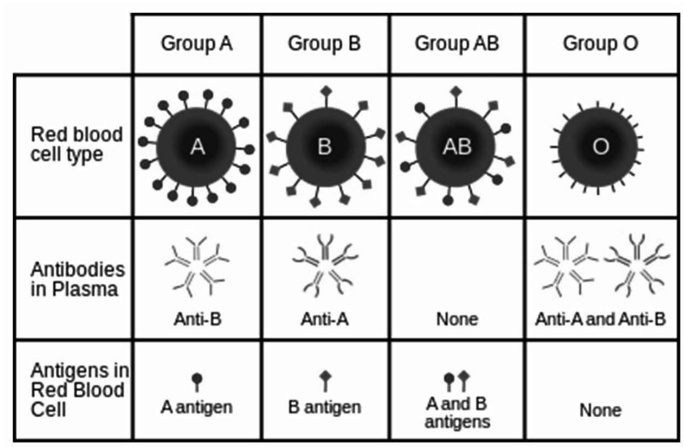

Fig. 3.4 *ABO Blood Group Typing*

When the serum containing anti-A or anti-B antibodies and mixed to a blood sample diluted with saline, agglutination will take place between the antibody and the parallel antigen. Reciprocally, cross-matching involves testing for agglutination of donor RBCs by the recipient's serum and of the recipient's RBCs by the donor serum also. Likewise, the Rh factor typing is done in the same mode as ABO blood typing

Blood Plasma

The plasma comprises more than half about 53.3% of the total blood volume and comprises proteins, factors for clotting, nutrients, and wastes (urea and ammonia) for its elimination. It is an aqueous solution constituting about 90% water, 8% proteins, 1% electrolytes, and 1% micro elements. The plasma is making about 2.7–3.0 liters of total human blood by volume. The plasma contains certain molecules in the dissolved state like respiratory gases (some extent), hormones, glucose, amino acids, proteins, lipids, fatty acids, and vitamins. The plasma also carries the waste products like urea and ammonia for their removal from body tissues. The largest section of solutes in plasma comprising three important proteins: albumins, globulins, and clotting proteins.

i. The albumins, formed in the liver, contribute about two-thirds of the total proteins in the plasma. It helps to keep up the osmotic equilibrium between the tissue fluids and blood. At the time of inflammation, the albumins depart the vascular endothelium and come into the tissues. This activity transport water and fraction of the plasma into the interstitial fluid to result into the exudate edema/ local swelling as symptom of inflammation.

ii. The globulins are a different group of proteins elected into three groups: gamma (γ), alpha (α), and beta (β), based on the, how remote these travel during electrophoresis tests? Their main occupation is to convey a variety of substances in the blood. For example, the beta globulin transporting iron; gamma globulins covey antibodies (immunoglobulin); and alpha globulins helps in inhibiting certain proteases in the body.

iii. The clotting proteins or factors are majorly formed in the liver. There are sum of twelve proteins known as clotting factors because of their active participation in the multistep series of clotting phenomenon at the time of endothelial injury. Amongst these, the one key clotting factor is fibrinogen that generates fibrin when activated by the coagulant thrombin. The fibrin then forms a mesh over the injury point to clots blood with the aid of platelet plug.

iv. On the contrary anticoagulants and fibrinolytic factors in the plasma like plasmin and heparin, rupture up fibrin clots and inactivate thrombin as well results to extended bleeding.

v. The serum is a phrase employed to explain plasma that has been taken out from its clotting factors. Serum still comprises albumin and globulins as well, which are frequently called serum proteins.

Functions of Blood

Blood is unique liquid connective tissue in the body to offer the vital gases (oxygen) supply and tissues and remove the waste gases like carbon dioxide. On the other hand, blood also helps in the regulation of pH and body temperature. Along with these aforesaid roles, blood performs many critical functions for metabolic physiological phenomenon, nutrient transport, immune system and homeostasis among higher organisms as well.

i. Carrier of Gases: Oxygen enters the blood from the lungs and thereafter transported to cell level. Meanwhile, the carbon dioxide, produced by cells during metabolism is exported through the blood to the lungs, and from which it is expelled out to environment through respiratory passage. There are three conditions associated with oxygen supply: Hypoxia (a condition in which the tissues do not obtain adequate oxygen supply); Ischemia (a reversible situation in which tissue does not receive sufficient blood supply); and Infarction (a usually irreversible state in which tissues die due to delayed oxygen or blood supply).

ii. **Carrier of Nutrients:** The digested nutrients, ions, and water are transported by the blood from the digestive tract to tissues and cells.

iii. **Carrier of Waste Products:** The waste or by products of the cell's metabolism are transported via blood to the kidneys for elimination or excretion.

iv. **Clot Formation:** The clotting factors assists in the slowing or stopping of blood loss from the site of blood vessels injury.

v. **Transport of Processed Molecules:** Most of the substances are synthesized in one part of the body and transported to another part through the blood.

vi. **Protection against Foreign Substances:** Antibodies are the proteins present in blood plasma, help in protection of the body from foreign particles or pathogens.

vii. **Transport of Regulatory Molecules:** There are several hormones and enzymes that control the normal body functions are transported from one part to another through the blood.

viii. **Maintenance of Body Temperature:** Among the warm-blooded organisms, the blood inside the body helps to maintain heat or temperature through a series of reactions.

ix. **pH and Osmosis Regulation:** Albumin is an important blood buffering compound and contributes to the osmotic pressure of blood by keeping water in the bloodstream.

Clinical Blood Conditions

Following are some of the blood-related medical issues:

- **Hemorrhage (Bleeding):** Blood leaking out of blood vessels from a wound penetrating the skin is obvious but the internal bleeding (such as, into the intestines) may not be apparent.
- **Hematoma:** The storage or collection of blood inside the body tissues during internal bleeding.
- **Leukemia:** It is a type of blood cancer, in which white blood cells multiply abnormally and circulate through the blood. The abnormal white blood cells make getting sick from infections easier than normal.
- **Multiple Myeloma:** It is a form of blood cancer of plasma cells alike to leukemia. The common complications in multiple myeloma are anemia, kidney failure, and high blood calcium levels.
- **Lymphoma:** It is a form of blood cancer, in which WBCs multiply abnormally in the lymph nodes and other associated tissues. The disruption of blood's functions because of lymphoma may ultimately result to organ failure.
- **Anaemia:** It is the condition of abnormally low count of RBCs in the blood. The noticeable symptoms of anaemia are fatigue and breathlessness.
- **Hemolytic Anaemia:** The hemolytic anaemia caused by the rapid bursting of large numbers of RBCs (hemolysis). It is a type immune system malfunction.

- **Hemochromatosis:** A disorder resulting to excessive levels of iron in the blood.
- **Sickle Cell Disease:** A genetic condition in which erythrocytes periodically lose their proper shape become sickles-shaped, rather than discs).
- **Bacteremia:** It is a bacterial infection of the blood.
- **Malaria:** It is a protozoan (*Plasmodium*) borne infection of red blood cells transmitted by mosquitos (female *Anopheles*). The symptoms of malaria include episodic fevers, chills, and potentially organ damage.
- **Thrombocytopenia:** It is an abnormally low count of platelets in the blood and results to bleeding.
- **Leukopenia:** Strangely low numbers of leukocytes in the blood called leukopenia leads to difficulty in fighting infections.
- **Disseminated Intravascular Coagulation (DIC):** An uncontrolled condition of simultaneous bleeding and clotting in very small blood vessels. The DIC frequently results of severe infections or cancer.
- **Hemophilia:** An inherited (genetic) deficiency of certain blood clotting factors results to frequent or uncontrolled bleeding.
- **Hypercoagulable State:** Copious conditions of augmented blood clotting which results to heart attack, stroke and blood clots in organs or lungs.
- **Polycythemia:** Abnormally elevated numbers of RBCs in the blood called polycythemia. It is a cancer-like condition.
- **Deep Venous Thrombosis (DVT):** A blood clot in a deep vein, usually in the leg is known as DVT. DVTs are dangerous when travel to the lungs, and causing a pulmonary embolism (PE).
- **Myocardial Infarction (MI):** It is commonly known as heart attack. The MI occurs when a sudden blood clot develops in one of the coronary arteries (artery that supply blood to the heart).

3.2.2 Evolution of Heart

The heart is an unpaired muscular organ solely responsible for blood circulation but its origin during embryogenesis is bilateral. It is a straight tube in pre-vertebrates but increases in its length and becomes S-shaped due to its fixed ends. The development of valves, partitions, and disparity in thickening wall of heart results to evolution of two to four-chamber hearts among vertebrates.

Embryonic Development of Heart

During embryogenesis, the mesenchyme constitutes a group of endocardial cells underneath the pharynx. These cells arranged in the way to create a pair of thin endothelial tubes. These tubes fuse approximately at once to shape a single endocardial tube occurring longitudinally below the pharynx. The splanchnic mesoderm occurring underneath the endoderm further twisted longitudinally around the endocardial tube. This two-layered tubular structure will be transformed into the heart. In side heart the splanchnic mesoderm become obese to figure an inner myocardium or muscular wall and outer thin epicardium or visceral pericardium of the heart. However, the endocardial tube becomes the inner lining of the heart to be known as the endocardium. Folds of splanchnic mesoderm meet above to form a dorsal mesocardium which is responsible for the suspension of the heart in the coelom. Meanwhile, a transverse partition is developed back to the heart, and separates the coelom into two chambers (anterior pericardial cavity occupying the heart, and posterior abdominal cavity).

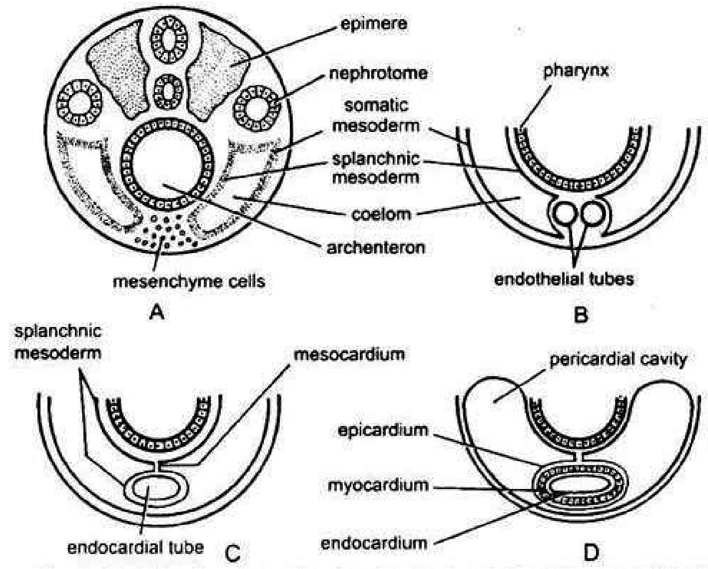

Fig. 3.5 *Bilateral Origin and Embryonic Development of Heart in Vertebrates*

Types of Heart in the Vertebrates

According to the course of evolution and habitat utilized by vertebrates, there are following four types of heart reported from vertebrates:

1. One–Chambered Heart

It is a simple tubular structure performing the functions of blood circulation in prevertebrate chordates. In *Amphioxus* (syn. *Branchiostoma*), a true heart is lacking, only a part of the ventral aorta underneath the pharynx becomes muscular and contractile that acts as the heart. In tunicates, inside the pericardium, there is a thin-walled, tubular, and contractile heart with striated muscles present and found to attach with pericardium by a thin connective tissue. A simple single-chambered heart is opened at both ends.

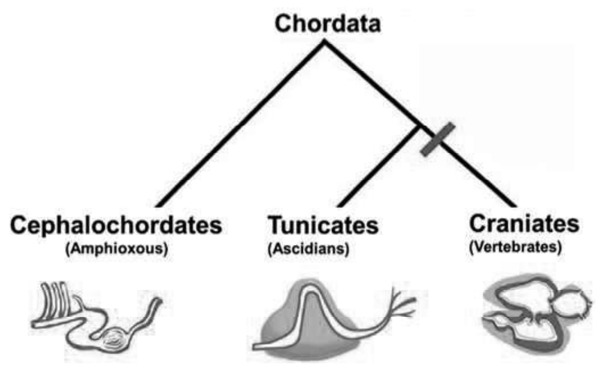

Fig. 3.6 *Evolutionary Lineage of Single-Chambered Heart and Multi-Chambered Vertebrate Hearts*

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2. Two–Chambered Heart

This type of heart primarily has two chambers, namely the atrium and ventricle. The two-chambered heart of cyclostomes having four sub-chambers arranged in a linear fashion: (i) a thin-walled sinus venosus, (ii) a slightly muscular atrium (auricle), (iii) a muscular ventricle, and (iv) a muscular conus arteriosus or bulbus cordis. During evolution, the heart adopted many changes and get alienated from other systems, and taken a position in a separate place.

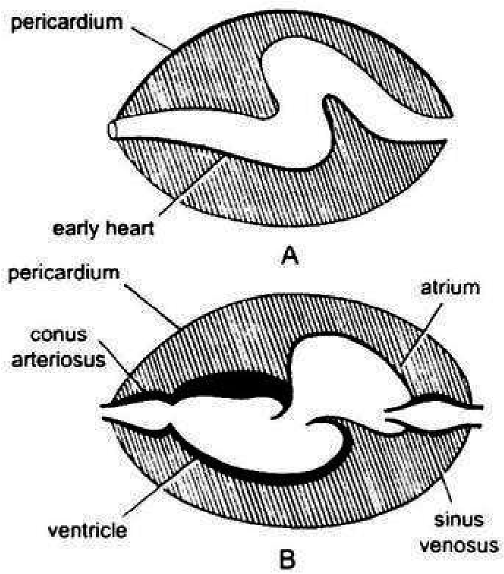

Fig. 3.7 *Development and Modifications of Two-Chambered Heart in Fishes*

Except for Dipnoi, the circulatory system in fishes from cyclostomes to teleosts, carries un-oxygenated blood through the heart, from here it is pumped or propelled to the gills, get aerated, and subsequently distributed to the body. The heart of cartilaginous dogfish is muscular and dorso-ventrally bowed in an S-shaped tube with a linear series of four compartments. The sinus venosus and atrium are receiving venous blood and are pumped to gills through a ventricle and conus arteriosus. This type of heart is called a branchial venous heart. The sinus venosus and conus arteriosus are accessory chambers that are quite reduced in teleosts and having single pair of valves only. The proximal part of the ventral aorta close to the conus becomes greatly enlarged and thick-walled, called bulbous arteriosus. It is elastic and dilates at the time of ventricular contraction. The heart is, thus, 2-chambered with a single circulation of blood.

3. Three–Chambered Heart

The three-chambered heart is found in:

i. **Lung Fishes:** In lungfishes, a septum divides the atrium into a right and left-chamber, while the ventricle is undivided and forms ultimately a three-chambered heart. This is interrelated with the application of the swim-bladder as an apparatus of respiration and denotes the pioneer step toward the development of the double circulatory system. Among lungfishes, blood from the right auricle moves into the right ventricle. After that it pumped into

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the primitive lung-like gas bladder through pulmonary arteries (branch off sixth pair of aortic arches). However, the oxygenated blood came back to the left atrium via of pulmonary veins.

ii. Amphibia: Among amphibians, the dorsal atrium shifted anterior to the ventricle. The sinus venosus opens into the right atrium antero-dorsally. The atrium is entirely separated into right and left chambers. The foramen ovale is absent in the inter-auricular septum. However, it (foramen ovale), remains open in dipnoans. There are deep pockets developed in the ventricular cavity. Among amphibians the conus arteriosus further divides into two (systemic and pulmonary vessels) by a spiral valve. In few urodeles (e.g., lung less salamanders), the inter-atrial septum is incomplete and lacking pulmonary veins as well.

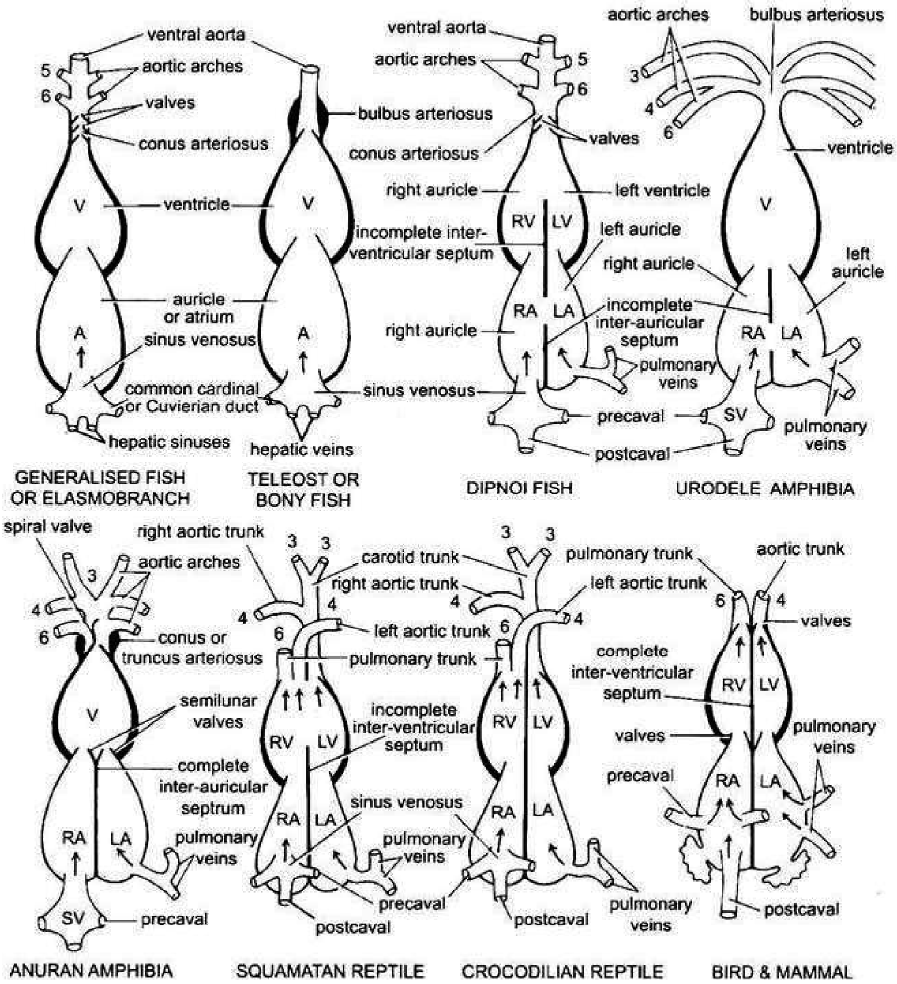

Fig. 3.8 Evolution and Diversity of Heart in a Different Group of Vertebrates

iii. Reptilia: The heart among reptiles is more advanced and three-chambered to incompletely four-chambered. The atrium is absolutely divided into two (right and left-chamber), with sinus venosus into the wall of right atrium. The ventricle is partially separated a septum among most reptiles. Therefore, the oxygenated blood from the lungs passes to the left atrium. However, the non-oxygenated blood collected from the body right side. The embryonic conus arteriosus divides into three vessels: (i) pulmonary arch shipping blood to the lungs from right side of ventricle, (ii) right systemic aorta transporting blood from left side of the ventricle to through right fourth aortic arch, and (iii) left systemic arch carrying from the right ventricle to the left fourth aortic arch.

iv. Crocodilia: The ventricle in the alligators and crocodiles is completely divided by a septum in two-chambered so that the heart becomes incompletely four-chambered. But some mixing may take place in other parts of the circulatory system. At the junction of systemic aorta to left ventricle, there is an opening present, called the foramen of Panizzae. The foramen of Panizzae is site for possible mixing of the oxygenated and deoxygenated blood..

4. Four–Chambered Heart

The heart among birds and mammals is four-chambered (2 auricles and 2 ventricles) for absolute separation of venous and arterial blood. The systemic aorta is collecting blood from the left ventricle, and transported into head and body. On the other hand pulmonary arteries are emerging from the right ventricle and transported blood to the lungs for its oxygenation. Thus, there is double circulation without mixing of arterial and venous blood at any place. The sinus venosus is entirely associated to right auricle. The left auricle collects oxygenated blood via pulmonary veins. The conus arteriosus is absent. The pulmonary aorta commenced from the right ventricle. However, single systemic aorta arises from the left ventricle.

3.2.3 Evolution of Aortic Arches and Portal System

The aortic arches or pharyngeal arch arteries (previously referred to as branchial arches in human embryos) are a series of six paired embryological vascular structures which give rise to the great arteries of the neck and head. They are ventral to the dorsal aorta and arise from the aortic sac. In the circulatory system of animals, a portal venous system occurs when a capillary bed pools into another capillary bed through veins, without first going through the heart. Both capillary beds and the blood vessels that connect them are considered part of the portal venous system.

Embryonic Development of Aortic Arches

During the origin of the heart in a developing vertebrate embryo, the ventral aorta arises mid-ventrally below the pharynx. It is a small vessel while gets connected to the conus arteriosus. The ventral aorta is originating from the heart moves anteriorly underneath the pharynx and, splits into pair of external carotid arteries into the head. The ventral aorta gives rise six pairs of lateral aortic arches at equal distance that passes through the visceral arches. Further, each aortic arch comprises ventral afferent branchial artery carrying venous blood to the gill and a dorsal efferent branchial artery taking oxygenated blood from the gill. The efferent branchial arteries of either side join dorsally with the lateral dorsal aorta or radix aorta which enters into the head as the internal carotid artery. The first aortic arch is a mandibular aortic arch, the second is a hyoid aortic arch, and the remaining ones are called third, fourth, fifth, and sixth aortic arches. The lateral dorsal aorta is amalgamated behind the pharynx to form a dorsal aorta which is continued mid-dorsally into the tail as a caudal artery.

NOTES

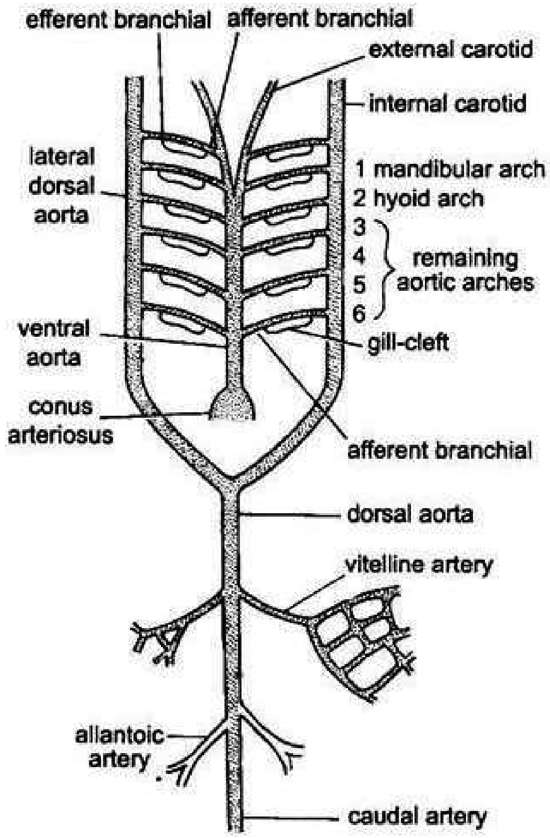

Fig. 3.9 *Embryonic Aortic Arches and Arteries in the Vertebrates*

From the dorsal aorta paired and unpaired arteries arise which supply various organs of the body. In a yolk sac embryo, a pair of vitelline arteries emerge from the dorsal aorta to leads the yolk sac. In the embryo of an amniote, a pair of umbilical's or allantoic arteries arise from the dorsal aorta supplying blood to the allantois however, in adults the vitelline arteries blend to form the main mesenteric artery, and the major part of allantoic arteries degenerated, but their remnants form hypogastric or internal iliac arteries.

Aortic Arches in the Vertebrates

In various adult vertebrates, the arterial system appears to be different due to the increasing complexity of the heart, and the change in respiration from gills to lungs, but they are built on the same basic fundamental plan. There is a progressive reduction in the number of aortic arches in the vertebrate series.

i. **Cyclostomata:** In *Petromyzon*, there are seven pairs of aortic arches. In other cyclostomes, these vary from six pairs in *Myxine* and 15 pairs in *Eptatretus*.

ii. **Pisces:** Although six is considered to have been the basic number of aortic arches for fishes. This number is reduced to five even in sharks and rays with the loss of the first pair, the mandibular aortic arch or it is represented by an efferent pseudobranchial artery. In most bony fishes both the mandibular (i) and hyoid (ii) aortic arches disappear or are much reduced. In *Polypterus* and Dipnoi (lung-fishes), gills are not well developed. So, the pulmonary artery arises from the efferent part of the 6th arch on either side which supplies blood to the air bladder or lung.

iii. Tetrapoda: In tetrapods, aortic arches do not break up into afferent and efferent parts because true internal gills are absent. In all tetrapods, the first and second arches disappear.

a. Amphibia: Here in amphibians the aortic arches illustrate modification due to loss of gills and appearance of the lungs even though the urodeles comprise external gills as respiratory organs along with lungs. The III, IV, V, and VI aortic arches are present, though the fifth pair is much reduced in *Siren, Amphiuma*, and *Necturus*. The VI aortic arch forms the pulmo-cutaneous arch or artery on either side taking blood to the lung and skin. It also retains a connection with the lateral dorsal aorta known as a ductus arteriosus (duct of Botalli).

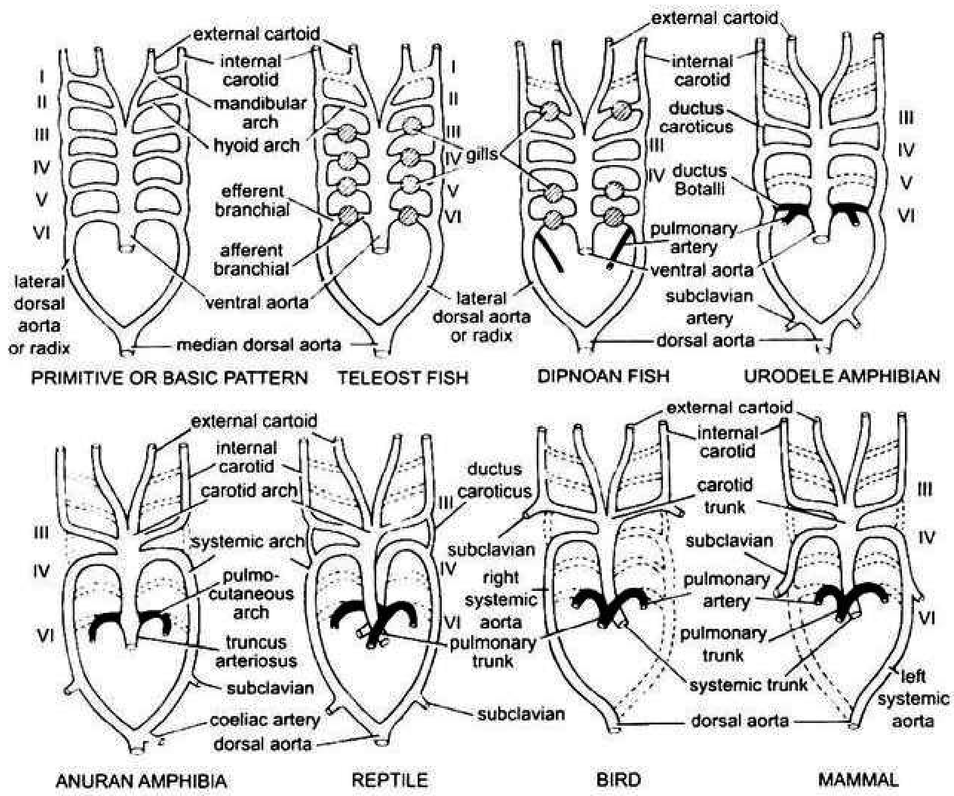

***Fig. 3.10** Comparative Illustrations of Aortic Arches in a Different Group of Vertebrates*

b. Reptilia: In reptiles, the gills are fully replaced by lungs and aortic arches like III, IV, and VI present only. With the partial separation of the ventricle into two parts, the distal portion of the conus arteriosus and the entire ventral aorta are split into three vessels, for example, two aortic or systemic and one pulmonary. The right systemic arch (IV) arises from the left ventricle carrying oxygenated blood to the carotid arch (III). The left systemic (IV) and pulmonary aorta (VI) take their origin from the right ventricle. The left systemic carries deoxygenated or mixed blood to the body through the dorsal aorta, however, the pulmonary artery collects deoxygenated blood to the lungs. The ductus caroticus disappears in most reptiles, but it persists in snakes and some lizards (*Uromastix*). Likewise, ductus arteriosus lacking in most reptiles while existing in a reduced form in *Sphenodon* (living fossil) and some turtles. Due to the mixing of blood, the reptiles are cold-blooded animals like pisces and amphibians.

c. **Aves:** In birds, the III, IV, and VI aortic arches are present and mostly follow the general pattern of reptiles with little differences. With the complete partition of the ventricle into two parts, the conus arteriosus and ventral aorta may also split to form two vessels, the systemic aorta arising from the left ventricle, and a pulmonary aorta from the right ventricle. The third aortic arch with leftovers of lateral and ventral aortae forms the carotids which arise from the systemic aorta. The fourth aortic arch constitutes the systemic aorta on the right side only. It further merged with the lateral aorta of its side and forms the dorsal aorta. The part of the fourth aortic arch at the left side forms the left subclavian arteries, the remaining along with its lateral dorsal aorta degenerated sooner. The sixth aortic arch forms the pulmonary aorta meanwhile the ductus caroticus and ductus arteriosus faded away.

d. **Mammalia:** In mammals also, the III, IV, and VI aortic arches are persistent. The ventricle is divided completely into two parts, the conus arteriosus and ventral aorta split to form two vessels: (i) A systemic aorta arising from the left ventricle, and (ii) a pulmonary aorta from the right ventricle. The third aortic arch along with the leftover lateral and ventral aortae forms the carotid arch. The fourth aortic arch develops the systemic aorta on the left side only, while on the right side its proximal portion forms an innominate and right subclavian artery however, the remaining parts along with its lateral dorsal aorta disappears very soon. The embryonic sixth aortic arch forms the pulmonary aorta in developed mammals. The ductus arteriosus disintegrates but it persists in some unhatched or pre-birth stages as a reduced thin ligamentum arteriosum forms on the left side.

Portal Venous System in the Vertebrates

The portal system is a system of blood vessels that begins and ends in blood capillaries. The hepatic portal carries nutrients from the digestive system to the liver to store and metabolize for life, after a meal. Thus the portal system can be defined as a part of the systemic circulation, in which blood draining from the capillary bed of one structure and passing through larger vessels to deliver the capillary bed of another structure, before returning to the heart. The venous portal system is broadly divided into two parts, i.e., hepatic portal system and the renal portal system.

The hepatic portal system is the venous system that taking back blood from the digestive tract and spleen to the liver (it is the site for processing raw nutrients in blood before the blood came back to the heart). Fundamentally, it drains the structures supplied in due course by the celiac (except for the gonads), anterior mesenteric, gastrosplenic, and posterior mesenteric arteries. In the renal portal system blood from the tail passes through the kidneys via the renal venous portal system before returning, through the posterior cardinal veins and sinuses, to the heart. The chief vessels of the renal portal system are the caudal and renal portal veins.

Embryonic Development of the Portal Venous System in the Vertebrates

The venous system is simple and similar in all vertebrates. The veins are typically paired and prearranged symmetrically. In embryos without a yolk sac, a sub-intestinal vein is formed in the splanchnic mesoderm below the gut that coils around the anus and is continued posteriorly as: (a). A caudal vein into the tail, (b). A pair of subcardinal veins arise between the kidneys and joins the caudal vein, (c). A paired anterior and posterior cardinal veins are formed, which carry the blood from the head and posterior parts of the body respectively, and (d) An inferior jugular vein comes from the ventral side of the head to join the common cardinal vein in fishes and urodeles. In amniotes, a pair of lateral or ventral abdominal veins comes from the body wall to enter the common cardinal veins.

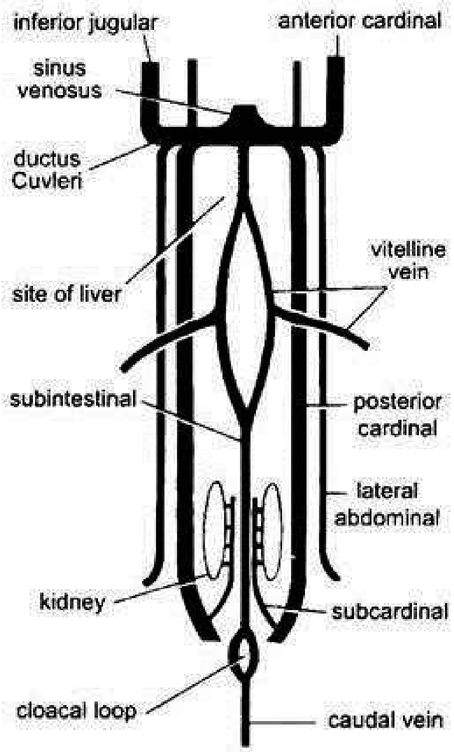

Fig. 3.11 *Embryonic Portal Venous System of Vertebrates*

i. **Pisces:** In fishes, the common cardinal vein (also called duct of Cuvier) leads to the sinus venosus from each side and is created by the fusion of anterior and posterior cardinal veins. The blood of the brain and head are collected by the anterior cardinals, however, blood from the kidneys and gonads is collected by the posterior cardinals. The others are the paired lateral abdominal veins to receive blood from the body wall and paired appendages. The renal portal system of fishes consists of the caudal vein and two renal portal veins that are situated lateral to the kidneys which take the shape of capillaries after reaching the kidneys. The hepatic portal system carries blood from the stomach and intestine after that returns to the liver, where, it passing through series of sinusoids, and ultimately leads the sinus venosus through paired hepatic veins.

ii. Tetrapoda: In the embryos of amniotes, the lateral abdominal veins are known as umbilical or allantoic veins because they drain the allantois. The vitelline and umbilical veins are lost at birth, only their leftovers persist.

a. Amphibia: The venous system of amphibians is very much similar to lungfishes except that the abdominal vein enters the hepatic portal system rather than the sinus venosus. Anterior cardinals persist as internal jugular veins in all adult tetrapods. Inferior jugular veins are lacking in amphibians. The common cardinals transformed into the anterior vena cavae or precavals, which in turn join to sinus venosus in amphibians and reptiles. In lungless salamanders, the pulmonary veins are absent since the inter-atrial septum is incomplete.

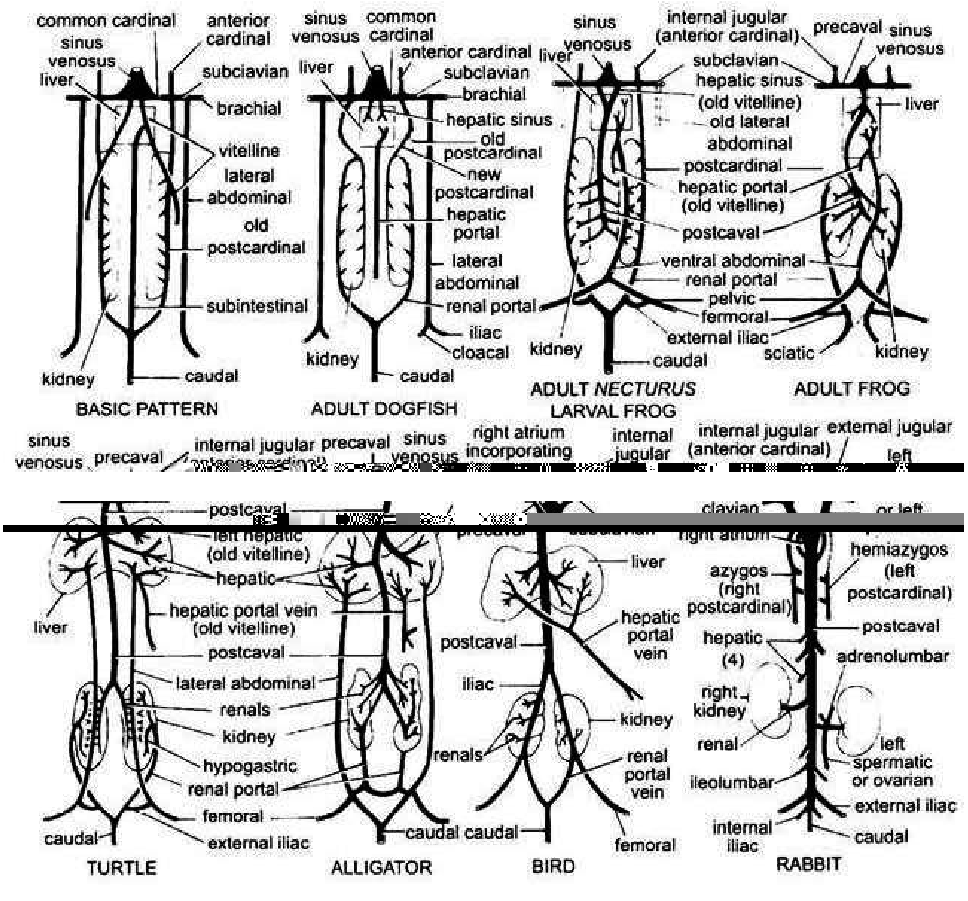

Fig. 3.12 *Modifications of the Venous Portal System in Vertebrates*

b. Reptilia: In reptiles, there is better development of pulmonary veins and postcaval veins while diminution in the renal portal system brings blood to the kidneys from the posterior part of the body.

c. **Aves:** In birds, there are two functional precaval veins formed by the union of the jugular and subclavian on each side, and a complete postcaval. The precaval vein receives blood from limbs by way of the renal portals, leads through kidneys, but does not break up into capillaries and are incomparable to the renal portals of lower vertebrates.

d. **Mammalia:** In mammals, there is a possibility of one or two precaval veins. There is a single postcaval vein, whose embryological development is quite intricate. All the caval veins go into the right auricle directly, because the sinus venosus is absorbed into the wall of the right auricle of the heart in embryonic life. There is no renal portal system in mammals even though the hepatic portal system is greatly alike to other vertebrates.

Evolution and Modifications of the Venous Portal System

The veins of different vertebrates are prearranged on the analogous fundamental pattern of arterial system. Any differentiation exposed by these follow a sequence during its development can be seen in embryos of its lower forms.

i. During liver development the proximal part of the vitelline veins or subintestinal veins gives raise the hepatic veins between the liver and the heart. The distant section left subintestinal vein becomes the hepatic portal vein, and which further forms sinusoids in the liver to modified into hepatic portal system as present among all.

ii. The anterior cardinal veins continue as internal jugular veins.

iii. Excluding fishes, the common cardinal veins turn out to be the precaval veins. These precaval veins passes to the sinus venosus (amphibians, reptiles) or the right autrium (birds, mammals). Further from the precaval vein, the subclavian vein is developed in each forelimb.

iv. The caudal vein breaks its connections to the subintestinal and subcardinal veins.

v. Posterior cardinal veins keep on as such among fishes. But in others groups they split into two portions: anterior (right anterior azygos vein, and the left hemiazygos vein), and posterior portions (joined the caudal vein to become the renal portal veins).

vi. The renal portal vein of each side develops capillaries in the kidney to constitute renal portal system. The renal portal system is complete in fishes, amphibians, and reptiles, but greatly reduced in birds, and absent among mammals.

vii. Among fishes, the renal portal veins receive blood only from the tail, but among amphibians, reptiles, and birds these also collect from the legs as well.

viii. There are two lateral abdominal veins continued alike in fishes, but from Dipnoi onwards these abdominal veins fuse to form an anterior abdominal vein. This abdominal vein joins to hepatic portal vein near the liver. Thus, connects the renal portal and hepatic portal systems together. An iliac vein is arised in each hind limb and joins to the anterior abdominal vein. The anterior abdominal vein loses its functions in reptiles, and birds and modified to form the epigastric and coccygeo-mesenteric veins. It is absent among mammals, except *Tachyglossus*.

ix. Among air-breathing forms, pulmonary veins grow out from the left auricle and go into the lungs.

x. The umbilical (allantoic) veins of the embryo degenerates as the lungs become functional as respiratory organs.

3.2.4 Lymphatic System

The lymphatic system is a subsystem of the blood vascular system in the vertebrates that comprises a multifarious set of connections of vessels, tissues, and organs. It assists in maintaining fluid balance in the body by collecting excess fluid and particulate matter from different tissues and depositing them in the bloodstream as well as plays a key role in absorbing fats and fat-soluble nutrients. It may also help to defend the body against infection or pathogens by supplying disease-fighting cells, the lymphocytes. Thus the lymphatic system is a part of the immune system. The lymphatic or lymph system involves an extensive network of vessels that passes through almost all our tissues to allow for the movement of fluid called lymph. Hence the lymphatic system is a system of thin tubes and lymph nodes that run throughout the body through lymph vessels or lymphatic vessels.

Lymph

The movements of plasma and leucocytes of blood or their escape from the blood capillaries into tissues are taking place due to filtration pressure. During this process, most of the fluid materials were absorbed by blood capillaries, but some of their passes across through diffusion into lymph capillaries, these passed materials are called lymph. Thus, the lymph is a colorless fluid as a part of the blood which has filtered out from blood capillaries. Hence, it may define as blood minus its red blood corpuscles and plasma proteins. As lymph fills body spaces and bathes the tissue fluid. It picks up colloids, broken tissue cells, and bacteria, may also acts as a medium of exchange between the blood and tissue cells. It carries food and oxygen to the cells and takes away water and waste substances from the cells. The lymph re-enters the blood through the lymphatics opening into veins, but some lymph enters the venous capillaries by osmosis.

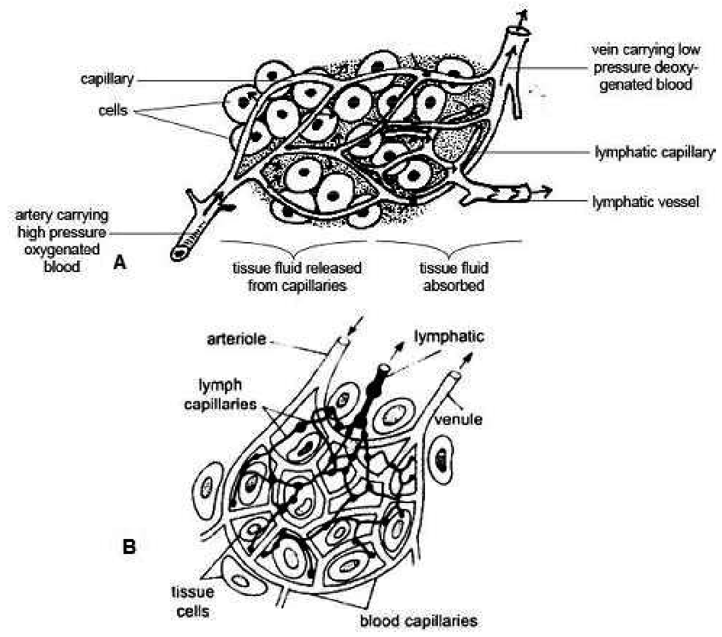

__Fig. 3.13__ Network of Blood and Lymph Capillaries in Vertebrate's Tissues

Structure of Lymphatics

The lymph vessels or lymphatics are a system of the tubular network that is made of connective tissue fibers with some unstriped muscles and are lined with endothelial cells. The largest lymphatics have three-layered walls: (i) A tunica externa, (ii) A tunica media, and (iii) A tunica interna just as in blood vessels. The lymphatics have valves arranged in pairs. These valves are more plentiful than veins and prevent backflow. The lymphatics of the intestine that have the potential or capacity to absorb emulsified fats in the intestine are called lacteals.

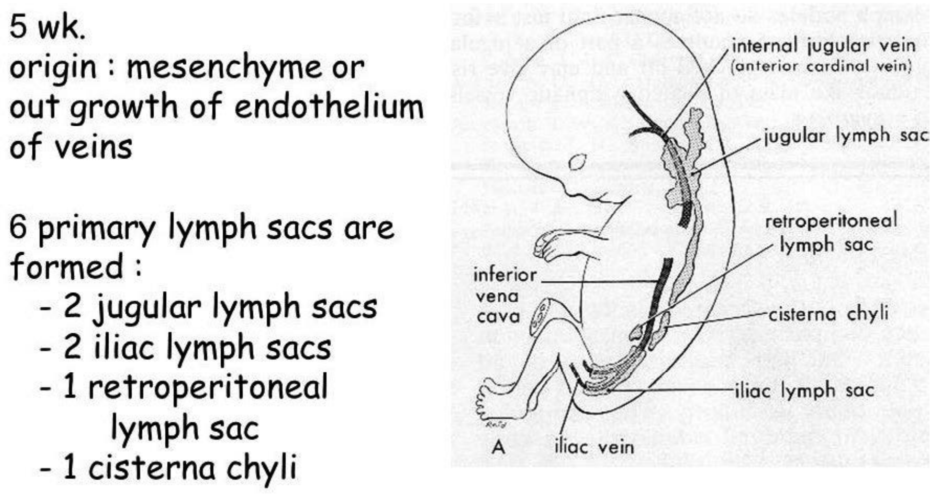

__Fig. 3.14__ The Origin and Distribution of Lymphatic System in a Vertebrate Embryo

Embryonic Development and Modification of Lymphatics

The embryonic development and modification of lymphatics are described below.

Lymph vessels or lymphatics arise as spaces in the mesenchyme of an embryo. They arise near the large veins but considerably later and independently of the blood vessels. The lymph spaces unite and then branch to form anastomosing lymph vessels running throughout the body. In certain places in some vertebrates, connective tissue covers plexuses of lymph capillaries to lymph nodes. The lymphatic system differs from the blood vascular system in being an open system having lymph spaces between tissue cells, and it does not form a complete circuit. Thus the lymphatic system includes the lymph capillaries, lymph vessels, and lymph nodes (tonsils, thymus, spleen, and Peyer's patches are the lymph nodes). The lymph flows only in one direction from the tissues towards the heart. Lymph capillaries form an anastomosing network in all the body organs except in the nervous system. At their commencement, the closed ends of lymph capillaries have small swollen knobs which help in collecting lymph from tissues. The lymph capillaries unite to form larger lymph vessels or lymphatics which finally discharge their contents into veins.

- **Lower Vertebrates:** Many lower vertebrates, except cyclostomes and cartilaginous fishes, have large lymph sinuses, the lymphatics. The lymphatics communicate not only with lymph sinuses but also with the coelom through tiny apertures or stomata. Among lower vertebrates, there are muscular lymph hearts that pump the lymph into veins. Lymph nodes produce lymphocytes and macrophases for destroying foreign bodies and bacteria through phagocytosis.
- **Pisces:** Lymph vessels are well developed in fishes. These are below the skin, in the muscles, and the viscera. These ran along the larger veins and extend into the head, tail, and fins. Lymph hearts are present only in some fishes but lymph nodes are lacking.
- **Amphibia:** In the tissues, there are lymph spaces from which lymph capillaries arise. The lymph capillaries unite to form lymph vessels, some of which dilate to form large lymph sinuses. The spacious subcutaneous lymph sinuses present between the skin and muscles. The dorsal aorta (subvertebral sinus) encloses the kidneys. The lymph is pumped into veins by two pairs of lymph hearts: (a) An anterior pair just behind the transverse processes of the third vertebra, opening into the subscapular veins. (b) A posterior pair of lymph hearts on either side at the end of the urostyle, which can be seen if the skin is removed. They open into the femoral veins.
- **Reptilia:** The lymphatic system has lymph spaces in tissues from which lymph capillaries arise and form numerous lymphatics. The main lymphatic, called the sub-vertebral trunk divides in front into two branches, each of which enters a precaval vein. There is only one pair of lymph hearts opening into the iliac veins posteriorly.

- **Aves:** There is an extensive distribution of lymph vessels, which finally form two thoracic ducts (homologous to subvertebral trunk) opening into precaval veins. In the embryo, there is a pair of lymph hearts in the sacral region. They are almost always lost so that the adult has no lymph hearts.
- **Mammalia:** In mammals the lymphatic system is highly developed, having an all-embracing network of lymph vessels and capillaries throughout the entire body. The larger lymphatics are interrupted at different places by lymph nodes. These lymph nodes occur in the head, neck, arm-pits, groins, close to large blood vessels, and they also make the tonsils and Peyer's patches on the intestine. The lymph nodes may be full of anastomosing lymph capillaries, lymphocytes, reticular cells, and macrophages, which are phagocytic engulfing bacteria and foreign particles. So that these are playing a key role in body protection and immunity. The lymph capillaries which are coming from intestinal villi called lacteals, and carry emulsified fats so that their lymph becomes milky-white in appearance and is called chyle. The lymphatics coming from the left side of the head, neck, arm, and thoracic region open into a thoracic duct lying below the vertebral column. It runs in front and opens into the left external jugular vein near its junction with the subclavian vein. The lower end of the thoracic duct, below the diaphragm, is expanded to form a receptaculum or cisterna chyli. However, lymphatics coming from the legs and lower trunk region, and the lacteals from the intestine pour their lymph into the cisterna chyli. In some mammals, but not in all, there is a right lymphatic duct that receives the lymphatics from the right side of the head and neck, right arm, and right side of the thorax. It opens into the right external jugular vein, where it joins the right subclavian vein. There are no lymph hearts in mammals but lymph is propelled slowly through the lymph vessels and nodes by the movements of the body muscles as well as osmotic pressure in lymph capillaries.

Spleen

The spleen is a lymphoid organ called or graveyard of RBCs. It is a dark red organ found in all vertebrates except cyclostomes and Dipnoi. It is haemolymphatic in character and interposed in the bloodstream and blood (not lymph), filters through it. During embryogenesis, the spleen is formed from mesenchyme cells as a thickening in the dorsal mesentery suspending the stomach. Blood vessels arise in it and bring about a differentiation of mesenchyme cells to form splenic cells and pulp. The spleen functions as a hemopoietic organ and storehouse for 16.25% of the total blood as well. The old or aged erythrocytes approaching into the spleen are destroyed by phagocytic macrophages and the irons of destroyed RBCs are sent to the bone marrow for being used again, and the hemoglobin goes to the liver to synthesize bile pigment. The spleen plays an important role in the production of antibodies from the cells received from the thymus gland and serves as a defense mechanism against bacteria and some diseases.

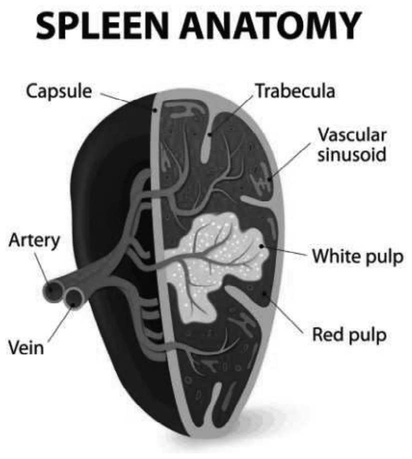

Fig. 3.15 *Topographical and Anatomical Structure of Spleen*

3.2.5 Blood Circulation in the Vertebrates

The blood circulation in our body is determined by the heart that provides a regular delivery of blood to the body through the blood vessels. The circulation of blood ensures the transportation of oxygen, nutrients from the gut, as well as the distribution of hormones, many other chemicals, and water to every cell of the body, and the removal of metabolic wastes from the body. The circulatory system is also essential for a healthy body to maintain cell-level metabolism, pH levels, osmotic pressure, body temperature, and protection from microbial and mechanical disorders. The never-ending movement of blood (blood circulation) covers the circulation of blood from the heart, through branches of arteries, to reach and traverse the microscopic vessels or capillaries in all parts of the body, re-converging in the veins and returning to the heart, to flow through the lungs and back to the heart to start the new circuit of circulation again. The sum of 5 liters of blood present in the blood vessels of a typical adult during rest completes the one circuit in about one minute, the blood re-circulates about 1500 times every day still without any exercise to speed it up. The course of blood circulation is of two types: single blood circulation and double blood circulation.

The single blood circulation is the type of circulatory system in which the blood flows only once through the heart in every complete circuit of the body and this type of circulation is found in fishes. Double circulation is the most efficient way of circulation occurs in mammals, in which the four-chambered heart, arteries, veins, and capillaries all have played a vital role. The blood gets pumped out of the heart, approaches to different organs and then blood again comes back to the heart. All this happens in a very methodical way through the different arteries and veins carrying oxygenated and deoxygenated blood respectively.

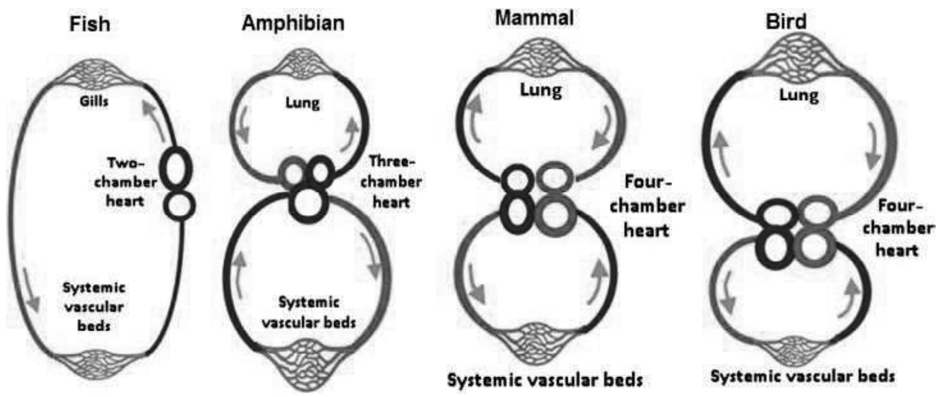

Fig. 3.16 *Comparative Illustration of Blood Circulation in Different Vertebrates*

Blood Circulation in Cephalochordata

In the Cephalochordates (Branchiostoma=*Amphioxus*) blood flows anteriorly in the caudal, sub intestinal, parietals, posterior cardinals, and ventral aorta. However, the blood flows backward in the laterals and median dorsal aorta, and anterior cardinals.

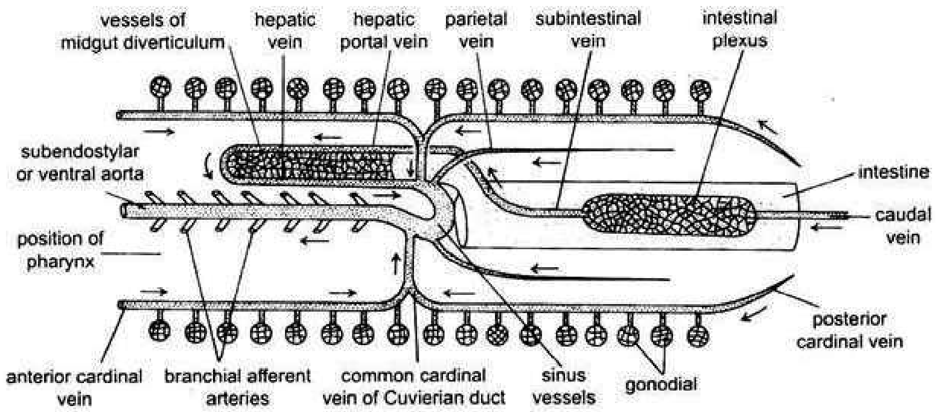

Fig. 3.17 The Course of Blood Circulation in a Cephalochordate

Blood Circulation in Urochordata

The peristaltic contractions of a small pear-shaped body and heart within the pericardium generates waves from one end of the heart to the other for quite a lot of beats, followed by a short pause thereafter the contractions begin again and the waves traverse in the opposite direction, thus, the flow of blood is alternatively in opposite directions. When the heart started beating in the dorso-ventral direction, then the blood is driven into the ventral aorta from where it goes to the tunic or test and pharynx through the transverse vessels. The blood is oxygenated here in the pharynx from where it approaches the dorsal aorta which enters the branchio-visceral vessel. From here the blood passes to the liver, gonads, esophagus, stomach, and intestine, and ultimately the blood from these organs and the test is collected by the cardio-visceral vessel and returned to the heart.

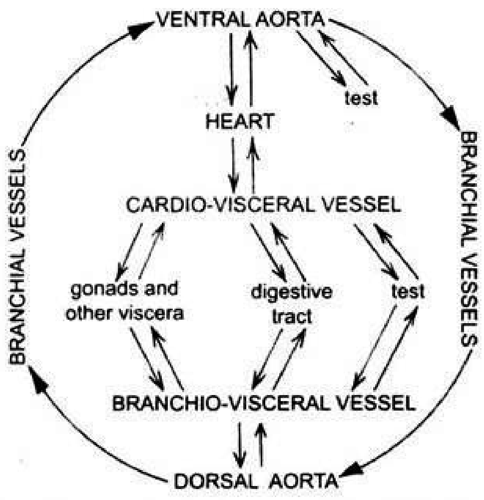

Fig. 3.18 *Course of Blood Circulation in Tunicates*

Blood Circulation in Pisces

In fishes, the cardiovascular system is of considerable interest because of its simple two-chambered heart. The fish heart is constructed for single circulation. In bony fish, it consists of two consecutive chambers pumping venous blood toward the gills via the ventral aorta. Thus, (i) the heart pumps blood toward the gills, (ii) the blood is aerated in the gills, (iii) arterial blood is dispersed into the capillaries where the transfer of oxygen and nutrients to the surrounding tissue takes place, (iv) the nutrients from ingested food are absorbed from the intestines, then transported to the liver and later dispersed in the blood throughout the body, and (v) in the kidneys the blood is 'purified' and waste products are excreted via the urine.

As the blood aerated in the gills, the arterial blood is collected in the dorsal aorta running underneath the vertebral column and from here it is distributed into the different tissues through capillaries. The venous blood returns to the heart, flowing in veins of increasingly larger size and all the veins are gathering into one blood vessel before entering the heart.

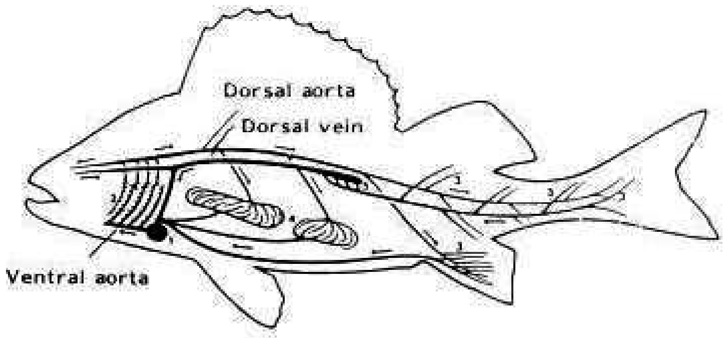

Fig. 3.19 *Pathways of Blood Circulation in Fishes*

Blood Circulation in Amphibia

In amphibians the heart continues to beat, taking dumpy rest between successive contractions, and drives the blood into the arteries. The heart muscles have an innate tendency to contract and relax with a definite rhythm. Each period of contrac-tion or systole is followed spontaneously by a shorter period of relaxation or diastole. The contraction starts at the sinus venosus, spreads to the auricles, thereafter to the ventricle, and ultimately to the conus arteriosus.

During the diastolic period, the sinus venosus receives deoxygenated blood from two precavals and the single postcaval vein. The left auricle simultaneously is filled with oxygenated blood through the common pulmonary vein. With the initiation of the systole, the sinus contracts, and the deoxygenated blood is pumped into the right auricle, through the sinuauricular aperture. This is followed by the auricular systole. The two auricles contract concurrently driving their contents into the single ventricle, through the auriculo-ventricular aperture. The regurgitation, of deoxygenated blood into the sinus venosus is disallowed by the shutting down of the sinuauricular valves. The ventricle now contracts and the blood does not flow back into the auricles due to the tight closing of the auriculo-ventricular aperture by the auriculo-ventricular valves.

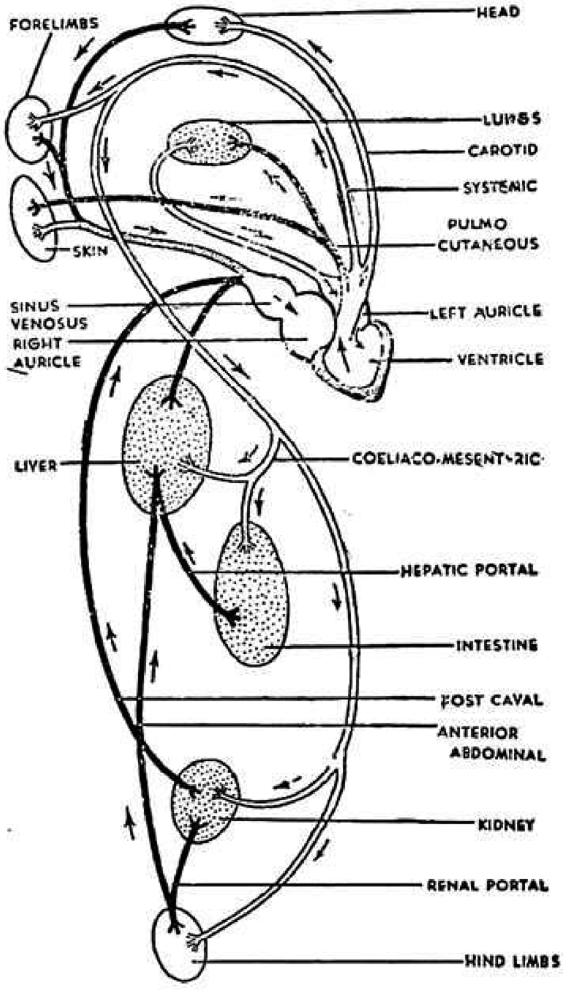

Fig. 3.20 *Course of Blood Circulation in an Amphibian*

They therefore, offer the least resistance to the entry of deoxygenated blood into them at the very beginning of the ventricular systole. The deoxygenated blood is aerated in the lungs and brought back to the left auricle through the pulmonary veins, thus completing the 'pulmonary circuit'. The portion of blood, which becomes oxygenated in the skin, is returned to the sinus venosus through the musculocutaneous vein. So this portion of oxygenated blood is mixed up with the deoxygenated bloodstream before it is returned to the heart. As the force of the ventricular contraction is increased, the mixed-blood in the middle of the ventricular cavity is pumped through the cavum aorticum into the systemic arches and distributed to the trunk and limbs. Lastly, the pressure exerted by the carotid labyrinths is overcome and the oxygenated blood in the left side of the ventricle is now forced into the carotid arches, through the cavum aorticum which is distributed to the head region of the animal.

It is to be clearly understood that the spiral valve directs the various courses of the three kinds of bloodstreams. During ventricular diastole, the blood cannot flow back from the arterial arches because of the pocket-like semilunar valves at the root of the conus. The systemic and carotid arches take the blood away to every part of the body, except lungs and skin. Food and oxygen are carried to the tissues in this way. The exchange of materials occurs by osmosis through the thin wall of the capillary networks. The blood is finally brought back to the heart by the three caval veins—thus completing the 'systemic circuit'. While returning, the blood collects carbon dioxide and nitrogenous waste products from the tissues.

Blood Circulation in Reptilia

In reptiles, the sinus venosus receives deoxygenated blood from the whole body by way of three venae cavae. The contraction of the sinus venosus is driving its blood into the right auricle through the sinuauricular aperture. Meanwhile, the left auricle receives oxygenated blood from the lungs through the pulmonary vein. Now the auricles contract almost simultaneously forcing the deoxygenated blood from the right auricle into the cavum pulmonale (right side of the ventricle). During this process, the return of blood to the sinus venosus is prevented by the sinuauricular valves. From the left auricle, the oxygenated blood enters the cavum dorsale (left side of the ventricle).

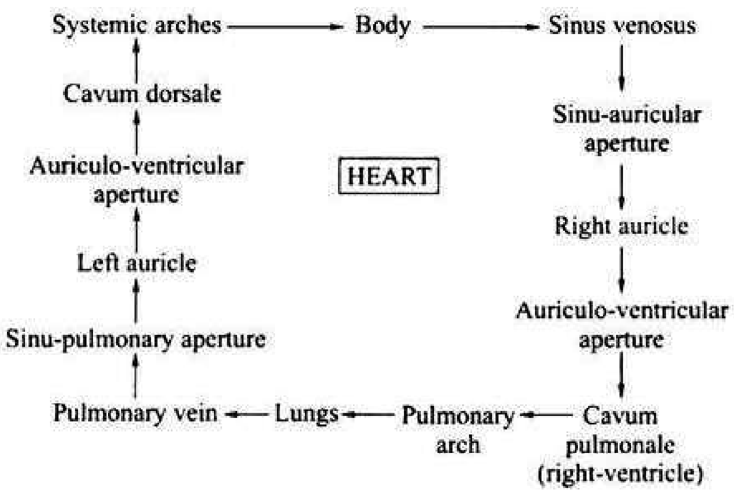

Fig. 3.21 *Corridor of Blood Circulation in a Reptile*

In the middle portion of the ventricle, some mixing of pure and deoxygenated blood takes place. Now the ventricle contracts in such a way that the muscular ridge keeps the deoxygenated and oxygenated blood separate. The contraction of the ventricle sends the deoxygenated blood from the cavum pulmonale into the pulmonary arch and the oxygenated and partly mixed blood from the cavum dorsal into the systemic arches which in turn is distributed to the entire body. The backward flow of blood from the ventricle into the auricles, during the contraction of the ventricle, is prevented by the auriculo-ventricular valves. However, the return of blood from the aortic arches in the ventricle is checked by the semilunar valves at the base of the arches. Therefore, it can be said that the heart of *Uromastix* is functionally four-chambered.

Blood Circulation in Aves and Mammalia

The course of blood circulation is quite more complex and interesting in both birds and mammals because of the four-chambered heart in which the venous and oxygenated blood remains completely separate. As far as the right part of the heart is concerned it receives venous blood and the left part having oxygenated blood. In one complete circuit in the body, the blood passes twice through the heart, once through its right side, and then through its left side. This type of circulation of blood is known as double circulation. The complete separation of ventricles into two chambers enables the venous and oxygenated blood not to mix at any stage.

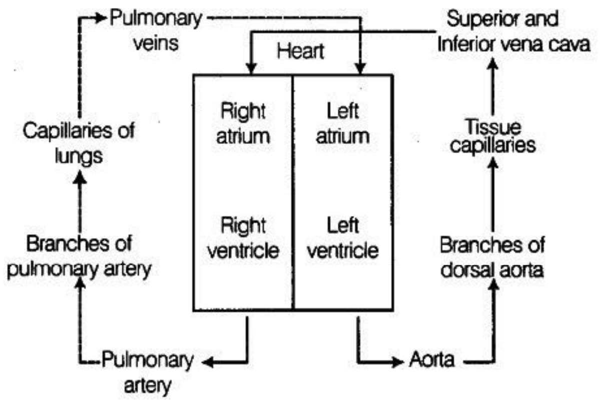

Fig. 3.22 *Course of Double Circulation in Birds*

The circulation of blood in the body parts from the heart can be represented as Oxygenated blood from lungs → left auricle → left ventricle → carotico- systemic aorta → arteries → arterioles and → arterial capillaries → various organs of the body → venous capillaries and venules (venous blood) → veins → precavals and postcaval → right auricle → right ventricle pulmonary aorta → pulmonary arteries → lungs (for purification) → pulmonary veins → left auricle (oxygenated blood). Thus, the blood passes through the heart twice – once through the pulmonary circuit and the second time through the systemic circuit.

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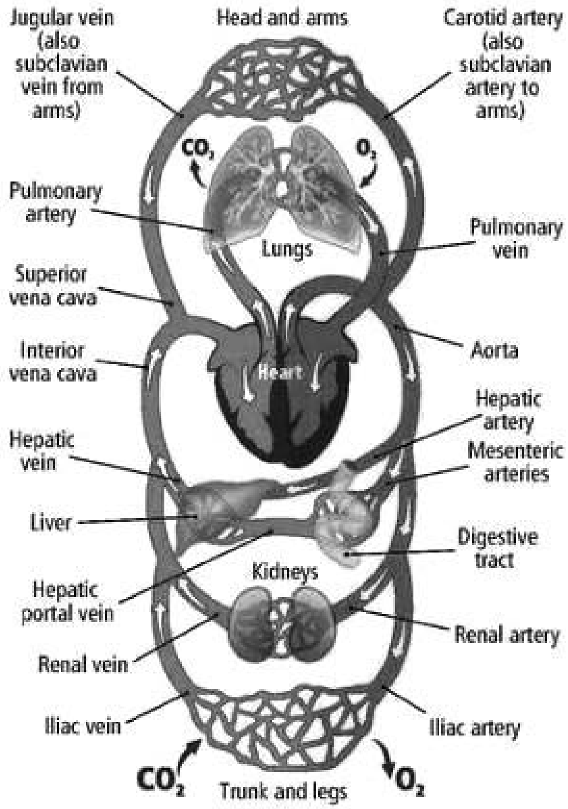

Fig. 3.23 *Schematic Representation of Double Circulation System in Mammals*

Check Your Progress

1. Define cardiovascular system.
2. Define blood.
3. What do you understand by erythrocytes?
4. What do you understand by leukocytes?
5. Define platelets.
6. Define hematocrit.

3.3 RESPIRATORY SYSTEM

Respiration and breathing are quite different biological activities but are sometimes used as a synonym in layman language. Breathing is a process of moving air into and out of the lungs and facilitates gaseous exchange to the internal environment, frequently by bringing in oxygen and flushing out carbon dioxide. On daily basis functions of the body such as digestion of food, movement of muscles or even just thinking, require oxygen. Thus during these physiological and metabolic processes, carbon dioxide is generated as a byproduct. So that the ultimate job of the lungs in this system is to provide oxygen for these processes and to get rid of the waste gas, carbon dioxide. While *respiration* refers to the mechanisms for obtaining oxygen from the air and delivering it to the tissues, meanwhile eliminating carbon dioxide from the body. Thus, respiration is a chemical reaction that happens in all living cells, including plant and animal cells. Hence, it is the way that energy is released from glucose so that all other chemical processes desirable for life can happen. Therefore, it is suggested do not to confuse respiration with breathing which is suitably called ventilation.

3.3.1 Characteristics of Respiratory Tissues and Comparative Account of Respiratory Organs

There is a great diversity in mode of breathing and respiration among chordates, therefore, modifications are found in respiratory organs accordingly based on evolutionary history, niche, habitats, and living styles. In the vertebrates, the skin may be respiratory (e.g., anurans), while in some fishes turtles, the vascular rectum or cloaca is respiratory. But broadly there are two main types of organs: gills for aquatic respiration and lungs for aerial respiration. The animals with amphibious habits comprise both lungs and gills within the same body. Besides the primary respiratory structures, some of the vertebrates having accessory respiratory organs also facilitate the better gaseous exchange to cope with the requirements.

Gills

The gills are the main organs for ventilation and respiration in aquatic and semiaquatic individuals. Usually, the amniotes are devoid of gills and solely depend on the lungs for breathing and respiration. Besides the exchange of gases at the surface of gills, salts are also eliminated from the surface of the gills in marine teleosts.

The gills develop on the walls of gill-pouches or gill-arches during embryogenesis. The gills are fashioned of rows of a series of gill-filaments or gill-lamellae evolved from the epithelial covering of the interbranchial septum on both sides. A single row of gill-filaments on one side of the interbranchial septum forms a hemibranch or demibranch, however, an interbranchial septum with two hemibranchs is termed as a complete gill or holobranch. These are richly supplied with blood vessels and associated with aortic arches for the exchange of gases.

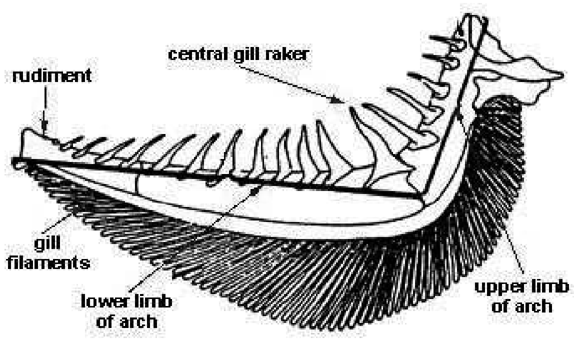

Fig. 3.24 *Schematic Presentation of a Gill Lamella*

a. **Gill Slits:** During ontogenesis, the gill-cleft develops as a result of evaginations or outgrowth from the pharynx and meets corresponding ectodermal invaginations from the outside. The gill-slits are persistent in adult cyclostomes, fishes, and certain amphibians, but missing in higher vertebrates. The numbers of gill-slits are 6-14 pairs in cyclostomes, 5-7 pairs in sharks, rays, and only 4 pairs in most of the bony fishes.

Types of Gills:

Gills are of two types based on their position: external gills and internal gills:

i. **External Gills:** In the larvae of aquatic and semiaquatic amphibians the surface integument of visceral arches gives off branching tufts of respiratory filaments. Thus, external gills are ectodermal in embryonic origin. In some urodeles, external gills and gill clefts are retained lifelong, but in some urodeles and all anurans are lost during metamorphosis.

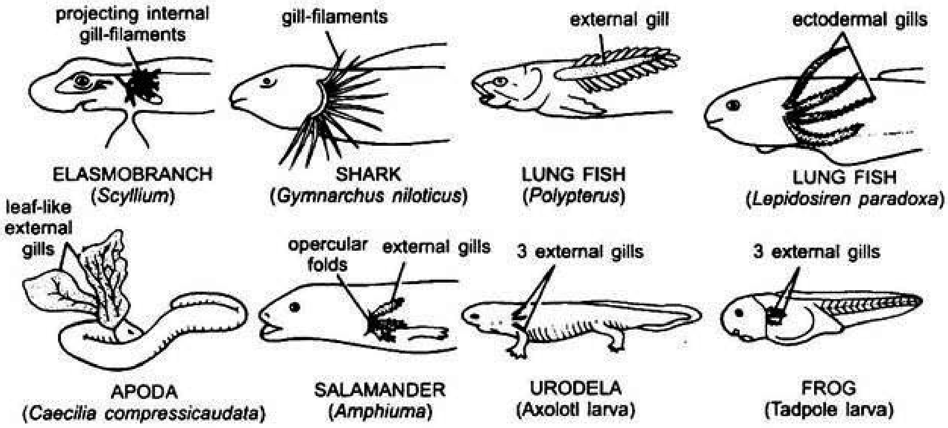

Fig. 3.25 *Diversity of External Gills in Different Groups of Vertebrates*

ii. **Internal Gills:** The internal gills are the noticeable feature of Pisces. These gills are placed in the gill clefts and attached to the visceral arches. In amniotes, the embryonic pharyngeal pouches do not correspond to the exterior through gill clefts in the adults. Therefore, gills are not found in them and they have advanced respiratory organs adapted to the aerial mode of respiration called lungs.

Comparative Account of Lungs

Most of the adult amphibians and every amniote breathe employing lungs. The lungs are also present in a group of fishes having discontinuous distribution, Dipnoi usually termed as lungfishes. In lower forms of vertebrates, the lungs are hollow bags, but in higher forms, the ridges were numerically added and united with one another across the lumen of the lung to transform or modify into a solid and spongy structure with incalculable air spaces. The types of lungs are:

a. **Pisces:** All the lungfishes (*Protopterus, Lepidosiren,* and *Neoceratodus*) are discontinuous in distribution placed in group Dipnoi. These are provided with paired ventral lungs that facilitate them to survive during droughts or unfavorable conditions.

b. **Amphibia:** In amphibians, the lungs are simple, sac-like structures with a central large cavity. On contrary to terrestrial amphibians, the lungs of aquatic amphibians comprise a smooth inner surface, while in others the inner walls contain numerous folds or inwards growth to increase the surface area.

c. **Reptilia:** The reptilian lungs are more complex than amphibians with an augment in the number of internal air chambers and alveoli (blind terminal sacs). The crocodilians lungs are quite more advance than the typical reptilian lungs and fairly similar to the mammals.

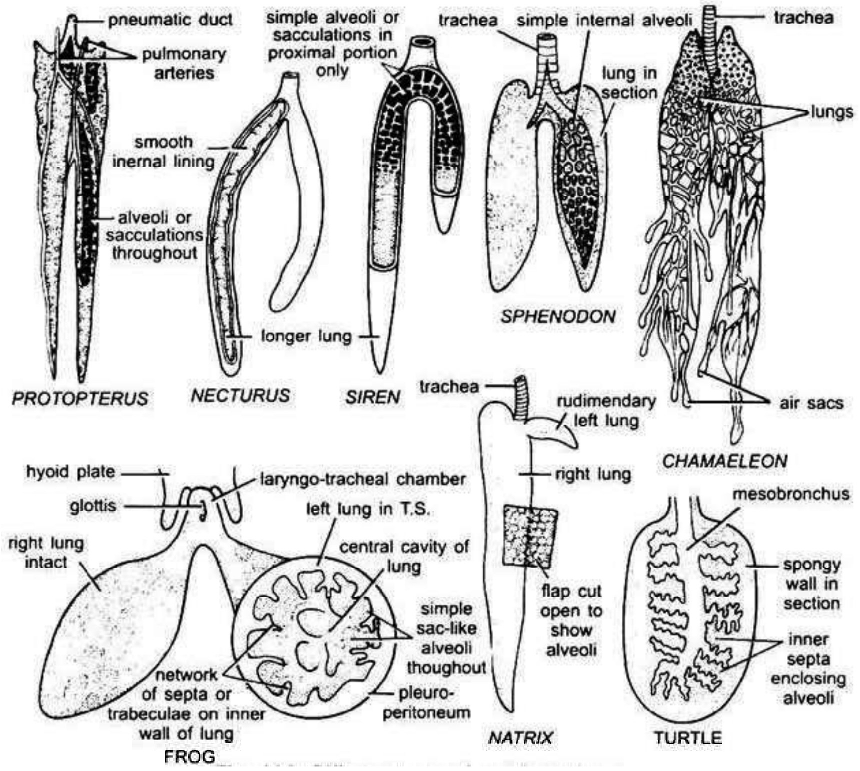

Fig. 3.26 *Structural Diversity of Lungs in Different Vertebrates*

d. **Aves:** The lungs of birds are smaller and incompetent in great expansion. The lungs of birds are associated with nine air sacs that are situated in the various parts of the body acts as an air reservoir or air basin. The air leads through bronchial circuits into air sacs and comes back, by and large through a different set of bronchi, to the air capillaries in the lungs.

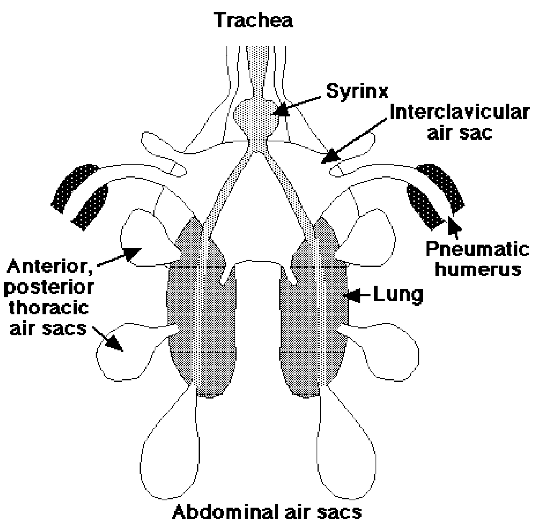

Fig. 3.27 *Respiratory System in Birds with Spongy Lungs and Air Sacs*

e. **Mammalia:** The mammalian lungs are less complicated than that the avian lungs. Mostly the mammalian lungs are externally subdivided into lobes. The left lung has two lobes while the right lung has three lobes in man and four lobes in the rabbit. The lungs of aquatic mammals (cetaceans and sirenians), elephants, and perissodactyls are simple and without lobes. The trachea or windpipe is divided into the two left and right primary bronchi which after entering the lung carve up into secondary bronchi that further alienated into many smaller bronchioles, and ultimately ending in numerous tiny alveoli or blind pockets. These alveoli or blind terminal pockets are the ultimate sites of gaseous exchange.

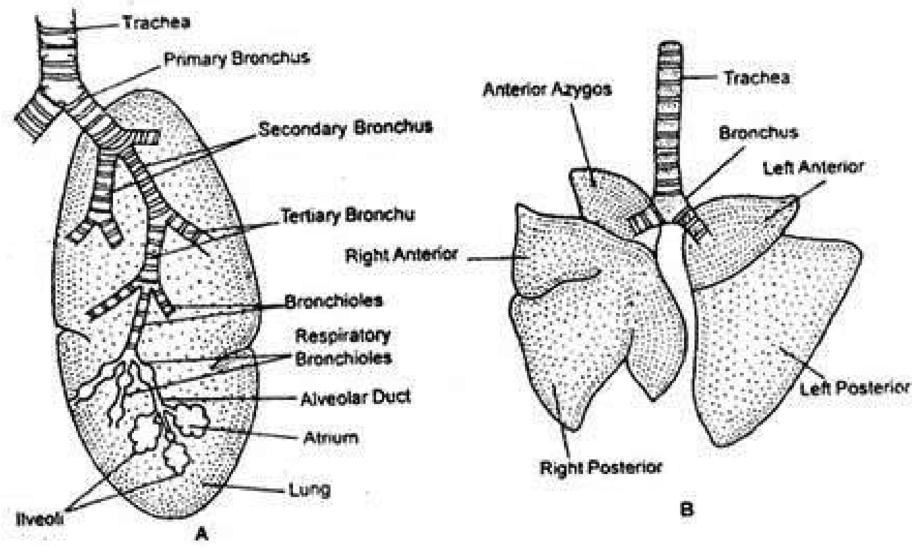

Fig. 3.28 *A Typical Structure of Mammalian Lungs: Bronchial System and Alveoli (A); External Lobed Structure of Complete Lungs (B)*

Development of Lungs

During embryogenesis, lung primordium arises as a hollow out pushing from the ventral wall of the pharynx. The primordia grow backward and divide into right and left lung buds. The anterior undivided part evolves into the trachea and soundbox (larynx). Later lung buds grow distally into coelom and branches over and over again and get surrounded by mesoderm.

Anatomically, each lung has an endodermal lining and an outer visceral peritoneum. In between these linings, mesodermal mesenchymes are present. The mesodermal mesenchyme has blood and lymph vessels, nerves, and smooth muscle fibers, and connective tissue. The inner endodermal epithelium of the lungs is raised into a network of ridges to increase the vascularised surface exposed to the exchange of gases.

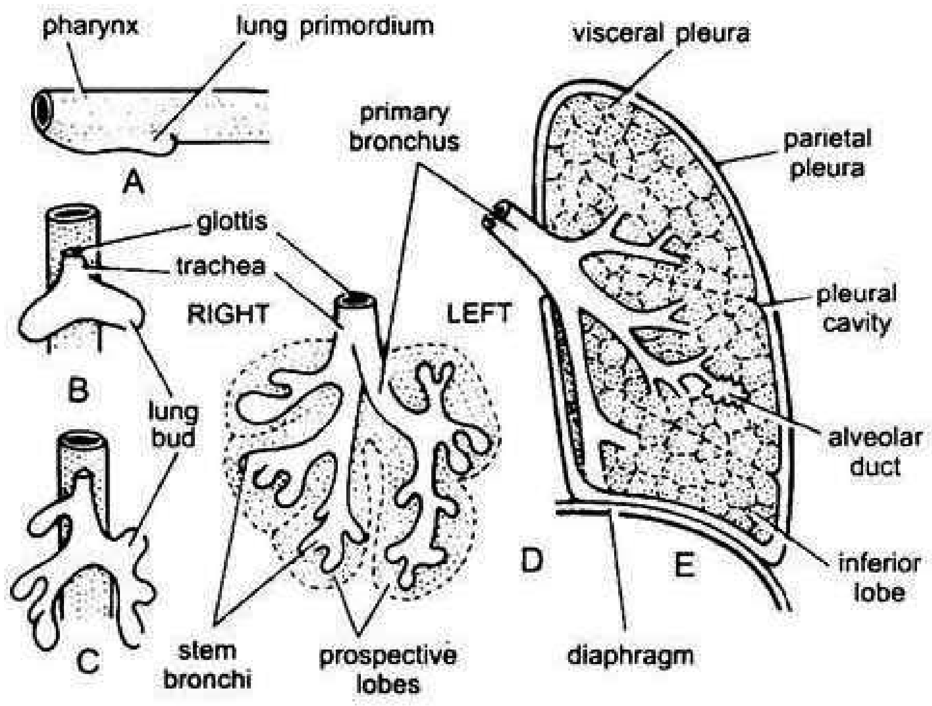

Fig. 3.29 *Embryonic Development of Lungs in the Vertebrates*

Accessory Respiratory Organs

There are many accessory structures for breathing and respiration. The structures which facilitate or taking part in the transport or take of oxygen directly from water or air are called accessory respiratory organs.

i. **Integument:** Some fishes can survive outside water during unfavorable or drought situations. The common eel, *Anguilla* even though has no special respiratory organs, but comprises vascular areas in the skin by which it knows how to breathe both in water and on land. The moist skin of amphibians is also highly vascular and suited for cutaneous respiration during semiaquatic or terrestrial life. Some urodeles including lungless salamanders opted to respire only by skin.

ii. **Air Chamber:** The climbing perch *Anabas* has special air chambers above the gills and comprising labyrinthine bony laminae, developed from the first epibranchial bone on each side. The vascular mucous membrane of the labyrinth assists in aerial respiration. The *amphibious*, *Channa, Heteropneustes,* and *Clarias* having accessory branchial cavities on each side above the gills also.

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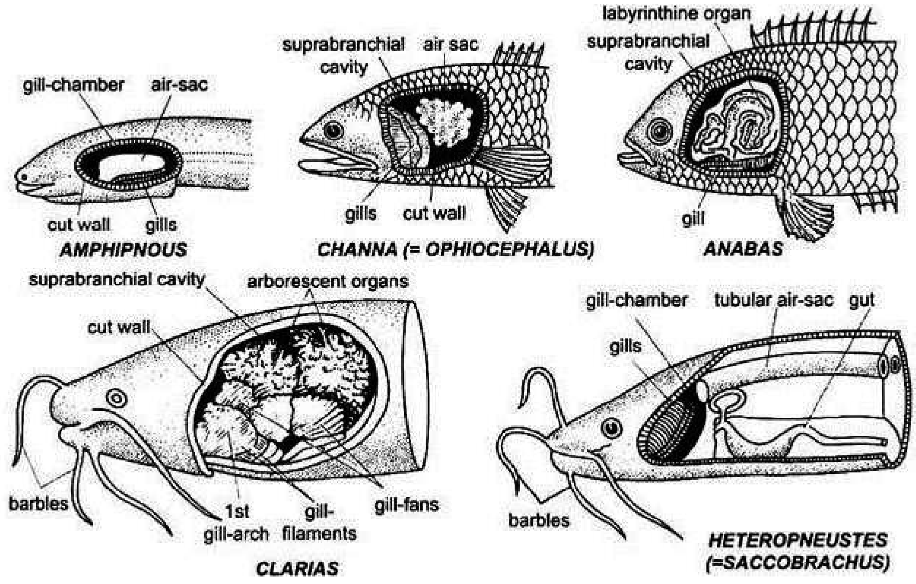

Fig. 3.30 *Structural Diversity of Accessory Respiratory Organs in Fishes*

iii. **Intestinal Epithelium:** The epithelial lining of the definite zone of the alimentary canal becomes vascular and customized to work as a respiratory organ in many fishes. It may be just behind the stomach (*Misgurus fossilis*) or intestine (*Lepidocephalus guntea*, *Gobitus*), or rectum (*Callichthyes, Hypostomus*, and *Doras*).

iv. **Pharyngeal Diverticula:** These are a pair of simple sac-like outgrowths of the pharynx, lined by obese vascular epithelium and extending above the gills. The *Amphipnous cuchia* comprises a pair of pharyngeal diverticula that opens anteriorly into the first gill-slit function physiologically as lungs.

v. **Branchial Diverticula:** These are the outgrowth from gill chambers and modified as aerial accessory respiratory organs in some fishes. Such air-breathing organs are found in *Heteropneustes, Clarias, Anabas, Trichogaster, Macropodus, Betta*, etc.

vi. **Air Bladder:** The air bladder of lower bony fishes acts as a lung to breathe air. The wall of the bladder is highly vascular and sacculated with blind air sacs present in *Amia* and *Lepidosteus*.

vii. **Fins:** During the breeding period, the pelvic fins of male American lungfish, *Lepidosiren*, become puffy and grow filamentous vascular outgrowths to make available fresh oxygen to the guarded eggs.

3.3.2 Mechanism and Significance of Respiration: External and Internal Respiration

The process of physiological respiration includes two major parts: external respiration and internal respiration. External respiration, also known as breathing, involves both bringing air into the lungs (inhalation) and releasing air into the atmosphere (exhalation). During internal respiration, oxygen and carbon dioxide are exchanged between the cells and blood vessels. Respiration begins at the nose or mouth, where oxygenated air is brought in before moving down the pharynx, larynx, and trachea. Trachea further branches into two bronchi and each leading into the respective lung. Each bronchus divides into smaller bronchi, and again into even smaller tubes called bronchioles. At the end of the bronchioles are air sacs called alveoli, and this is where gas exchange occurs. During the gas exchange in animals, oxygen and carbon dioxide diffuse in and out of the blood in the lungs and metabolizing tissues. Oxygen is used in cellular respiration, produces metabolic energy to carry out cellular functions. During cellular respiration, carbon dioxide is produced as waste. The gas exchange occurs at the respiratory membrane in the lungs and in metabolizing tissues like skeletal muscles. The partial pressure gradient of each gas determines the direction and the rate of diffusion across the respiratory membrane. The main difference between internal respiration and external respiration is that internal respiration refers to the gas exchange across the respiratory membrane in the metabolizing tissues whereas external respiration refers to the gas exchange across the respiratory membrane of lungs. While pulmonary ventilation is the process by which oxygen enters and carbon dioxide exits the alveoli. However, respiration is the process by which oxygen and carbon dioxide diffuse in and out of the blood.

Mechanism of Respiration

The mechanism of respiration is quite alike in pisces and amphibians. When the floor of the buccal cavity is lowered and water (in fishes) or air (in amphibians) is taken in, followed by the closing of the mouth. The floor of the buccal cavity is raised and forces the water into gill clefts (in fishes) or the air into lungs (in amphibians). However, in amniotes air is taken in after increasing the volume of lungs by an expansion of the thoracic cavity. The expansion of the thoracic cavity is achieved by the movement of ribs and diaphragm (in mammals). As in turtles, the ribs are fixed to the carapace therefore, the volume of the lungs is increased by movements of the neck and limbs. The respiratory system has many different parts that work together to help to breathe. Each group of parts has many separate components. The airways deliver air to your lungs that include: (i) Mouth and nose (Openings that pull air from outside your body into your respiratory system); (ii) Sinuses (Hollow areas between the bones in your head that help regulate the temperature and humidity of the air you inhale); (iii) Pharynx (throat is a tube that delivers air from your mouth and nose to the trachea (windpipe); (iv) Trachea (Passage connecting your throat and lungs); Bronchial tubes (Tubes at the bottom of your windpipe that connect into each lung); (v) Lungs (Two organs that remove oxygen from the air and pass it into your blood). From the lungs, the bloodstream delivers oxygen to all the organs and other tissues. Meanwhile, the muscles and bones help move the air inhale (inspiration) into and out of the lungs (expiration). Some of the bones and muscles in the respiratory system include (i) the Diaphragm (Muscle that helps lungs pull in air and push it out); (ii) Ribs (Bones that surround and protect your lungs and heart). When breathe out, blood carries carbon dioxide and other waste out of the body. Other components that work with the lungs and blood vessels include (i) Alveoli (Tiny air sacs in the lungs where the exchange of oxygen and carbon dioxide takes place); (ii) Bronchioles (Small branches of the bronchial tubes that lead to the alveoli); (iii) Capillaries (Blood vessels in the alveoli walls that move oxygen and carbon dioxide); (iv) Lung lobes (Sections of the lungs- three lobes in the right lung and two in the left lung); (v) Pleura (Thin sacs that surround each lung lobe and separate your lungs from the chest wall). There are some of the other components of the respiratory system which assist the mechanism of respiration, like: (i) Cilia (Tiny hairs that move in a wave-like motion to filter dust and other irritants out of airways); (ii) Epiglottis (Tissue flap at the entrance to the trachea that closes when swallowed to keep food and liquids out of airway); (iii) Larynx or voice box (Hollow organ that allows to talk and make sounds when air moves in and out).

Functions of the Respiratory System

The respiratory system is responsible for obtaining oxygen and getting rid of carbon dioxide and aiding in speech production and in sensing odors. From a functional perspective, the respiratory system can be grouped into two major areas: the conducting zone and the respiratory zone. The conducting zone consists of all of the structures that provide passageways for air to travel in and out of the lungs, e.g., nasal cavity, pharynx, trachea, bronchi, and most bronchioles. The nasal passages contain the conchae and meatuses that expand the surface area of the cavity to regulate the temperature and humidity of moving air. The pharynx is composed of three major sections: the nasopharynx (continuous with nasal cavity); the oropharynx (borders the nasopharynx and oral cavity), and the laryngopharynx (borders the oropharynx, trachea, and esophagus). The respiratory zone includes the structures of the lung that are directly involved in the exchange of gases, e.g., the terminal bronchioles and alveoli.

The accessory respiratory organs of *Heteropneustes* and *Clarias* are the modifications of the gills. During the Tertiary and Quaternary periods of the Cenozoic era, the oxygen level of the atmosphere and water was quite more reduced. So that due to the depletion of oxygen levels in rivers and swamps, the gills were not able to deal with the necessities of the body. Hence, several teleostean species developed and evolved diversified accessory respiratory organs to absorb oxygen from the air to fulfill the requirement. This shows the capability of accessory respiratory organs in maintaining the life of the fish and other vertebrates in oxygen-deficient water. The respiratory system has many functions besides helping to inhale (breath in) and exhale (breath out). It: (i) Allows you to talk and to smell; (ii) Warms air to match your body temperature and moisturizes it to the humidity level your body needs; (iii) Delivers oxygen to the cells in your body; (iv) Removes waste gases, including carbon dioxide, from the body when you exhale; (v) Protects your airways from harmful substances and irritants.

Clinical Conditions in the Respiratory System

Conditions that can cause inflammation (swelling, irritation, and pain) or otherwise affect the respiratory system include:

- **Allergies:** Inhaling proteins, such as, dust, mold, and pollen, can cause respiratory allergies in some people. These proteins can cause inflammation in your airways.
- **Asthma:** A chronic (long-term) disorder, asthma causes inflammation in the airways that can make breathing difficult.
- **Infection:** Infections can lead to pneumonia (inflammation of the lungs) or bronchitis (inflammation of the bronchial tubes). Common respiratory infections include the flu (influenza, COVID-19) or a common cold.

- **Disease:** Respiratory disorders include lung cancer and chronic obstructive pulmonary diseases, Severe Acute Respiratory Syndrome (SARS). These illnesses can harm the respiratory system's ability to deliver oxygen throughout the body and filter out waste gases.
- **Aging:** Lung capacity decreases as you get older.
- **Damage:** Damage to the respiratory system can cause breathing problems.

Check Your Progress

7. Define breathing.
8. What do you understand by gills?
9. What do you understand by branchial diverticula?
10. Define pharyngeal diverticula.

3.4 SKELETAL SYSTEM

The skeletal system is the body's central framework which consists of bones and connective tissue, including cartilage, tendons, and ligaments. It's also called the musculoskeletal system. In other words, the skeletal system can be defined as a network of many different parts that work together to help you move. The main part of the skeletal system consists of bones, hard structures that create the body's framework called the skeleton. There are 206 bones in an adult human skeleton while children's skeletons contain more bones because some of them, including those of the skull, fuse as they grow up. There are also some differences in the male and female skeletons. The male skeleton is usually longer and has a high bone mass. The female skeleton, on the other hand, has a broader pelvis to accommodate for pregnancy and childbirth. The human skeletal system consists of all of the bones, cartilage, tendons, and ligaments in the body. Altogether, the skeleton makes up about 20% of a person's body weight.

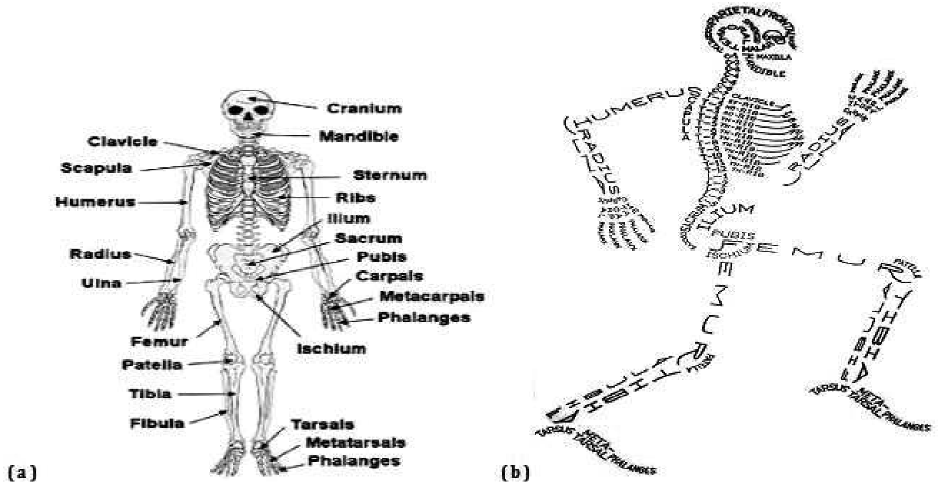

Fig. 3.31 In Situ Front-Ventral View (a), and Schematic Lateral View (b) of the Human Skeletal System

3.4.1 Elements of the Skeletal System

The components of the skeletal system include cartilage, joints, ligaments, tendons, and bones.

i. **Cartilage:** This smooth and flexible substance covers the tips of your bones where they meet. It enables bones to move without friction (rubbing against each other). When the cartilage wears away, as in arthritis, it can be painful and cause movement problems.

ii. **Joints:** A joint is where two or more bones in the body come together. There are three different joint types. The types of joints are: (a) Immovable joints don't let the bones move at all, like the joints between your skull bones, (b) Partly movable joints: allow limited movement. The joints in your rib cage are partly movable, and (c) Movable joints allow a wide range of motion. Your elbow, shoulder, and knee are movable joints.

iii. **Ligaments:** Bands of strong connective tissue called ligaments hold bones together.

iv. **Tendons:** Tendons are bands of tissue that connect the ends of a muscle to your bone.

v. **Bones:** Bones are living tissues that make up the body's skeleton. There are 3 types of bone tissue: (a) Compact tissue (this is the harder, outer tissue of bones also called periosteum), (b) Cancellous tissue (this is the sponge-like tissue inside bones), and (c) Subchondral tissue (this is the smooth tissue at the ends of bones, which is covered with another type of tissue called cartilage). Cartilage is a specialized, rubbery connective tissue. Based upon the forms constituents the bone may be compact bone and or spongy bone.

3.4.2 Forms and Body Size of the Skeletal System

Regardless of age or sex, the skeletal system can be broken down into two parts, known as the axial skeleton and the appendicular skeleton. The adult axial skeleton consists of 80 bones. It's made up of the bones that form the vertical axis of the body, such as the bones of the head [skull bones, i.e., 22 (8 cranial and 14 facial bones); 6 ear ossicles (3 (malleus, incus, stapes) in each ear); and U-shaped hyoid], vertebral column, i.e., 26 bones (8 cervical vertebrae in the neck; 12 thoracic vertebrae in back; 5 lumbar vertebrae in the waist; sacrum and coccyx as rudimentary tail), chest [i.e., thoracic cage made of the sternum (breastbone) and 12 pair of ribs], and spine. However, there are a total of 126 bones in the appendicular skeleton that make up the arms and legs, as well as the bones that attach them to the axial skeleton. It comprises 2 pectoral girdles or shoulder bones [each with the clavicle (collarbone) and scapula (shoulder blade)]; 2 sets of upper limb bones [each set with 30 bones (humerus in upper arm area, Radius and ulna in lower arm area, carpals (8 bones in wrist area), metacarpals (5 bones in palm area) and phalanges (14 bones that make up the fingers)]; 2 pectoral girdles or hip bones (each hop bone comprises ilium, ischium, pubis); 2 sets of lower limb bones [each set with 30 bones (femur in the upper leg area, tibia, and fibula in lower leg area; patella or kneecap, tarsals (seven bones that make up the ankle), metatarsal (five bones that make up the middle foot), phalanges (14 bones that comprise the toes).

3.4.3 Functions of the Skeletal System

The skeletal system has many functions. Besides giving us our human shape and features, it:

i. **Allows Movement:** Skeleton supports body weight to help stand and move. Joints, connective tissue, and muscles work together to make body parts mobile.

ii. **Produces Blood Cells:** Bones contain bone marrow. Red and white blood cells are produced in the bone marrow.

iii. **Protects and Supports Organs:** Skull shields or covers brain, ribs protect heart and lungs, and backbone protects the spine.

iv. **Stores Minerals:** Bones hold the body's supply of minerals like calcium and vitamin D.

3.4.4 Clinical Conditions of the Skeletal System

Many conditions can affect the bones, joints, and tissues that make up the skeletal system. Some happen as a result of disease or injury. Others develop due to wear and tear as you get older. Conditions that may affect the skeletal system can include:

(a) **Arthritis:** Age, injury, and medical conditions such as Lyme disease can lead to arthritis, a painful wearing down of joints,

(b) **Fracture:** Disease, a tumor, or trauma can put stress on a bone, causing it to break,

(c) **Osteosarcoma:** Cancer that forms in the bones can cause tumors that may weaken and break bones,

(d) **Osteoporosis:** Bone loss caused by not getting enough calcium can lead to fragile and brittle bones, known as osteoporosis, and

(e) **Sprains and Tears:** Age, disease, and trauma can cause connective tissue to overstretch and tear.

3.4.5 Comparative Account of Jaw Suspensorium

The axial skeletal framework of a vertebrate head is called a skull which is a structure of several bones that fused. A lamprey has a skull consisting of a braincase and cartilages of the tongue, and sharks having a skull made of a braincase and isolated upper and lower jaw bars. But commonly in animals ranging from fishes to mammals, the skull has a braincase to which the upper jaws are welded by a series of bones, the lower jaw is not included.

Jaw suspensorium is a structure of attachment of the lower jaw and upper jaw. The jaw suspensoria can be defined as the attachment of the lower jaw with the upper jaw or the skull for efficient biting and chewing. There are different ways in which these attachments are attained depending upon the modifications in visceral arches in the vertebrates. Some workers may explain it as a method by which the upper and lower jaws are suspended or attached from the chondrocranium is known as jaw suspension or suspensorium. Amongst the visceral arches, the first (mandibular) arch consists of a dorsal palato-pterygoquadrate bar forming the upper jaw, and ventral Meckel's cartilage forms the lower jaw. The second (hyoid) arch consists of a dorsal hyomandibular supporting and suspending the jaws with the cranium, and a ventral hyoid. The remaining visceral arches support the gills hence, called branchial arches. Thus, splanchnocranium forms the jaws and suspends them with chondrocranium.

Types and Comparison of Jaw Suspensoria

There are nine types of jaw suspensoria or jaw suspension found in vertebrates.

- **Amphistylic:** In ancient elasmobranchs, there is no modification of visceral arches because of cartilaginous features. The pterygoquadrate forms the upper jaw and the Meckel's cartilage makes the lower jaw and both are highly flexible. The lower jaw is attached to both the pterygoquadrate and hyoid arch and hence it is called amphistylic. Thus the upper jaw (mandibular arch) has basal and otic processes which are attached by ligaments to the chondrocranium. On the other hand, the hyomandibular of the hyoid arch is also attached to the chondrocranium. This type of suspensorium is found in Crossopterygii and some primitive sharks *Heptanchus* and *Hexanchus*.
- **Autodiastylic:** In this case, the upper jaw is attached to the skull and the lower jaw is directly attached to the upper jaw. The second arch is branchial and does not take part in jaw suspension so that the jaws are attached by ligaments to the chondrocranium. The hyoid arch does not support the jaws but remains completely free as the posterior branchial arches. The gill-cleft in front of the hyoid arch does not form a spiracle but forms a complete gill, e.g., early bony fishes (acanthodians).
- **Hyostylic:** In modern sharks, the lower jaw is attached to pterygoquadrate which might be in turn attached to the hyomandibular cartilage of the second arch. It is the hyoid arch that is found to be braced with the jaw by ligament attachment and therefore, it is called hyostylic. Thus the upper jaw (palatoquadrate) is loosely articulated with the cranium by the anterior ethmopalatine ligament and posterior spiracular ligament. Both jaws are suspended from the hyomandibular which is attached to the otic region of the skull. Thus, only the hyoid arch binds both the jaws with the cranium and, hence, it is called hyostylic. It is found in most elasmobranchs and bony fishes. These fishes can swallow large prey. In fishes, the autodiastylic suspension is the most primitive, the amphistylic condition was derived from it, while the hyostylic condition is the most recent having arrived independently.

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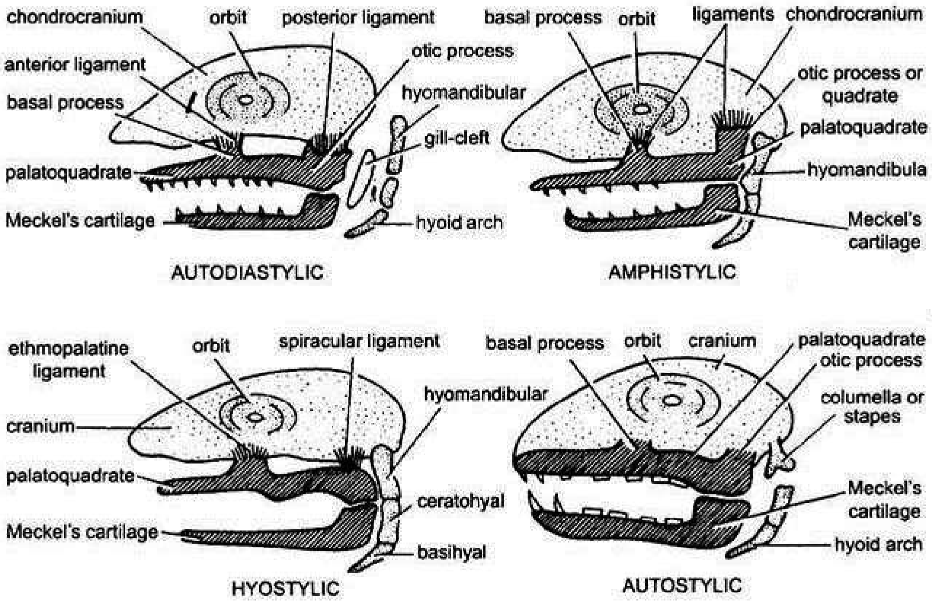

Fig. 3.32 *Comparative and Illustrative Outline Different Types of Jaw Suspensoria in Various Vertebrates*

- **Autostylic (=Autosystylic):** The pterygoquadrate is transformed to epipterygoid and quadrate. Out of these two the latter braces the lower jaw with the skull. Hyomandibular of the second arch transforms into columella bone of the middle ear cavity and hence not available for jaw suspension. Thus the upper jaw (palatoquadrate) is completely fused by its processes to the bony skull and the articular of the lower jaw is suspended from the quadrate of the upper jaw. The hyomandibular does not take part in suspensorium and is modified into columella or stapes of the middle ear, therefore, some authorities may use the term autosystylic for autostylic. It is found in extinct placoderms, chimaeras, lungfishes, and tetrapods. In these, the quadrate of the upper jaw articulates with the articular of the lower jaw.
- **Methystylic:** In bony fishes, pterygoquadrate is wrecked into epipterygoid, metapterygoid and quadrate, which become part of the skull. Meckel's cartilage is modified as articular bone of the lower jaw, through which the lower jaw articulates with quadrate and then with the symplectic bone of the hyoid arch to the skull. This is a modified hyostylic jaw suspension that is more advanced.
- **Monimostylic:** This type of suspension is a modification of autosystylic suspension in which the quadrate is immovable and not flexible as in amphibia and many reptiles. Hyomandibular is modified as columella bone of the middle ear cavity.
- **Streptostylic:** This type is found in snakes, lizards, and birds, in which quadrate bone is movable and flexible at both ends making the jaw highly flexible. The columella is a single bone in the middle ear cavity and is sometimes may be termed as stapes.

- **Holostylic:** This type is found in lungfishes and Holocephali. The upper jaw is fused with the skull and the lower jaw is attached directly with it. The hyoid arch does not participate in jaw suspension and is a typical branchial arch. There is no columella bone.
- **Craniostylic:** It is found in mammals, and in this type of jaw suspension, pterygoquadrate is modified into alisphenoid and incus, while Meckel's cartilage is changed into malleus and not available for jaw suspension. The lower jaw is directly attached to the skull bone called the squamosal. The upper jaw is fused with the cranium in its entire length. The hyomandibular forms the stapes of the middle ear bone, however, the quadrate and articular are modified into malleus and incus respectively. Thus, the squamosal of the skull and dentary of the lower jaw articulates with each other and some consider it as a modification of autostylic type.

3.4.6 Comparative Account of the Vertebral Column

The vertebral column is a sigmoid structure in human beings and is also called backbones. It is the replacement or modification of embryonic notochord that comprising several unitary structures called vertebrae which is usually 33 in number. Out of these 33, three are 24 presacral vertebrae (7 cervical, 12 thoracic, and 5 lumbar) followed by the sacrum (5 fused sacral vertebrae) and coccyx (4 frequently fused coccygeal vertebrae). The 24 presacral vertebrae allow movement and hence render the vertebral column flexible. Stability is provided by ligaments, muscles, and the form of the bones. The abbreviations C., T., L., S., and Co. are used for the regions, and these are sometimes followed by V. for vertebra or N. for nerve.

The adult vertebral column presents four anteroposterior curvatures: Thoracic and sacral both concave anteriorly, and cervical and lumbar, both concave posteriorly. The thoracic and sacral curvatures termed primary, appear during the embryonic period proper, whereas the cervical and lumbar curvatures, termed secondary, appear later (although before birth) and are accentuated in infancy by the support of the head and by the adoption of an upright posture.

Notochord

The primitive axial skeleton is a notochord present in all chordate embryos. It is formed from chordamesoderm cells. It is a stiff rod below the nerve cord and above the alimentary canal running from the infundibulum to the hind end of the body. At first, the cells of the notochord are packed closely but later they fuse and become vacuolated, except for a layer of peripheral cells. The notochord is enclosed in an inner and outer elastic fibrous sheath of connective tissue called elastica interna and elastica externa respectively.

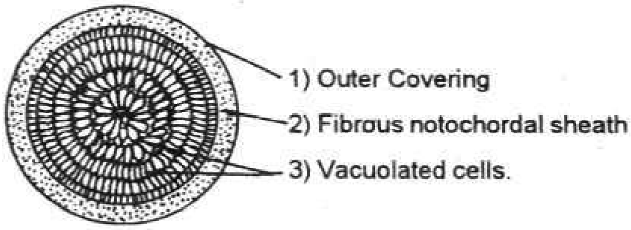

Fig. 3.33 *T.S. of a Typical Notochord in Pre-vertebrate Chordates*

In protochordate (*Branchiostoma=Amphioxus*) and cyclostomes (lamprey), the axial skeleton is primarily the notochord, which persists throughout the life of the animal. In hagfishes, small cartilaginous elements are present in the caudal region, and in lampreys, two pairs of cartilaginous elements occur on either side of the spinal cord in each body segment.

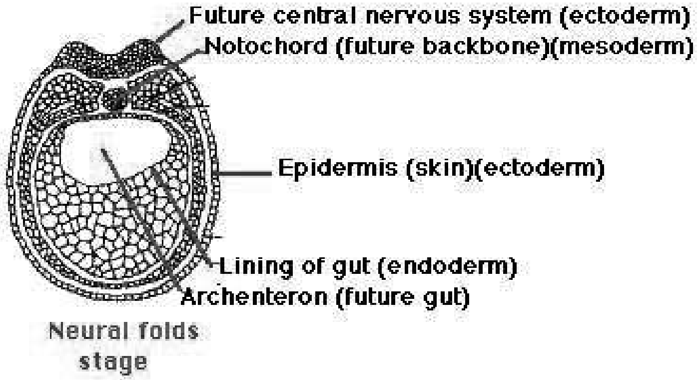

Fig. 3.34 *Diagrammatic Representation of Neural Fold Stage Showing Notochord*

They do not meet above to form a neural arch. In some lower bony fishes (sturgeon), the notochord persists unchanged and, although neural and haemal arches are present, a centrum is lacking. In chimaeras and lungfishes, cartilage begins to invade the notochordal sheath. In most fishes centrum is well developed. In fishes and higher animals, the notochord is later surrounded by cartilaginous or bony rings called vertebrae. The notochord is practically obliterated in tetrapods. The vertebral column is made of a metameric series of vertebrae extending longitudinally from the skull to the tip of the tail.

Vertebrae

Vertebrae of various animals are different, even in the same vertebral column there are differences, but all vertebrae conform to a basic plan. Generally, fish vertebrae are divisible into trunk or preanals and the caudal or postanals. The caudals are recognizable by the presence of a haemal arch on the underside of the centrum or notochord. Centrum in fishes is amphicoelous. In tetrapods, the vertebral column has five regions- cervical, thoracic, lumbar, sacral, and caudal, each has several vertebrae. Amphibians have a single cervical (atlas) and one sacral (9th) vertebra.

Structure of Vertebrae

A typical vertebra has a cylindrical body or centrum which encloses or replaces embryonic notochord. Above the centrum is a neural arch enclosing a neural canal through which the nerve or spinal cord passes. The neural arch is produced dorsally into a neural spine. In the caudal region of fishes, below the centrum is a haemal arch enclosing a haemal canal through which the caudal artery and vein pass. The haemal arch is produced below into a haemal spine. In addition to the transverse and spinous processes, which serve as short levers, the 12 thoracic vertebrae are connected by joints with paired, long levers, namely the ribs.

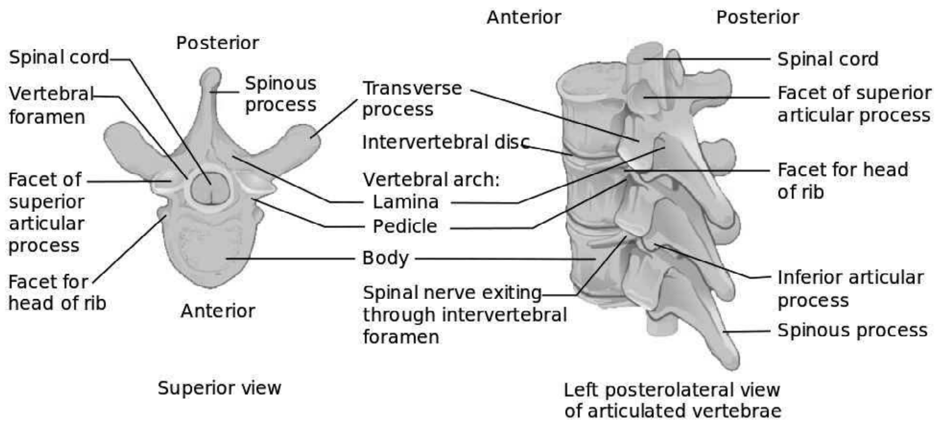

Fig. 3.35 *Structure of a Typical Vertebra*

The bodies of the vertebrae are separated from each other by intervertebral discs. The body is mainly spongy bone and red marrow, but the margins of the upper and lower surfaces consist of a ring of compact bone, the vertebral end-plates. The body is marked on its sides by vascular foramina.

The vertebral arch consists of right and left pedicles (which connect it to the body) and right and left laminae. The transverse processes emerge laterally at the junction of the pedicles and laminae, and the spinous process proceeds posteriorly from the union of the laminae. The superior and inferior articular processes project vertically from the vertebral arches on each side and bear articular facets. When the vertebra is in its anatomical position, notches between adjacent pedicles form intervertebral foramina, each of which typically transmits neural structures including a spinal ganglion and a ventral root of a spinal nerve.

Development of Vertebrae

Mesenchyme cells are produced from metameric sclerotomes. A sclerotome becomes differentiated into a dense posterior or caudal half and a less dense anterior or cranial half. The caudal and cranial halves separate, then the caudal half of each sclerotome fuses with the cranial half of the following sclerotome. Thus, definite sclerotomes are formed and they come to lie inter-segmentally alternating with myotomes. This is an adaptation by which each myotome will become connected with two successive vertebrae and their ribs by such arrangement movements of the vertebral column occur. The mesenchyme cells of the definite sclerotomes spread to form a skeletogenous layer around the notochord and nerve cord.

Arcualia

Four pairs of cartilages, called arcualia are laid down in each sclerotome lying on the two sides of the notochord. The dorsal arcualia are two interdorsals and two basidorsals, the ventral arcualia are two interventrals and two basiventrals. The basidorsals and basiventrals are derived from the caudal half of the sclerotome and will form the anterior parts of a vertebra, while the interdorsals and interventrals arise from the cranial half of the sclerotome and will form the posterior parts of a vertebra. Generally, the basidorsals and basiventrals are larger than the other arcualia. The two basidorsals extend above the nerve cord and unite to form a neural arch.

Types of Neural Processes

Various kinds of projections or apophyses arise from a vertebra. These are:

- **i. Zygapophyses:** These are presenting over anterior and posterior faces of neural arch are articulations between successive vertebrae. Prezygapophyses are anterior projections facing upwards and postzygapophyses are posterior projections facing downward.
- **ii. Transverse Processes:** The lateral transverse processes arise from the centrum.
- **iii. Diapophyses:** These arising from the neural arch or the centrum and serve for the attachment of the upper head (tuberculum) of a two-headed (bicipital) rib.
- **iv. Parapophyses:** These arise laterally from the centrum for attachment of the ventral head (capitulum) of a bicipital rib.
- **v. Basapophyses:** These are ventrolateral processes of the centrum or haemal arch, they are remnants of a haemal arch or articulate with the haemal arch when present.
- **vi. Pleurapophyses:** These are lateral projections to which short ribs are fused.
- **vii. Hypapophysis:** It is a mid-ventral projection from the centrum.

Centrum and its Evolution

The basiventrals, interdorsals, and interventrals form a centrum around the notochord. In the tail region, the basiventrals also extend below to form a haemal arch. The parts forming a centrum are not always homologous and different lines of evolution are seen.

a. In some elasmobranchs, notochordal sheath and secreted cartilage form a ring-shaped centrum around the constricted notochord, such a centrum is called a chordal centrum.

b. In bony fishes and tetrapods, the arcualia grow around the notochord outside the notochordal sheaths to form a centrum known as a perichordal centrum.

c. In tetrapods the perichordal mesenchyme forms four embryonic cartilages; they are a pair of ventral hypocentra and a pair of dorsolateral pleurocentra. The hypocentrum or intercentrum incorporates the basiventrals and the pleurocentrum incorporates the interdorsals forming large pieces.

d. In crossopterygians and some fossil amphibians, the two hypocentra fuses form a large piece incomplete dorsally, but the two pleurocentra remain separate, the neural arch rests on the hypocentrum and pleurocentra, such a vertebra is rachitomous.

e. In some other extinct amphibia, the hypocentrum and pleurocentrum are equal, the former is anterior and the latter posterior and each forms a disc-like centrum, but on both, there is a single neural arch, this is an embolomerous vertebra, it was evolved from a rachitomous vertebra.

f. On the other hand, the rachitomous vertebra gave rise to a stereospondylous vertebra of modern amphibians in which the hypocentrum enlarges to form a centrum and the pleurocentrum disappears.

g. The embolomerous vertebra gave rise to the gastrocentrous vertebra of reptiles and mammals in which the pleurocentrum enlarges to form the centrum, while the hypocentrum is reduced to a small piece (reptiles) or is changed to form an intervertebral disc (mammals).

h. Generally, there is one vertebra per segment, this is known as monospondyly. In some cases the arcualia form two centra and only one neural arch in one segment, this is known as diplospondyly.

Types of Vertebrae Based on the Shape of Centra

The centra of the vertebra are placed end to end in a row, the shape of the ends of the centra is of importance for articulation. There are six principal shapes of centra.

i. Amphicoelous: Vertebra has its centrum concave at both ends. This is the most primitive type and is found in nearly all fishes.

ii. Procoelous: Vertebra has its centrum concave at the anterior end and convex at the posterior end. It is found in frogs and most reptiles.

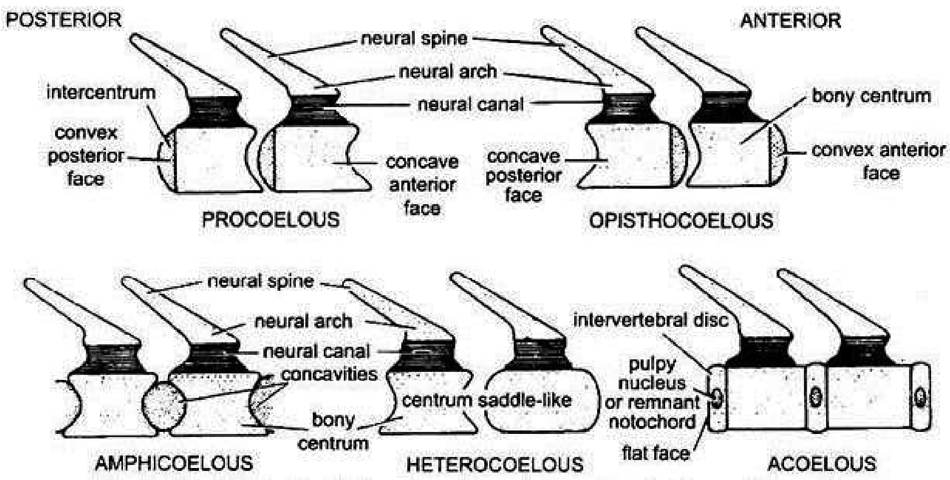

Fig. 3.36 Diversity and Types of Vertebrae Based on the Shape of Centra

iii. Opisthocoelous: Vertebra has a centrum convex at the anterior end and concaves posteriorly. It is not characteristic of any group but occurs in all classes.

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iv. **Heterocoelous:** Vertebra has the centrum saddle-shaped transversely. The anterior end is convex dorso-ventrally and concave sideways, while the posterior end is opposite of the anterior end. This is the most specialized vertebra and is found in the neck region of birds.

v. **Amphiplatyan or Acoelous:** Vertebra has its centrum flat at both ends and is found in mammals.

vi. **Biconvex:** Centrum is convex at both ends. It is found in the 9th (sacral) vertebra of the frog.

Types of Vertebrae Based on Position

There are a total of 26 bones constitute the entire vertebral column. These bones are called vertebrae and grouped into five categories: cervical vertebrae [C1 (Atlas), C2 (Axis), C3 to C7 vertebrae in head and neck region], thoracic vertebrae (T1 to T12 vertebrae in upper back or thorax region), lumbar vertebrae (L1 to L5 vertebrae in lower back or waist region), sacrum and coccyx (fused as rudimentary tail).

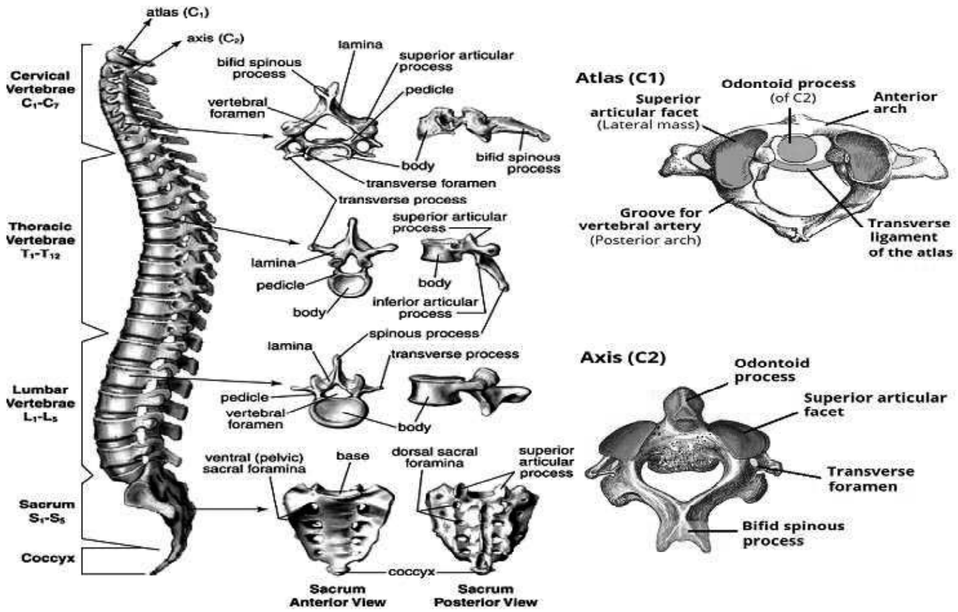

Fig. 3.37 *Vertebral Column and Different Types of Vertebrae*

Modifications of the Vertebral Column in the Vertebrates

The vertebral column, also known as the backbone or spine, is part of the axial skeleton. The vertebral column is the defining characteristic of a vertebrate in which the notochord (a flexible rod of uniform composition) found in all chordates has been replaced by a segmented series of bones. According to the mode of living style, habit, posture, and evolutionary lineage, the vertebral column is modified accordingly.

A. Vertebral Column in Fishes

The vertebral column of fishes has two types of vertebrae, trunk vertebrae, and caudal vertebrae; the anus marks the point of transition between the two types of

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vertebrae. The vertebrae are amphicoelous. In fishes, the shape of the tail is correlated with the direction taken by the terminal portion of the notochord or vertebral column.

i. **Protocercal:** When the notochord extends straight to the tip of the tail and the caudal fin is divided equally then the tail is protocercal, as in embryonic fishes, adult cyclostomes, and some amphibians.

ii. **Heterocercal:** Heterocercal tail has the vertebral column bent upwards in the posterior region so that the caudal fin is divided into a narrow dorsal lobe and a broader ventral lobe. It is typical of elasmobranchs (Scoliodon) and some lower bony fishes. The heterocercal tail made its appearance after the protocercal tail, and it gave rise to the next two types of tails.

iii. **Diphycercal:** Diphycercal tail has lost the terminal upturned part of the vertebral column, and the vertebral column does not reach the end. Externally the tail has become symmetrical secondarily having two equal lobes of the caudal fin. It is found in Dipnoi, Polypterus, and Latimeria.

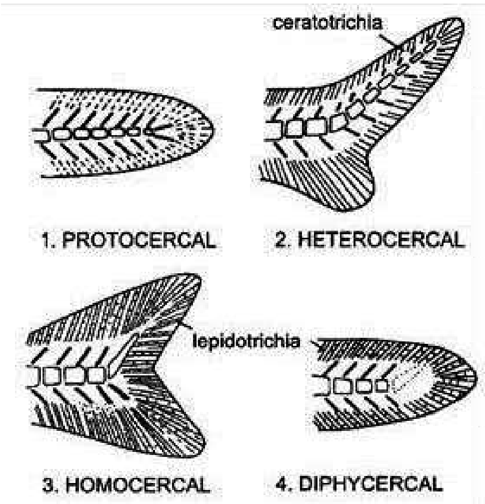

Fig. 3.38 *Types of Caudal Fin in Fishes Based on Shape and Modifications of the Vertebral Column*

iv. **Homocercal:** In the homocercal tail, the terminal part of the vertebral column is bent upwards, but the dorsal lobe of the caudal fin is lost during development and the ventral lobe divides into two equal parts so that the caudal fin appears symmetrical externally. This tail is common in bony fishes.

v. **Hypocercal:** Hypocercal tail has a larger lower lobe of the caudal fin into which the vertebral column is bent downwards. It is found in some primitive fishes and in extinct reptiles called ichthyosaurs.

B. Vertebral Column in Tetrapods

The tetrapods on emergence from water to land underwent many changes. One of these changes involved a differentiation of the vertebral column into regions. For movement of the head, the anterior trunk vertebrae called cervicals had their ribs reduced. With the formation of limbs for use on land, the last few trunk vertebrae called sacrals were modified for articulation with the pelvic girdle. These sacral vertebrae bear short stout ribs for bracing the pelvic girdle against the vertebral column.

The caudal vertebrae are reduced in number, and the terminal ones are reduced to small cylindrical centra only with no arches. Thus, tetrapods have a cervical, trunk (dorsal), sacral and caudal vertebrae. In many reptiles and all birds and mammals, the trunk vertebrae are further differentiated into thoracic vertebrae having ribs and lumbar vertebrae with reduced or no ribs.

i. **Amphibia:** The centra of vertebrae are stereospondylous being formed from hypocentra, the pleurocentra having disappeared. There is a single cervical vertebra (atlas) that articulates with the skull. This is followed by trunk vertebrae, then there is a single sacral vertebra connected to the pelvic girdle. Caudal vertebrae are found only in tailed forms. All caudal vertebrae, except the first, bear haemal arches with haemal spines.

ii. **Reptilia:** The vertebrae are gastrocentrous, i.e., the centra are formed from pleurocentra, the hypocentrum being lost, but in *Sphenodon*, it persists as a small ventral remnant. The vertebral column in most lizards and crocodilians are differentiated into cervical, thoracic, lumbar, sacral, and caudal regions. In all living reptilian forms, two sacral vertebrae fuse to form a sacrum. The caudal vertebrae have small V-shaped chevron bones on the ventral side of the centrum, they are formed from the hypocentra and are not homologous with haemal arches of lower forms in which haemal arches are formed from basiventrals. All types of centra are found in reptiles, in turtles and *Sphenodon* these are amphicoelous, but some have opisthocoelous vertebrae. Most lizards, snakes, and crocodilians have procoelous vertebrae. The sacral vertebrae of crocodilians are amphiplatyan. In snakes and some lizards in addition to zygapophyses, there is a special pair of apophyses called zygosphenes at the anterior end fitting into concavities called zygantra located on the posterior side of each vertebra.

iii. **Aves:** The vertebrae are formed in a typical manner from four pairs of arcualia. The chief characteristic of the vertebral column is its rigidity due to ankylosis between vertebrae. The rigidity is an advantage in flight. The cervical region is very mobile but the other regions are capable of little movement. The vertebral column provides a fulcrum for the wing strokes. In the cervical region, the number of vertebrae is variable from 8 to 25. These vertebrae are heterocoelous or saddle-shaped, the anterior face of the centrum is convex dorsoventrally, but concave from side to side, the posterior face has its curves in just the opposite direction so that there is proper articulation. Thus, in the vertical section, the centrum appears opisthocoelous and in the horizontal section, it is procoelous. But parrots have opisthocoelous cervical vertebrae, and in *Archaeopteryx* they were amphicoelous.

Cervical vertebrae bear short ribs, ventrally each vertebra has a hypapophysis. Thoracic vertebrae are more or less fused, though some are free, their centra are produced below into hypophysis, their broad transverse processes bear ribs. Ribs are attached to thoracic vertebrae and are united ventrally to the sternum. The posterior thoracic, lumbar, sacral, and the first few caudal vertebrae are all fused to form a single synsacrum, which becomes fused with the pelvic girdle. The number of vertebrae making up the synsacrum varies from 13 to 20 in different birds. On examining the ventral side of the synsacrum the separate transverse processes of vertebrae are seen which reveal the number of vertebrae forming the synsacrum. Only two of the vertebrae of the synsacrum are sacral, except in ostrich which has three. The number of caudal vertebrae is small, the first few after the synsacrum are free but the posterior ones are fused to form a pygostyle that supports the tail. The free caudal vertebrae are amphicoelous.

iv. **Mammalia:** The vertebrae are gastrocentrous. The centra being formed from pleurocentra, while the hypocentra form intervertebral discs. During development each centrum has an epiphysis at each end, except in monotremes and sirenians, the epiphyses finally fuse with the centrum. Between the centra are intervertebral discs. In front of the sacrum, these discs are made of fibrocartilage with a remnant of the notochord in the center, called nucleus pulposus.

In the sacral and caudal regions, the intervertebral discs are bony. The vertebral column has cervical, thoracic, lumbar, sacral, and caudal regions. The vertebrae are amphiplatyan (acoelous), but in Perissodactyla the cervical vertebrae are opisthocoelous. An outstanding feature is the presence of 7 cervical vertebrae in most mammals, except in some Edentata which have 6 to 9 vertebrae. In many whales, moles, and armadillos the cervical vertebrae fuse.

The atlas and axis are modified as in amniotes. Ribs are fused to cervical vertebrae. There being a vertebrarterial canal between the two heads of the rib. Behind the neck, the number of vertebrae is variable in mammals. Thoracic vertebrae bear ribs that connect directly or indirectly with the sternum, but some posterior ribs do not reach the sternum and are called floating ribs.

Lumbar vertebrae are strong and longer than others. They have prominent transverse processes directed forward. The anterior lumbar vertebrae bear two additional processes called mammillary processes or metapophyses. The sacrum has several vertebrae fused- 3 in a dog, 4 in a rabbit, 5 in the horse, and 5 in a man.

There is no sacrum in whales because of a reduced pelvic girdle. Caudal vertebrae are variable in number- 16-18 in rabbit, 20-23 in a dog, 15-21 in the horse, and 3-4 in man which unites to form a single coccyx. Usually, the most posterior caudal vertebrae are reduced to only centra, whereas the more anterior ones possess all the parts.

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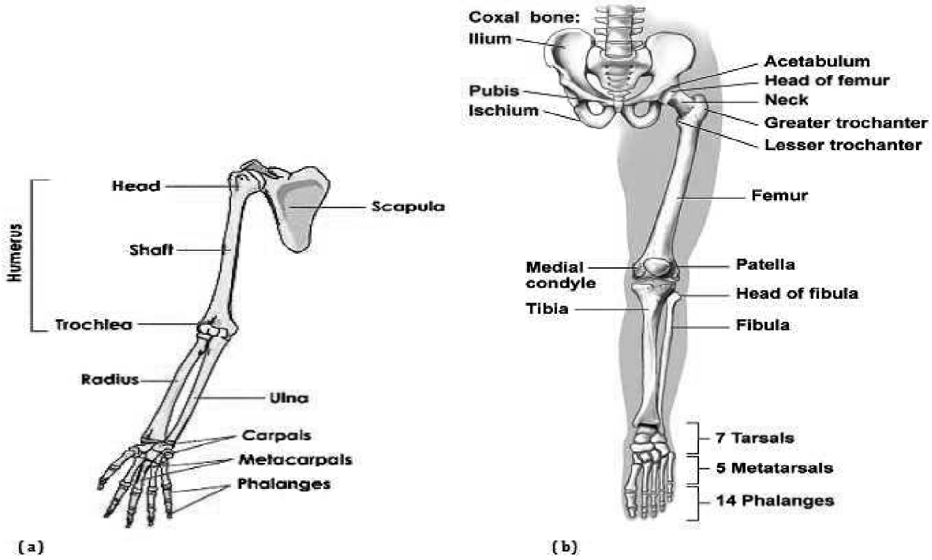

Fig. 3.39 *Girdles and Limbs: (a) Pectoral Girdle and Forelimb; (b) Pelvic Girdle and Hindlimb*

3.4.7 Girdles and Limbs

The girdles and paired limbs of tetrapods are remarkably similar and have homologous parts. The bones of the pectoral and pelvic girdles are homologous, the scapula with the ilium, the precoracoid with the pubis and cotyloid, and the coracoid with the ischium. The clavicle is a dermal bone and is not homologous with the pubis which is a cartilage bone. The limbs of tetrapoda are pentadactyl. They are used not only for locomotion but also to support the weight of the body above the ground. Thus, they are provided with joints. Each has three segments, the stylopodium, zeugopodium, and autopodium with joints between the segments. The stylopodium is the upper arm (or thigh), having a single humerus (or femur). The humerus joins the pectoral girdle at the glenoid cavity, while the femur joins the pelvic girdle at the acetabulum cavity.

Pectoral Girdle and Forelimbs

Each half of the pectoral girdle has a triangular scapula or shoulder blade, at the end of which is a glenoid cavity. Near the glenoid cavity, there is a coracoid process formed by the reduced coracoid. On the outer surface of the scapula is a spine that has two projections, an acromion process and a metacromion process for the attachment of muscles. There is a clavicle, a dermal bone forming a slender rod attached by ligaments to the acromion process and manubrium of the sternum. Clavicles are retained only in those mammals which have an extensive movement of forelimbs, in others, they are reduced or lost.

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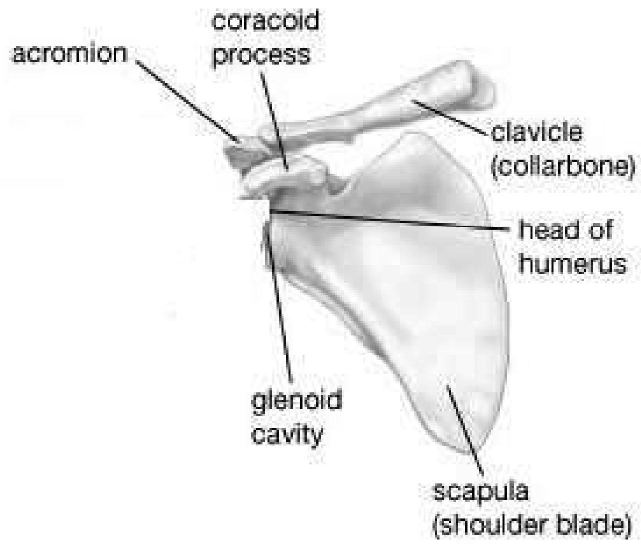

Fig. 3.40 *Pectoral Girdle (Shoulder and Collar Bone)*

The forelimbs of most mammals are capable of extensive rotation, extension, and bending. The humerus is stout with a deltoid ridge; the distal end has two expanded condyles between which are pulleys or trochlea for articulation with ulna. Above the trochlea is an olecranon fossa perforated by a supratrochlear (supracondylar) foramen for the passage of a nerve and brachial artery.

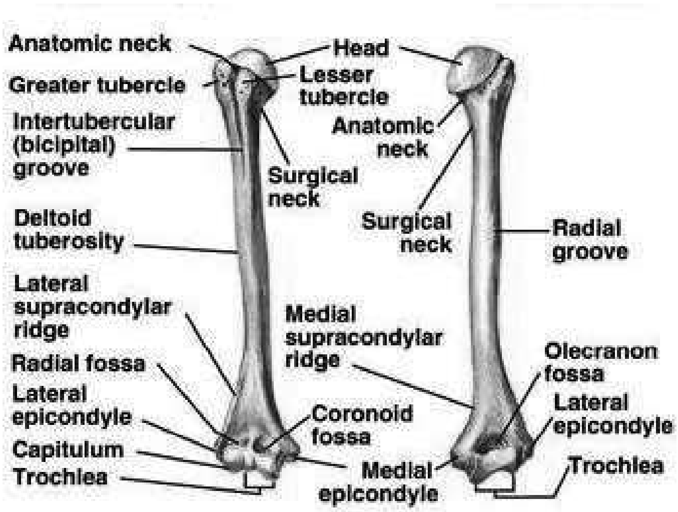

Fig. 3.41 *Upper Forelimb Bone (Humerus)*

Radius and ulna are separate but tightly bound together. In primates, with prehensile forelimbs, the radius and ulna are not fixed but the radius can rotate over the ulna to turn the hand to either a prone or a supine position. The ulna is produced into an elbow or olecranon process, in front of which is a sigmoid notch for articulation with the humerus.

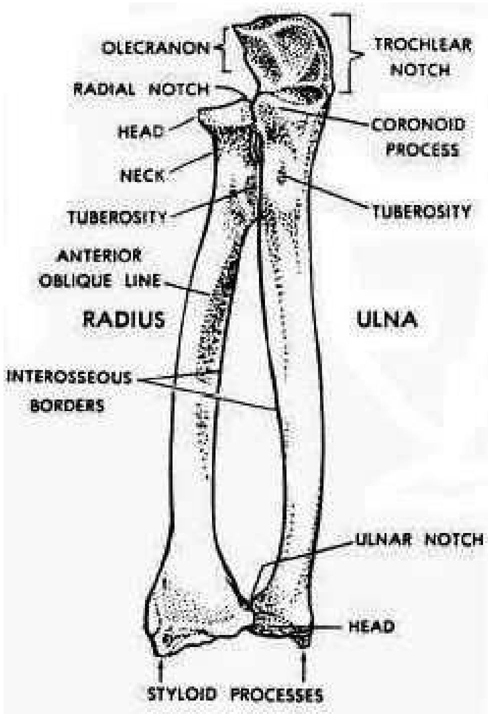

Fig. 3.42 *Lower Forelimb Bones (Radius and Ulna)*

Carpus has eight bones, three in the first row, then a small entral, and four distal carpals. Five metacarpals are having five digits with 2, 3, 3, 3, 3 phalanges ending in claws. In primates, the first digit or pollex is independent of the others. It can be brought opposite the other digits and palm. This opposable thumb can handle minute objects. This factor has led to a superior position of primates.

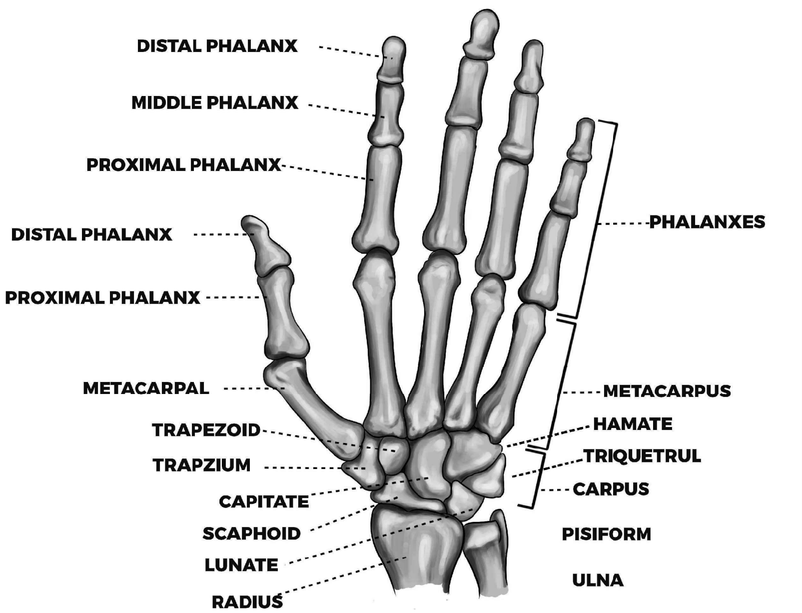

Fig. 3.43 *Wrist and Hand Bones (Corpus, Metacarpus, and Phalanxes)*

Pelvic Girdle and Hind Limb

In each half of the pectoral girdle, there are (Ilium), (Ischium), and (Pubis) fuse to form an innominate bone. The two halves meet by a midventral pubic symphysis. In rabbits and some others, there is a small acetabular (cotyloid) bone at the lower margin of the acetabulum. The acetabulum lies where all three bones meet (except the pubis). There is a large obturator foramen between the pubis and ischium on each side. The two ilia articulate with the transverse processes of the first vertebra of the sacrum. In most tetrapods, the pelvic girdle is attached to the axial skeleton through the ilia articulating with the sacral vertebrae.

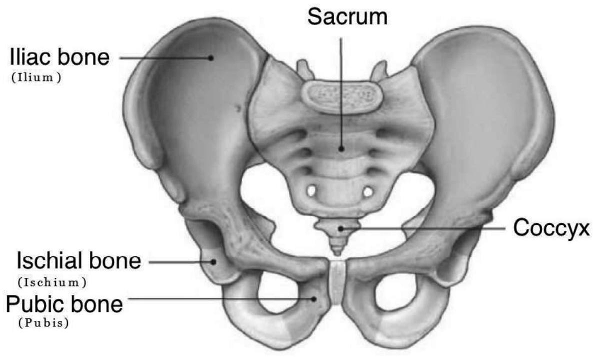

Fig. 3.44 *Pelvic Girdle (Hip Bone)*

The femur is strong with a head for articulation with the acetabulum. There are three trochanters for the attachment of muscles, the distal end of the femur has two smooth condyles.

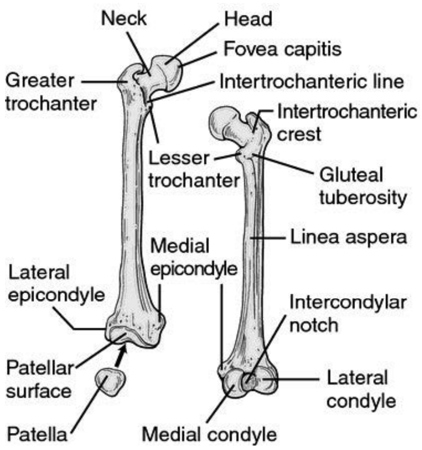

Fig. 3.45 *Femur (Thigh Bone)*

The tibia is strong and has a cnemial crest, above is a sesamoid bone or patella formed in the tendon of the triceps femoralis muscle. It forms a knee cap which reinforces the ligaments of the knee joint. The fibula is reduced and fused distally to the tibia but separate proximally.

NOTES

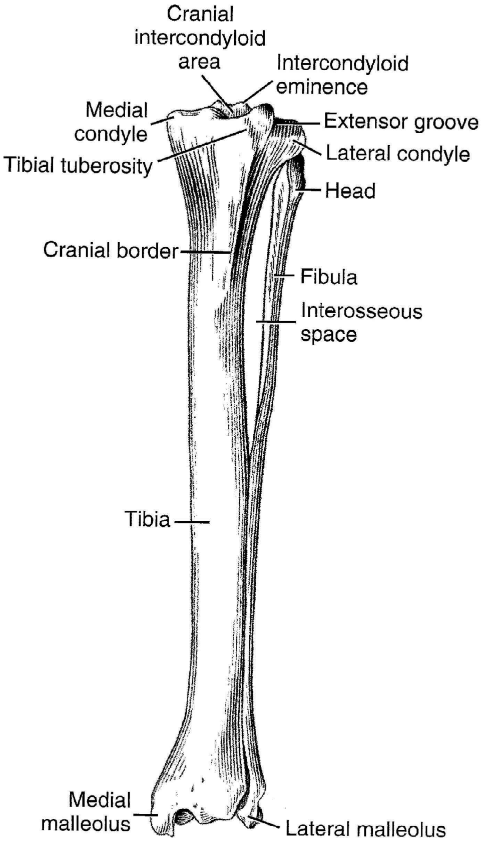

Fig. 3.46 *Tibia and Fibula (Shank Bone)*

Tarsus has six bones, the proximal row has astragalus and calcaneum, its posterior projection, the calcaneal process forms a heel. Centrale lies in front of the astragalus, the distal row has three tarsals. There are four metatarsals bearing digits. Each digit has three phalanges ending in claws. The first digit or hallux is absent. In some primates, the hallux is opposable in the same way as the pollex of the hand.

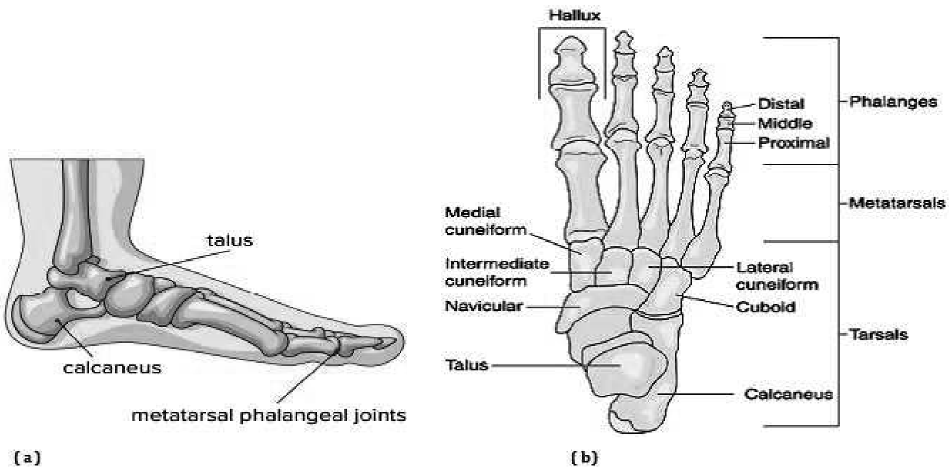

Fig. 3.47 *Ankle and Foot Bones (Tarsals, Metatarsals, and Phalanges)*

NOTES

Postures of Foot in Mammals

In terrestrial mammals, there are three kinds of postures of hands and feet in locomotion.

a. **Plantigrade:** Plantigrade locomotion is the most primitive, in which the entire hand and foot are in contact with the ground, as in bears, rabbits, some insectivores, and man.

b. **Digitigrade:** Digitigrade locomotion is used for increased speed. In it, only the digits are placed on the ground. The wrist and ankle are listed above, as in dogs, cats, and wolves.

c. **Unguligrade:** Unguligrade locomotion is an extreme condition in which only the tips of the digits are placed on the ground and the tips are covered with hoofs. This is the most specialized condition, as in deer, horse, and cattle.

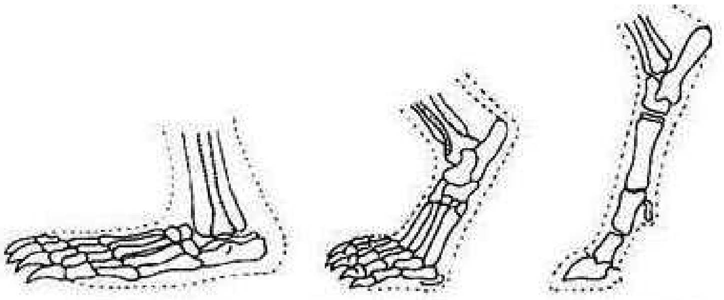

Fig. 3.48 *Postures of Foot in Mammals*

Check Your Progress

11. Define skeletal system.
12. How many bones are present in human body?
13. Define skull.
14. What do you understand by vertebral column?

3.5 ANSWERS TO 'CHECK YOUR PROGRESS'

1. The cardiovascular system is sometimes called the blood-vascular, or simply the circulatory, system. It consists of the heart, which is an anatomical muscular pumping device, and a closed system of vessels called arteries, veins, and capillaries that traverse the whole human body carrying blood.
2. Blood is continually moving or circulating liquid connective tissue in the body. It offers nutrition, oxygen to body cells and removes the wastes as well.
3. Erythrocytes or RBCs are small, flexible cells like biconcave flattened discs measuring about 7-8µm in diameter.
4. Leukocytes are frequently larger than RBCs and ranged between 10–14 µm in diameter.

5. Platelets are not cells in the firm sense, but these are trash of bizarre multinucleated cells called megakaryocytes, which pinch off thousands of anucleate platelet 'pieces'.
6. The ratio of RBCs to blood plasma is called hematocrit and normally sharing about 45%.
7. Breathing is a process of moving air into and out of the lungs and facilitates gaseous exchange to the internal environment, frequently by bringing in oxygen and flushing out carbon dioxide.
8. The gills are the main organs for ventilation and respiration in aquatic and semiaquatic individuals.
9. These are the outgrowth from gill chambers and modified as aerial accessory respiratory organs in some fishes. Such air-breathing organs are found in *Heteropneustes, Clarias, Anabas, Trichogaster, Macropodus, Betta*, etc.
10. These are a pair of simple sac-like outgrowths of the pharynx, lined by obese vascular epithelium and extending above the gills.
11. The skeletal system is the body's central framework which consists of bones and connective tissue, including cartilage, tendons, and ligaments. It's also called the musculoskeletal system.
12. There are 206 bones in an adult human skeleton while children's skeletons contain more bones because some of them, including those of the skull, fuse as they grow up.
13. The axial skeletal framework of a vertebrate head is called a skull which is a structure of several bones that fused.
14. The vertebral column is a sigmoid structure in human beings and is also called backbones. It is the replacement or modification of embryonic notochord that comprising several unitary structures called vertebrae which is usually 33 in number.

3.6 SUMMARY

- The cardiovascular system is sometimes called the blood-vascular, or simply the circulatory, system. It consists of the heart, which is an anatomical muscular pumping device, and a closed system of vessels called arteries, veins, and capillaries that traverse the whole human body carrying blood.
- The respiratory system is the network of organs and tissues that helps in breathing. It includes your airways, lungs, and blood vessels. The muscles that power the lungs are also part of the respiratory system.
- The vertebrates having a median vertebral column or backbone comprising vertebrae, and an internal framework centered on a prominent spine. This entire framework of vertebrates is called the skeletal system.
- Blood is a constantly circulating fluid providing the body with nutrition, oxygen, and waste removal. It is liquid connective tissue with numerous cells and proteins suspended in it to making blood 'thicker' than pure water.

- Erythrocytes or RBCs are small, flexible cells shaped like biconcave discs-flattened discs with depressed centers on both sides; measuring about seven to eight micrometers (µm) in diameter. RBCs contain hemoglobin molecules that bind to oxygen so they can be transported to tissues.
- Leukocytes or WBCs are usually larger (10–14 µm in diameter) than red blood cells. They lack hemoglobin but contain organelles, a nucleus, and nuclear DNA.
- Platelets or thrombocytes are not cells in the strict sense; these are fragments of bizarre multinucleated cells called megakaryocytes, which pinch off thousands of anucleate platelet 'pieces' that quickly seal themselves off from surrounding fluids.
- The types of blood groups are based on two antigens: type A or type B. A person inherits; absence of both antigens results in type 'O' blood, and presence of either antigens leads to type 'AB', and the presence of either A or B antigen yields type 'A' or type 'B' blood groups.
- The heart is an unpaired muscular organ solely responsible for blood circulation but its origin during embryogenesis is bilateral.
- The lymphatic system is a subsystem of the blood vascular system in the vertebrates that comprises a multifarious set of connections of vessels, tissues, and organs.
- The mammalian lungs are less complicated than that the avian lungs. Mostly the mammalian lungs are externally subdivided into lobes.
- The trachea or windpipe is divided into the two left and right primary bronchi which after entering the lung carve up into secondary bronchi that further alienated into many smaller bronchioles, and ultimately ending in numerous tiny alveoli or blind pockets.
- During embryogenesis, lung primordium arises as a hollow out pushing from the ventral wall of the pharynx. The primordia grow backward and divide into right and left lung buds.
- The skeletal system is the body's central framework which consists of bones and connective tissue, including cartilage, tendons, and ligaments. It's also called the musculoskeletal system.
- There are 206 bones in an adult human skeleton while children's skeletons contain more bones because some of them, including those of the skull, fuse as they grow up.
- The male skeleton is usually longer and has a high bone mass. The female skeleton, on the other hand, has a broader pelvis to accommodate for pregnancy and childbirth.
- The axial skeletal framework of a vertebrate head is called a skull which is a structure of several bones that fused. Jaw suspensorium is a structure of attachment of the lower jaw and upper jaw.
- The vertebral column is a sigmoid structure in human beings and is also called backbones. It is the replacement or modification of embryonic

notochord that comprising several unitary structures called vertebrae which is usually 33 in number.

- Out of the 33 vertebrae, three are 24 presacral vertebrae (7 cervical, 12 thoracic, and 5 lumbar) followed by the sacrum (5 fused sacral vertebrae) and coccyx (4 frequently fused coccygeal vertebrae).
- The girdles and paired limbs of tetrapods are remarkably similar and have homologous parts. The bones of the pectoral and pelvic girdles are homologous, the scapula with the ilium, the precoracoid with the pubis and cotyloid, and the coracoid with the ischium.

3.7 KEY TERMS

- **Blood:** Blood is continually moving or circulating liquid connective tissue in the body. It offers nutrition, oxygen to body cells and removes the wastes as well.
- **Erythrocytes:** Erythrocytes or RBCs are small, flexible cells like biconcave flattened discs measuring about 7-8μm in diameter.
- **Hematocrit:** The ratio of RBCs to blood plasma is called hematocrit and normally sharing about 45%.
- **Leukocytes:** Leukocytes are frequently larger than RBCs and ranged between 10–14 μm in diameter.
- **Portal Venous System:** The portal system is a system of blood vessels that begins and ends in blood capillaries.
- **Lymphatic System:** The lymphatic system is a subsystem of the blood vascular system in the vertebrates that comprises a multifarious set of connections of vessels, tissues, and organs.
- **Breathing:** Breathing is a process of moving air into and out of the lungs and facilitates gaseous exchange to the internal environment, frequently by bringing in oxygen and flushing out carbon dioxide.
- **Gills:** The gills are the main organs for ventilation and respiration in aquatic and semiaquatic individuals.

3.8 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. What is the significance of blood typing?
2. Which of the vertebrates possess three-chambered heart? Briefly explain.
3. Write a short note on the embryonic development and modification of lymphatics.

4. What are the functions of respiratory system?
5. What are the elements and functions of skeletal system?
6. Briefly explain the significance and types of girdles and limbs.

NOTES

Long Answer Questions

1. Discuss the components of blood and their respective functions.
2. Explain some of the medical issues related to blood.
3. Comment on the aortic arches in the different vertebrates.
4. Evaluate the blood circulation in the vertebrates.
5. Describe the characteristics of respiratory organs.
6. Discuss the structure and modification of vertebral column in vertebrae.

3.9 FURTHER READING

Kardong, Kenneth. 2012. *Vertebrates: Comparative Anatomy, Function, Evolution*. Delhi: McGraw-Hill Education.

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Millard, Ronald W. and Roy E. Weber. 1992. *Physiological Adaptations in Vertebrates (Respiration: Circulation, and Metabolism)*. Delhi: Taylor and Francis.

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UNIT 4 URINOGENITAL, SENSORY, AND NERVOUS SYSTEM IN VERTEBRATES

NOTES

Structure

4.0 INTRODUCTION

The urinogenital or urogenital system in vertebrates is the group of organs concerned with sexual reproduction and elimination of nitrogenous waste as urinary excretion. It is also known as genitourinary system because of the common external opening for both reproductive and excretory system. Even though the functions of these two systems are unrelated, the structures taking part in excretion and reproduction are morphologically connected and often employ common ducts.

The nervous system is the major controlling, regulatory, and communicating system in the body and supposed to be the center of all mental activities together with thought, learning, and memory. The nervous system along with endocrine system is accountable for regulating and maintaining homeostasis.

In this unit, we will discuss the evolution of urinogenital system in vertebrates series, along with sense organs. It will also focus on the nervous system and its functions.

4.1 OBJECTIVES

After going through this unit, you will be able to:

- Discuss the evolution of urinogenital system in vertebrates
- Describe the significance of different sense organs
- Explain the significance and functions of nervous system in detail

4.2 EVOLUTION OF URINOGENITAL SYSTEM IN VERTEBRATES

The genitourinary system or urogenital or urinogenital system is the organ system of the reproductive and the urinary system in vertebrates because these are grouped together by their immediacy to each other, common embryological origin, and the use of universal pathways. The end products of metabolism are waste substances like carbon dioxide, ammonia, urea, uric acid, pigments, creatinine and some inorganic salts. The carbon dioxide is taken out through the skin and gills or lungs, however, the others are excreted through the kidneys usually. Most excretory substances are in solution in water, and any excess of water is also eliminated by kidneys. The excretory and reproductive systems are closely associated structurally, particularly in the males in which the male urinary ducts are also used to discharge sperms. Hence, it is customary to consider the two systems together as a urogenital or urinogenital system. But the evolutionary tendency is towards a complete separation of the two systems.

4.2.1 Urinary System of Vertebrates

The urinary or excretory system is a group of organs in the body concerned with filtering out surplus fluid and other substances of the bloodstream in the form of urine. Thus the urine is a liquid substance produced by the kidneys as blood filtrate containing excess minerals, vitamins, blood corpuscles, and water, collected in urinary bladder and eliminated out through the urethra. So that the urinary system include the kidneys, ureters, bladder, and urethra as well as it works with the other systems of the body to retain homeostasis, acid-base and salt-water balance of the blood.

Origin of Kidney and Kidney Tubules:

During embryogenesis, the kidneys originate from the lateral plate, which transforms and differentiates into the nephric ridges and buds into blocks or knobs of tissue called nephrotomes, after that modifies into nephrons or renal tubules or may also called kidney tubules, i.e., the structural and functional units of the kidney or excretory system.

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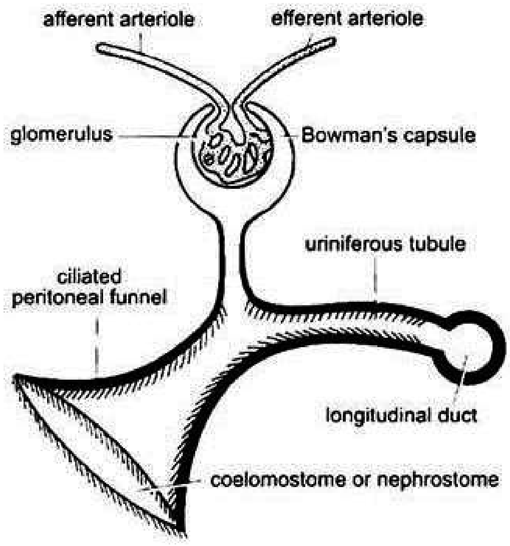

Fig. 4.1 *Schematic Layout of Origin and Differentiation of Embryonic Renal Tubule*

The renal or uriniferous tubules arise as a special part of the mesoderm, called mesomere or nephrotome running on each side along the complete trunk in between upper segmental mesoderm or epimere and lower lateral plate mesoderm or hypomere in a vertebrate embryo. Primitively the kidney tubules develop from the nephrotome in a sequence commencing from the anterior end and are arranged segmentally one pair for each trunk segment.

Structure of Kidney

The kidneys are a pair of compressed bean shaped, brown organs about the size of your fist lying dorsal to the coelom in trunk region, one at each latero-dorsal position of vertebral column at the rear wall of the abdominal cavity just above the waistline, and are protected by the ribcage. The kidneys are surrounded by the renal capsule, a tough fibrous connective tissue are considered retroperitoneal, which means they lie behind the peritoneum, and having a concave and convex surface. The concaved side of the kidney has a depression enervated by the renal artery and vein as well as a ureter came out from the kidney.

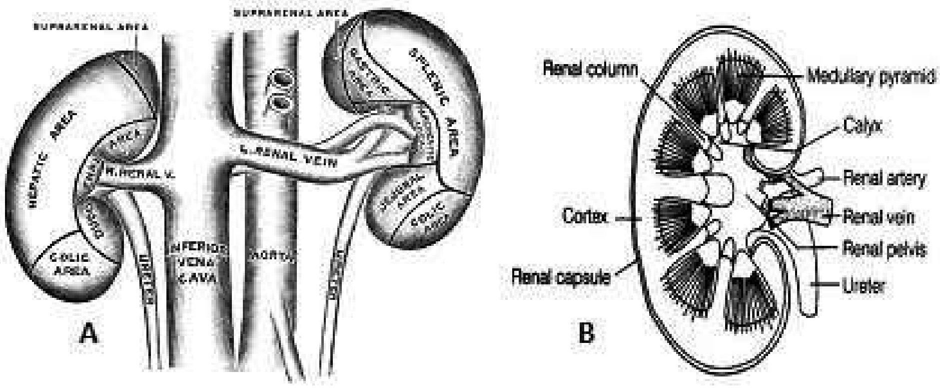

Fig. 4.2 *Typical Vertebrate Kidney: Position and Topography (A), Anatomy (B)*

There are three major regions of the kidney, renal cortex, renal medulla and the renal pelvis. The outer, granulated layer is the renal cortex. The cortex stretches down in between a radially striated inner layer. The inner radially striated layer is the renal medulla. This contains pyramid shaped tissue called the renal pyramids, separated by renal columns. The ureters are continuous with the renal pelvis, and are the very center of the kidneys. A kidney is made of a large number of uriniferous tubules or nephrons. Their number, complexity, and arrangement are different in different groups of vertebrates.

Structure of Kidney Tubules

A kidney tubule or uriniferous tubule also called as nephron which is structural and functional unit of vertebrate kidney and has three main parts: (i) A ciliated peritoneal funnel near the proximal end of the tubule which opens into the splanchnocoel by a nephrostome or coelomostome (frequently the peritoneal funnel may also termed as nephrostome), (ii) A convoluted ciliated tubule opening into a longitudinal collecting duct, and (iii) A malpighian body or renal corpuscle. The proximal terminal of the renal tubule forms a cup-like structure called the Bowman's capsule that surrounds a knot of capillaries called the glomerulus. The blood flows to glomerulus enters from the afferent arteriole and leaves through the efferent arteriole, and these capillary bed surrounding the renal capsule internally hence called an internal glomerulus occurs among vertebrates. If the capillary bed discharges into the coelom then called the external glomerulus which is found in embryos and larvae. The malpighian bodies with glomeruli are lacking in some fishes, embryos, and larvae and such types of kidneys are called aglomerular kidneys. In an adult the uriniferous tubules are elongated and coiled, so that their segmental arrangement is lost and they become enclosed in a connective tissue capsule to form a kidney.

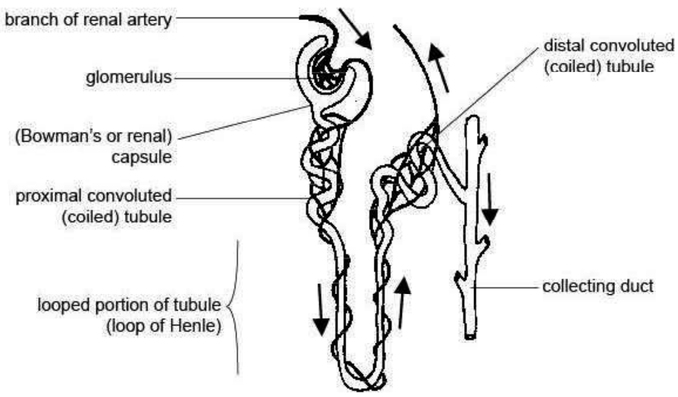

Fig. 4.3 *Complete Mammalian Uriniferous Tubule Nephron*

Evolution of Kidney in Vertebrates

The mammalian kidney, or the metanephros, is a mesodermal organ classically regarded its origin from the Intermediate Mesoderm (IM). Indeed, both the Ureteric Bud (UB), which gives rise to the ureter, collecting ducts, and the Metanephric Mesenchyme (MM), which constitutes the rest of the kidney, all are derived from the IM. During evolution, mammals inherited their kidney traits before the evolution of diapsids (reptiles and birds) whose kidneys have the potential to convert nitrogenous wastes into uric acid. There are many reptiles live in arid environments, to cope with their surroundings, so that they have evolved very efficient kidneys. In fish, the kidney is basically a large water pump, which maintains water balance, rather than an organ of excretion of nitrogenous compounds. Based on evolutionary lineage criteria, there are following types of kidney: archinephros, pronephros, mesonephros, and metanephros.

Archinephros

The foremost or primitive vertebrates had a pair of kidneys running through the entire length of the coelom with segmentally arranged tubules, i.e., one pair in each segment of the body. Each tubule opened separately into the coelom by a peritoneal funnel and nephrostome bearing external glomerulus (without capsule) suspended in coelom. All the kidney tubules opened into a common longitudinal duct (Wolffian or archinephric duct) which joined the cloaca may also called holonephros. Among the living vertebrates the archinephros found only in the larval *Myxine* and some apodan amphibians which modifies through evolution antero-posteriorly in two or three successive stages pronephros, mesonephros and metanephros. Thus, in present vertebrates, kidneys are of only three types **(**Pronephros, Mesonephros, Metanephros) and all are fundamentally similar only differing principally in their relationship to the blood system, degree of complexity, and efficiency.

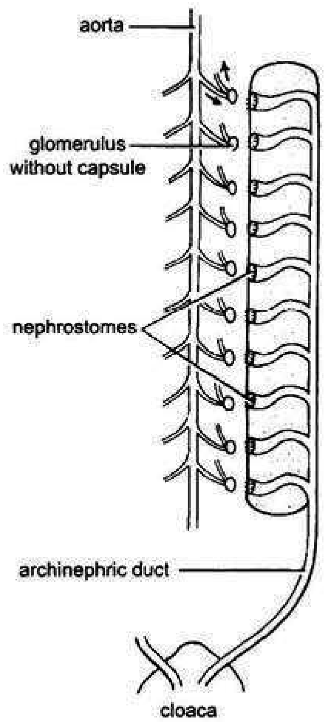

Fig. 4.4 *Archinephric Kidney: The Kidney of Primitive Vertebrates*

Pronephros

The pronephros or pronephric kidney is the most primitive and while present in the embryonic development of all vertebrates, is functional in the adult of none. Some larval cyclostomes, however, have a kidney, part of which appears to be homologous to the embryonic pronephros of higher vertebrates. The pronephros develops in the anterior-most part of the nephrotome and about 3 to 15 uriniferous tubules in each. Each tubule comprises a glomerulus projecting into the coelom, and the tubules of each pronephros open into a common pronephric duct that leads to the embryonic cloaca. In some, there is a large pronephric chamber which surrounds the glomus (all glomeruli) and tubules. A pair of pronephros appears in all vertebrate embryos but they become functional kidneys only in some cyclostomes and embryos of all anamniotes. In those vertebrates in which pronephros become adult kidneys, they are called head kidneys due to its anterior position behind the head.

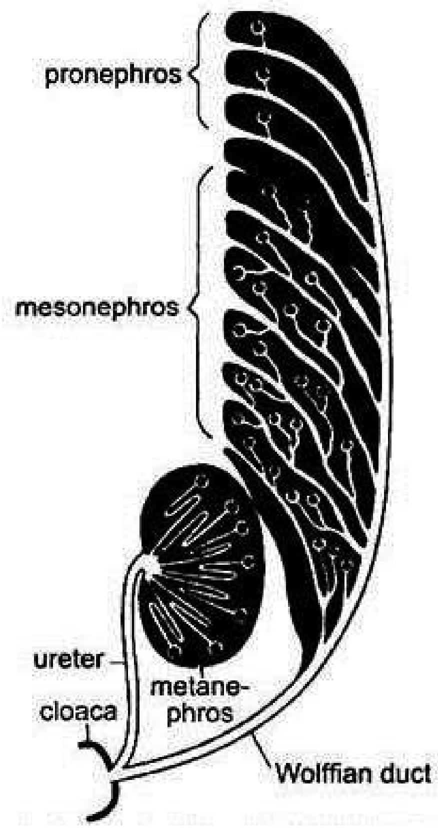

Fig. 4.5 *Developmental Outline and Differentiation of Pronephros, Mesonephros and Metanephos*

Mesonephros

The mesonephros develops from the middle part of the nephrotome behind the pronephros and consists of paired segmental uriniferous or mesonephric tubules, each with a peritoneal funnel opens into the coelom as well as internal glomerulus encircled in a Bowman's capsule. These mesonphric uriniferous tubules join the existing pronephric or archinephric tubules on each side, which is called a mesonephric or Wolffian duct with the loss of pronephros. After that the mesonephric tubules go through budding to form hundreds of tubules, so that their segmental arrangement is lost. The mesonephric tubules are quite convoluted both proximally and distally and escort into a common longitudinal collecting duct the archinephric duct and ultimately connect to the outside, frequently by way of the cloaca. In sharks it functions as a gonadal duct and the kidneys have developed new accessory urinary ducts without peritoneal funnels. The mesonephros of the adult functions as kidneys in some cyclostomes, fishes, amphibians and the embryos of amniotes in which they deteriorate in the adult and lacking peritoneal funnels, except in monotremes. The mesonephros of anamniotes is not exactly equivalent to that of amniotic embryos because in anamniotes the mesonephros extends throughout the length of the coelom behind the pronephros and is formed from the entire nephrotome behind the pronephros and found to be functional both in the embryos as well as adults.

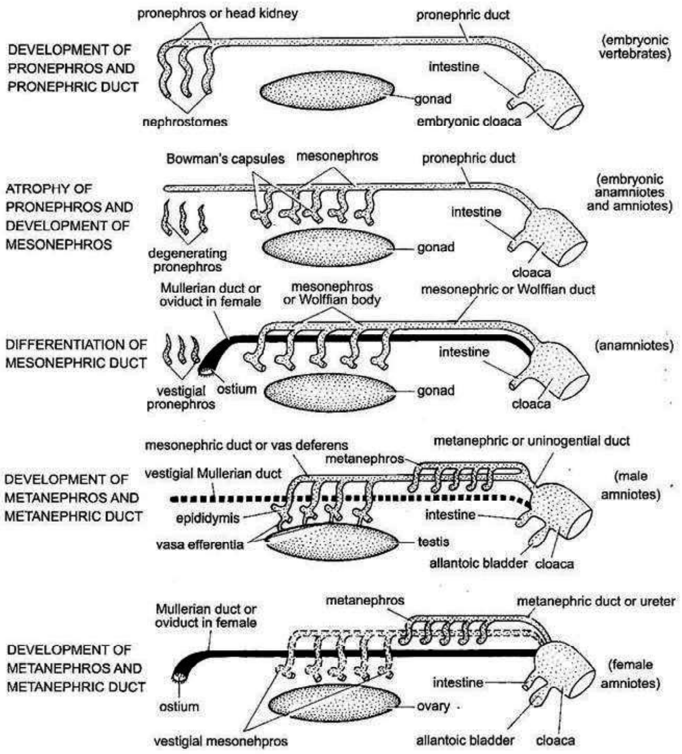

Fig. 4.6 *Evolutionary Lineage and Modification of Kidney in Vertebrates*

The kidney of marine fishes, play a major part in maintaining the proper balance with in the body. Salt water tends to dehydrate the body, which is only slightly saline, and it also increases the salt concentration in the body on contrary to freshwater. Some marine bony fishes have salt-excreting glands on the gills which help to eliminate excessive salt. While in adults anurans, urodeles and amniote embryos the mesonephros is formed only from the middle part of the nephrotome and it does not extend throughout the length of the coelom. In sharks, fishes, caecilians, and tailed amphibians the kidney is opisthonephros, i.e., mesonephric tubules extend posteriorly throughout the length of the coelom but in anurans there is a tendency for these structures to be short and compact. The renal capsules are comparatively larger to lend a hand in the elimination of water and thus, prevents excessive dilution of the body fluids. In some amphibians the archinephric duct is both genital and excretory in nature in the male, whereas, in others the archinephric duct serves only for the transport of sperms, and the kidney is drained by a new duct, somewhat comparable to the ureter of higher vertebrates.

Metanephros

It is the most functional kidney and found to be developed only in amniotes. It is derived and developed from the posterior-most part of the nephrotome behind the embryonic mesonephros which is displaced somewhat antero-lateral in position. The metanephros essentially similar to the mesonephros, but arises more posteriorly in the body, is more compact and contains a few greater number of renal units. Furthermore, the renal tubules, instead of draining into the archinephric duct open into larger collecting tubules that eventually approaches to a new excretory duct called the ureter. The metanephric kidney has dual origin, a tubular outgrowth arises from the base of mesonephric duct in the vicinity of the cloaca and it grows antero-dorsally and eventually the metanephric tubules open into it. Its distal end dilates to form the pelvis which further divides many times to form collecting tubules, while its proximal part becomes the ureter or metanephric duct. The metanephric tubules become long and much coiled and have glomeruli enclosed in Bowman's capsules but they lacking peritoneal funnels so that all connection with the coelom is lost. In metanephros, the metanephric tubules are much convoluted, and a thin U-shaped loop of Henle is formed in between proximal and distal convolutions of the tubule which is lacking in reptiles and rudimentary in birds. Kidney is differentiated into outer cortex having renal capsule, and inner medulla possessing collecting tubules and loops of Henle. These two aggregated into one or more pyramids projecting into pelvis. Metanephric kidneys of adult amniotes have achieved the separation of the urinary function from the genital function which appears to be the trend in the evolution of the urinogenital system. The renal portal system has begun to lose its importance and some of the blood from the caudal region goes directly through the kidneys instead of filtering slowly through the capillary network in reptiles. However, in birds, the renal portals do not break up into capillaries and are, therefore, not comparable to the renal portals of lower vertebrates, and in mammals it is absolutely absent.

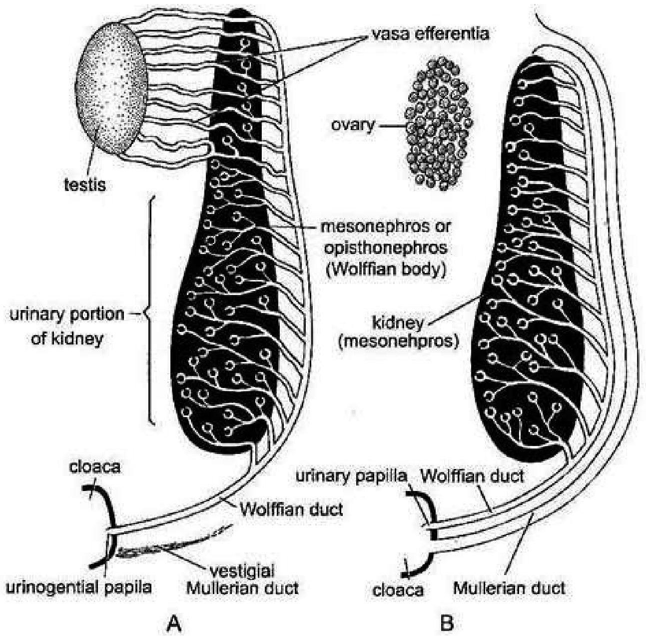

Fig. 4.7 Diagrammatic Plan to Show Relation of Kidney and Genital Ducts in Anamniotes: Male (A), Female (B)

NOTES

Formation of Urine

The process of excretion by vertebrate kidneys achieved through three processes: i. A filtration of blood in the glomerulus, ii. Secretion of certain waste substances by the cells of uriniferous tubules into the lumen of the tubules, and iii. A selective reabsorption by uriniferous tubules of useful substances from the glomerular filtrate. The ultimate nitrogenous byproduct of most of the vertebrates called urine or excreta of varying chemical nature. In aquatic vertebrates the kidneys are concerned chiefly with exclusion of surplus water absorbed in the body, and they excrete ammonia well diluted with water, if ammonia is not diluted, it is highly toxic, whereas, in terrestrial vertebrates one of the chief functions of the kidneys is to conserve water for maintaining the water balance of the body, and they excrete urea or uric acid. The functioning of kidneys is not under the control of nervous system but is under the control of several hormones.

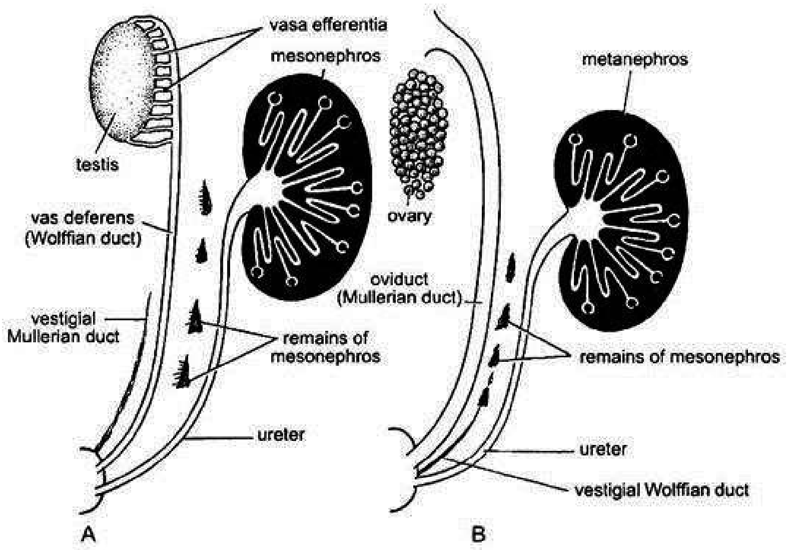

Fig. 4.8 *Diagrammatic Plan to Show Relation of Kidney and Genital Ducts in Amniotic Vertebrates: Male (A), Female (B)*

Urinary Bladder

In most vertebrates there is a bag-like urinary bladder serving as storage or temporary reservoir for urine which is derived as an enlargement of the terminal parts of mesonephric ducts. In amphibians, the urinary bladder is derived as a diverticulum from the ventral wall of the cloaca, and not from the proctodaeum, it is lined with endoderm and is called a cloacal bladder. Thus, the urine at outset passes from the ducts of the kidneys into the cloacal chamber and then forced into the bladder for storage. It is lacking in crocodilians, snakes, some lizards, and birds except ostrich. In embryos of amniotes, a large bag-like allantois arises from the hindgut serves both excretory and respiratory function, but at the time of hatching or birth the allantois is lost completely, only its basal part persists along with a portion of the cloacal wall that becomes the adult urinary bladder which is endodermal, and is called an allantoic bladder. Usually the ureters or kidney ducts do not open into the urinary bladder but open dorsally into the cloaca, except in mammals. In mammals, except monotremes, the ureters open directly into the bladder that opens outside through a short, narrow tube the urethra. Cloaca is not found in mammals except monotremes.

Function of Kidney Tubules and Kidney

The foremost major function of the urinary system is the process of excretion and elimination nitrogenous metabolic wastes from the body and homeostasis. The excretion is a physiological process of eliminating waste products of metabolism and other materials that have no use in body of an organism. The urinary system maintains a standard fluid volume by adaptable amount of water, salt and minerals that is excreted in the urine. Other aspects of its function include regulating the concentrations of various electrolytes in the body fluids and maintaining normal pH of the blood other than the stable internal environment (homeostasis) for optimal cell and tissue metabolism or function. They do this by separating urea, mineral salts, toxins, and other waste products from the blood along the job of conserving water, salts, and electrolytes. At least one kidney must function properly for healthy life to be maintained. The six most important functions of the kidneys are:

i. **Regulation of Plasma Ionic Composition:** Ions, such as, sodium, potassium, calcium, magnesium, chloride, bicarbonate, and phosphates are regulated by the amount that the kidney excretes.

ii. **Regulation of Plasma Osmolarity:** The kidneys regulate osmolarity because they have direct control over how many ions and how much water a person excretes.

iii. **Regulation of Plasma Volume:** The kidneys control plasma volume by controlling how much water a person excretes. The plasma volume has a direct effect on the total blood volume, which has a direct effect on blood pressure.

iv. **Regulation of Plasma Hydrogen Ion Concentration (pH):** The kidneys partner up with the lungs and they together control the pH. The kidneys have a major role because they control the amount of bicarbonate excreted or held onto. The kidneys help maintain the blood pH mainly by excreting hydrogen ions and reabsorbing bicarbonate ions as needed.

v. **Removal of Metabolic Waste Products and Foreign Materials:** The excretion of nitrogenous wastes is one of the most important things to kidneys that are generated by the liver after the breaks down amino acids in to ammonia. In the liver these ammonia quickly combines with carbon dioxide, to generate urea (less toxic) which is the primary nitrogenous end product of metabolism in humans. Human may also excrete some ammonia, creatinine and uric acid as a break down end product of nucleotides. Because of the insoluble nature, the uric acid in the blood will build up and form crystals that can be collected in the joints and results in gout, a joint problem.

vi. **Secretion of Hormones:** The renin is released by the kidneys which are facilitated by secretion of aldosterone released from the adrenal cortex. The aldosterone promotes the kidneys to reabsorb the sodium ($Na+$) ions. The kidneys also able to secrete erythropoietin which stimulates red blood cell production and the activation of vitamin D.

4.2.2 Genital or Reproductive System

The reproductive system or genital system is a system of sex organs within an organism which work together for the purpose of sexual reproduction. Many non-living substances such as fluids, hormones, and pheromones are also important accessories to the reproductive system. The genital system of male individual called male reproductive system comprises gonads (testes), ducts, accessory reproductive organs and glands. Likewise, the genital system of female individual called female reproductive system comprises gonads (ovaries), ducts, accessory reproductive organs and glands.

Gonads and Gonadal Ducts

The gonads are cytogenous paired sex glands present separately in individual sex (dioecious), like testes and ovaries in human males and females respectively with the exception of the hermaphrodite cyclostomes and some bony fishes. In hagfishes, *Myxine* the anterior part of gonad produces ova and the posterior part able to form sperms. The ova or sperm occurs directly into the coelom and moves to the outside through genital pores. The most marine bony fishes are functionally hermaphroditic are marine, although a few are freshwater also (e.g., killifish *Rivulus marmoratus* and the asiatic synbranchid *Monopterus albus*). Some cyclostomes like the hagfishes firstly function first as one sex, and thereafter, transform into the opposite sex. Some other possesses ovotestes in which the mature ova are fertilized by sperm produced within the same organ before they are laid. During the embryogenesis, the mesodermal coelomic epithelium forms a pair of thick, elevated, elongated genital ridges lying longitudinally along the dorsal surface of the coelom. The middle part of mesoderm of genital ridges gives rise to the gonads, whereas, the anterior (progonal) and posterior (epigonal) parts remain sterile. While the peritoneum covering them becomes the germinal epithelium. The gonads, thus, formed become suspended from the dorsal body wall by bands of tissue known as mesorchium in the male and mesovarium in the female. In the mature individual the germinal epithelium of ovaries lies on their outer surface and gives rise to ova, consequently the ova are discharged from the surface into the coelom. On the other hand the germinal epithelium of testes lines their seminiferous tubules, hence; spermatozoa are released into the lumen of seminiferous tubules.

Origin and Development of Gonads and Genital Ducts

The gonads begin as a thickening of coelomic epithelium, which forms a genital ridge. The central part of the genital ridge forms the functional gonad. The primordial germ cells migrate from their original location at the base of the yolk sac and into the germinal epithelium. The gonad has a cortex of epithelium and a medulla formed from mesenchyme. The primary sex cords then develop from cords of germinal epithelium that grow into the medullary tissue. During the time of origin the genital ducts develop from a network of tubules in the medullary region of the gonads and communicate the primary sex cords and the cranial mesonephric tubules that contribute to the sperm passages in males and regress in females. Both sexes also begin to develop an oviduct during embryonic development, the Mullerian duct, which generates from the archinephric duct.

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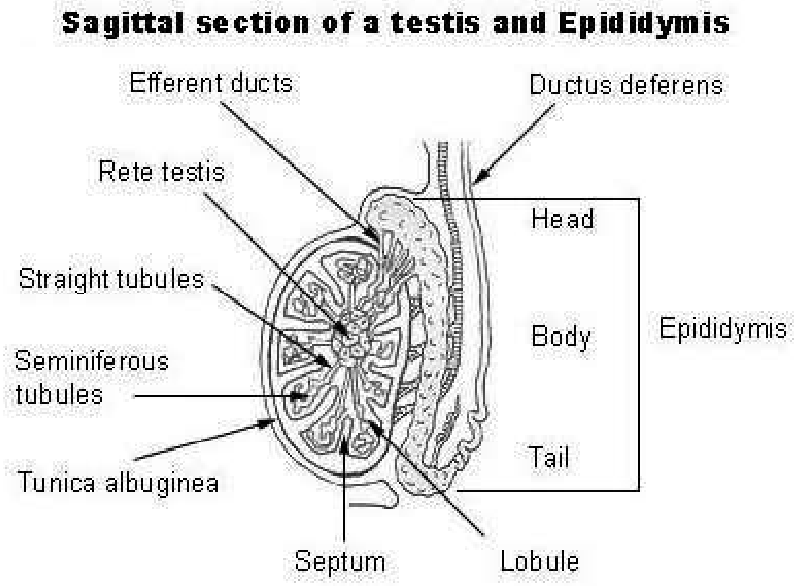

Fig. 4.9 *Sagital Section of Testis and Accessory Genital Ducts*

The testes develop comparatively earlier than the ovaries during embryonic life and are usually derived from the medulla of the undifferentiated gonad and thereafter germinal epithelium becomes the internal lining of the testes. The fundamental primary sex cords separated from the epithelium and become hollow to produce the coiled seminiferous tubules (These are the tubules that have potential to give rise sperms and surrounded by interstitial cells of Leydig, which secrete testosterone). Thus the wall of the seminiferous tubule consists of sperm-forming cells and Sertoli cells, and plays a key role in the maturation of sperm. The formation of sperms, i.e., spermatogenesis commenced through mitotic division of sperm-forming cells or spermatogonia, to produce primary spermatocytes. These cells thereafter undergo one meiotic division to form secondary spermatocytes, and then followed by 2nd meiotic division to form spermatids, that later on metamorphosed, maturate and transform to motile spermatozoa.

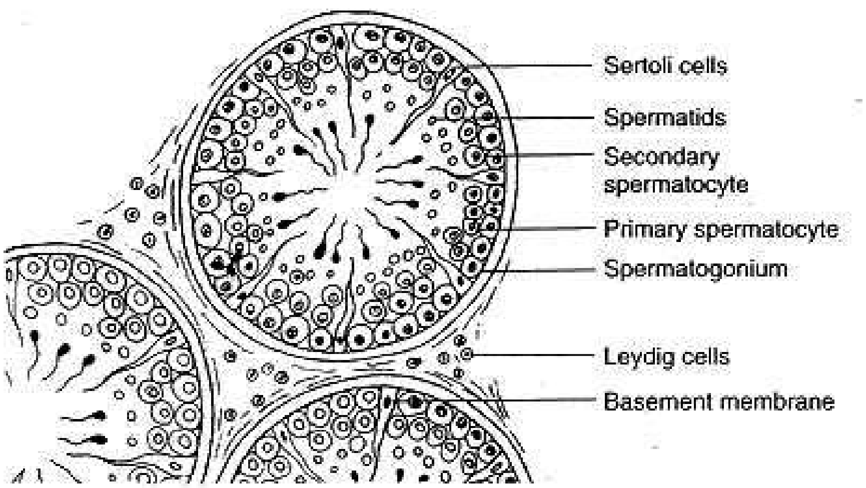

Fig. 4.10 *The Transverse Section of Testis Showing Stage of Spermatogenesis*

Similarly the germinal epithelium of the indifferent gonad becomes the thin covering of the ovaries. The ovaries consisting thousands of oogonia which transforms into mature ova by the process of oogenesis or ovogenesis. The primary sex cords disintegrate in females and are replaced by secondary sex cords, which form follicle cells that surround, nourish and assist the developing ova. There are different types of ova based on the amount of yolk present and whether the animal is oviparous, ovoviviparous or viviparous. The mammalian ovaries are generally smaller than those of other species, and are connected by the gubernaculum to the body wall.

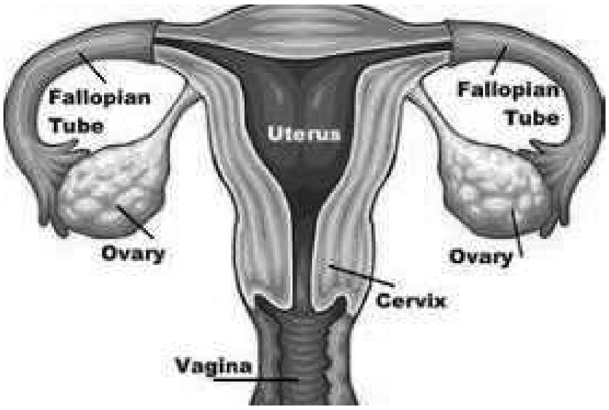

Fig. 4.11 *Sagital Section of Female Reproductive Ducts and Genitalia*

The eggs are found in primordial follicles which are around 2 million in human females at birth but just about 400 are ever actually ovulated. Each follicle ruptures and releases ova by the process of ovulation during reproductive cycle, and thereafter follicle is converted to the corpus luteum, or hard yellowish body that acts as an endocrine gland during reproductive life. The female reproductive ducts are more independent to the excretory system than are those of males. The oviduct (or Mullerian duct) in females continues to develop and rise posteriorly to the cloacal region to transformed into the passage for removal of eggs. The eggs of gnathostomes rupture into the coelom before entering the duct system. In cleidoic species, oviducts comprises shell glands that envelop eggs in albumen and a calcified shell.

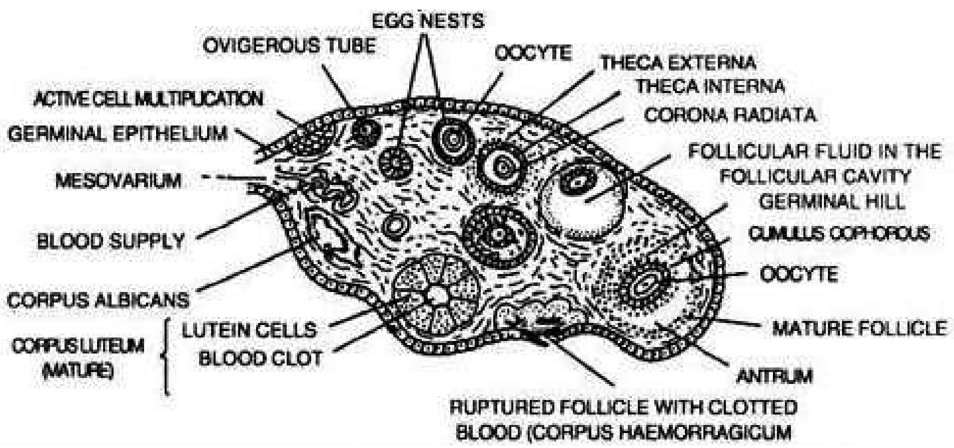

Fig. 4.12 *The TS of Mammalian Ovary Showing Follicle Maturation and Ovulation*

Modifications of Male Gonad and Genital Ducts in Vertebrates

In this section, we will discuss the male gonad and genital ducts in vertebrates.

- **Pisces:** The cartilaginous and bony fishes have paired gonads and the sexes are generally distinct. In cyclostomes gonads are unpaired and ducts are absent. Testes are paired in other vertebrates and are usually found attached to the kidneys. A testis is a compact gland covered over by coelomic epithelium and formed of a mass of highly coiled seminiferous tubules in connective tissue. These are lined by the germinal epithelium. In dogfish, the testes are elongated structures. In anamniotes the anterior portion of the mesonephric kidney comes to serve the male genital system and the posterior part as renal organ. This anterior portion loses its peritoneal funnels and malpighian bodies and its uriniferous tubules loose excretory function and form vasa efferentia which become continuous with seminiferous tubules of adjacent testis. Thus, the mesonephric kidney of adult anamniotes has an anterior genital portion and a posterior renal portion. The mesonephric duct is a urinogenital duct in male, it serves both as a urinary duct for urine and as a vas deferens for sperms. But in many elasmobranchs (e.g., dogfish) special accessory urinary ducts are formed, one for each kidney to drain urine from kidney to cloaca and the mesonephric duct is only genital in function and is a vas deferens. The anterior genital part of kidney with a part of mesonephric duct forms the epididymis.

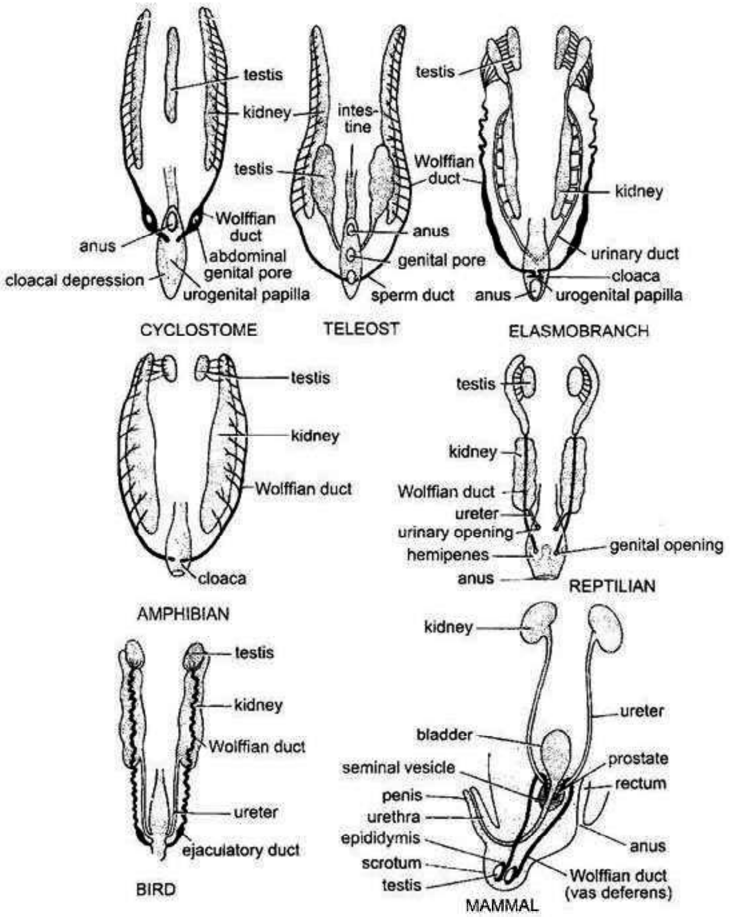

Fig. 4.13 Modifications of Male Urinogenital System in Different Vertebrates

- **Amphibia:** In amphibians, testes are paired and are connected either directly or by way of mesonephric tubules to the archinephric duct which in turn opens into the cloaca. No special copulatory organs are present. In some toads, there is a structure called *bidders organ* located anterior to each testis. Under certain circumstances this may develop into an ovary.
- **Reptilia:** In many species of reptiles, special copulatory organs for the transference of sperm to the females are present. In lizards and snakes, a pair of extrusible structures in the cloaca called hemipenes is present, while crocodiles and turtles possess a structure that may be homologous with the mammalian penis.
- **Aves:** In male amniotes, the adult functional kidneys are metanephroi, Each has its own ureter for conducting urine, hence, the persistent mesonephric duct is taken by the testis and becomes an entirely genital vas deferens or deferent duct. Its upper end is greatly coiled and forms a compact structure called the epididymis. In ducks and geese, a single penis-like structure, similar to that of turtles is present. It is derived from the antero-ventral wall of the cloaca.
- **Mammalia:** The testes as male gonads in mammals are either situated posteriorly in the body (intra-abdominal) or they are outside the body cavity (ex-abdominal) in a sac called the scrotum guided by the gubernaculum, or cord of tissue that extends between the embryonic testes and the decadence of scrotum is accompanied by an evagination of muscular and connective tissue of the body wall (cremasteric pouch) which are layers of the body wall that suspend the testes. Rete cords become the sperm passage in males. In amniotes, sperm leaves the epididymis, where sperm matures and is stores; accessory glands associated with the male reproductive tract include the prostate gland (which surrounds the urethra), the vesicular gland, and the bulbourethral gland. These glands secrete seminal fluid that increases mobility of sperm and neutralizes acids in the female reproductive tract. Sperm and seminal fluid are released into the urethra during sperm transfer to the female in male amniotes, the intermittent organ is the penis (single copulatory structure), which develops from the wall of the cloaca; in other species, sperm transfer occurs through cloacal apposition. In few confident species testes descend into the scrotal sac only during the breeding season, otherwise to be found in abdominal cavity.

Modifications of Female Gonad and Genital Ducts in Vertebrates

The ovaries are generally cytogenous masses of connective tissue within an outer germinal epithelium in which ova of various stages found to be developed from germinal epithelium. The ovaries are connected neither kidneys nor its associated excretory ducts in most of the vertebrates; therefore, the ova passes into the coelom whenever being discharged. In female anamniotes a coelomic funnel is formed from the nephrotome, the funnel grows back to form a groove on each side. The groove becomes closed to form a tube known as oviduct or Mullerian duct which lies on the outer side of the mesonephric duct and runs backwards to join cloaca. Thus, there are two ducts on each side in female anamniotes, a mullerian duct acting as an oviduct and a mesonephric duct serving as a ureter.

- **Pisces:** In most of the elasmobranchs the original pronephric duct splits longitudinally into two ducts, one becoming the mesonephric duct for urinary purpose and the other forming an oviduct for ova which approaches one or more peritoneal funnels to form its opening into coelom. The method of formation and differentiation of oviduct in elasmobranch is considered to be indication for its vertebrate origin. In cartilaginous and bony fishes, the female usually has two oviducts, and the upper ends of these oviducts are fused so that there is a single funnel-like opening or ostium through which eggs from the ovaries may pass. The oviduct of the fishes may also possesses a shell gland, since the eggs are fertilized internally and then encased in a horny shell. In some bony fishes, however, where huge number of eggs is produced during the short breeding season, the ovaries are continuous with the oviducts so as to prevent the ova from escaping into the coelom. In many teleosts the lower parts of the paired oviducts are fused and they are oviparous, but there are some in which eggs hatch internally (ovoviviparous).

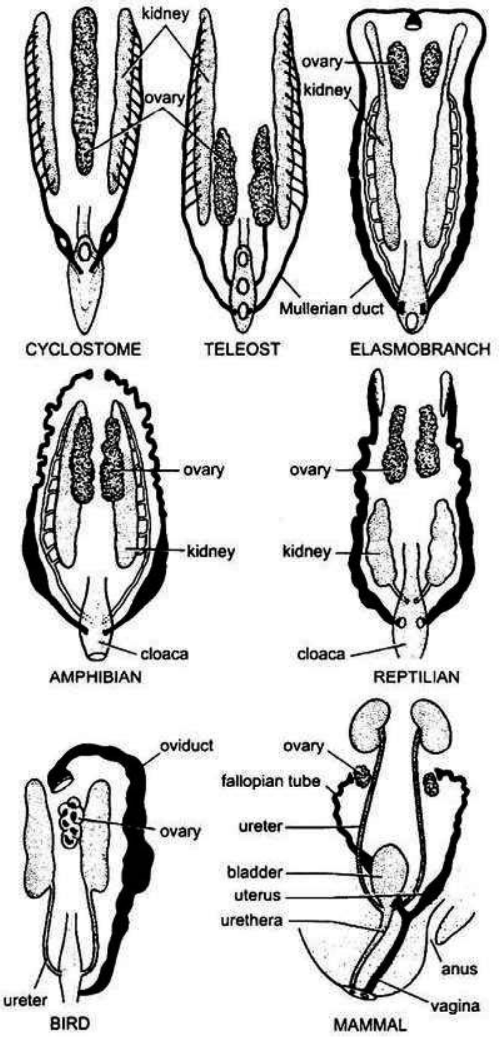

Fig. 4.14 *Diversity and Differentiation of Female Urogenital System of Different Vertebrates*

- **Amphibia:** In the amphibians, the female gonads are paired ovaries and containing a cavity filled with lymph like tissue fluid. The oviducts are also paired even though in some forms the lower ends are merged together. Commonly, the lower end of each oviduct is distended into a uterus-like structure or ovisac which serves as a provisional reservoir for ova before passing away. The glands that secrete a jelly-like covering for eggs are usually situated along the oviduct.
- **Reptilia:** In reptiles, ovaries are also paired in number having cavities filled with lymph as in amphibians, or may be solid as in birds and mammals. The paired oviducts open separately into the cloaca and comprise albumen and shell producing glands are located along the length also.
- **Aves:** In most of the birds the right ovary and oviduct present in embryonic development becomes vestigial or degenerated in adults so that he left genital system is functional in adult birds. There are many glands having capacity to secrete membranes around the eggs (including layers of albumen, shell membranes and a calcareous shell) are present along the length of oviduct. The Mullerian duct acts as an oviduct is not differentiated into parts, and the two oviducts remain separate and approaches cloaca individually.
- **Mammalia:** The urogenital system is quite more complicated and advanced in mammals than other groups. In mammals, the genital tract is divided into three regions: (i) The oviduct conveys eggs from the ovary to the remaining genital tract, (ii) The uterus that houses the fetus during pregnancy and provides the foeto-maternal connection through placenta; composed of an endometrium (lining) and myometrium (smooth muscle layer), and is bounded caudally by the cervix and (iii) The vagina acts as a birth canal during parturition. The uterus of mammals having great diversity, for example, the duplex uterus is doubled, and is found in monotremes, marsupials, elephants and rodents; the bipartite uterus is y-shaped externally and divided internally (ungulates, carnivores); the bicornuate uterus is y-shaped but has no internal partition (some ungulates, whales); and the simplex uterus has only one uterine chamber (primates). In marsupials there are two uteri (hence, Didelphia), and the terminal portions of oviducts are differentiated as vaginae. The two vaginae are separate but joined along the median line to receive the penis of the male.

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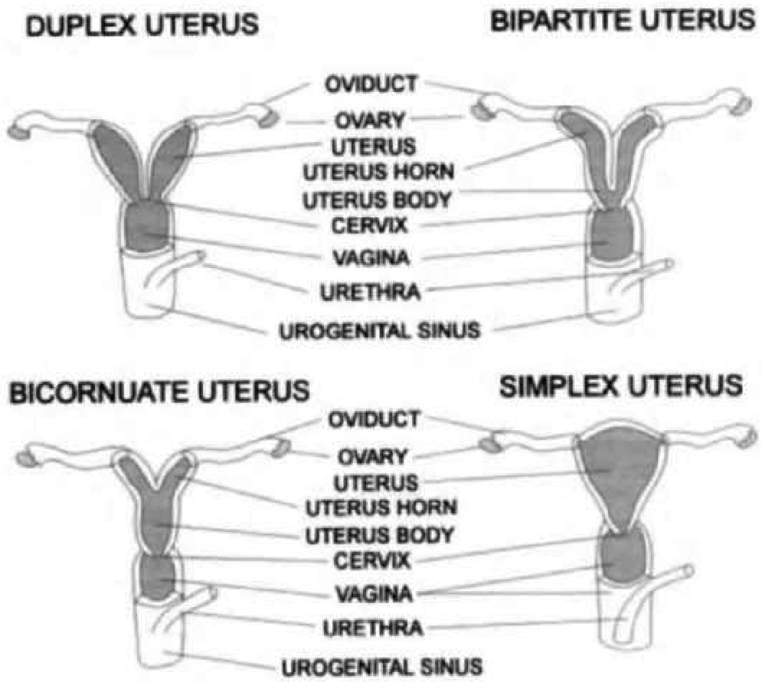

Fig. 4.15 *Modifications of Uterus in Mammals*

- But in eutherian mammals, the two vaginae fuse into a single tube. The two uteri may fuse partly or completely, thus, four kinds of uteri are recognized in Eutheria:
    i. **Duplex:** Duplex uterus found in rodents, elephants, and some bats. The two uteri do not fuse but enter and open separately in the vagina.
    ii. **Bipartite:** Bipartite uterus found in carnivores, pigs and cattle. The lower ends of the two uteri fused together so that they open by a single aperture (os uterus) into the vagina.
    iii. **Bicotnuate:** Bicornuate uterus found in ungulates, whales and most bats. The lower ends of the two uteri fused more completely with no partition wall between the fused portions and this part has a single cavity.
    iv. **Simplex:** Simplex uterus found in primates. The two uteri fused completely forming a single body with one cavity. There is no correlation between the development of various types of uteri and the phylogenetic relationship between the orders of mammals.

NOTES

Check Your Progress

1. What do you understand by urinogenital system?
2. Define nephrotomes.
3. What are the major parts of kidney?
4. What is the role of urinary bladder in vertebrates?
5. What do you understand by excretion?
6. What is the major function of urinary system?
7. What is the foremost function of reproductive system?

4.3 SENSE ORGANS

The sense organs are the organs that respond to external stimuli by conveying impulses to the sensory nervous system. The sense organs include eyes, ears, tongue, skin, and nose, which are helpful in protection of the body. The human sense organs comprise receptors that relay information through sensory neurons to the appropriate places within the nervous system. Each sense organ contains two different receptors: (i) General Receptor (present in skin, visceral organs, muscles, and joints); (ii) Special Receptors: (include chemoreceptors (in the mouth and nose), photoreceptors (in the eyes), and mechanoreceptors (found in the ears).

4.3.1 Simple Receptors

The thigmotactic and thermoreceptos are the group of general receptors responds to felling of touch, temperature, pain, and pressure present in the skin. These skin receptors generate an impulse when activated, which is carried to the spinal cord and then to the brain. The other organs made of tissues, like joints, ligaments, and tendons contain proprioceptors or proprioreceptors, which detect the position and movement of the limbs.

The auditory receptors are the organs to perceive sound principally. The ear is the principal auditory receptor which not only assists hearing, but also responsible for maintaining equilibrium or balance. For maintaining equilibrium or balance of body, the ear must detect movement that is picked up by the mechanoreceptors in the inner ear through the hair cells containing cilia in the semicircular canals and the vestibule. However, the hearing/ listening by the ear must respond to mechanical stimulation by sound waves hits the eardrum which moves tiny bones (the malleus, incus, and stapes) and brain then interprets the information as a specific sound.

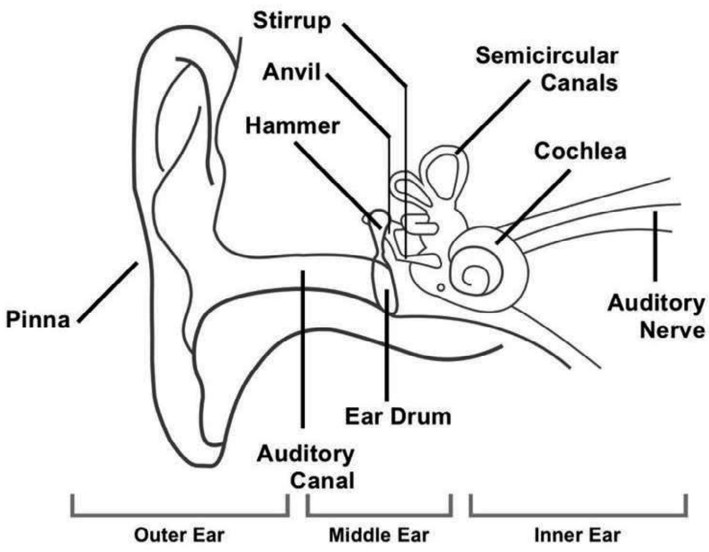

Fig. 4.16 *Structure of Ear: An Organ of Sound and Balance*

The photoreceptor are associated to seeing or visualization and include the organ eye, which consisting iris as part to detect different color. The iris in fact is a pigmented muscle that regulates the size of the pupil, to allow light into the eyes. The iris and pupil are enclosed by the cornea. The anterior chamber behind the pupil is containing lens in its backward. The ciliary body contains a small muscle that connects to the lens and the iris. The ciliary muscle connects the iris and lens to changes the shape of the lens for the adjustment of distant (far) or vicinity (near) vision. When the lens flattens then able to see farther away, however, it becomes rounded for the near vision. The mechanism of changing the shape of the lens is called accommodation. Back to the lens in the vitreous body, there is a gelatinous material called vitreous humor responsible for the shape to the eyeball and transmission of light to the retina lies. The retina contains photoreceptors, which detect light. There are two types of sensors detect light: (i) Rods to detect motion of light; and (ii) Cones to detect fine detail and color, and work best in bright light. There is a clinical condition associated to the detection of color called color blindness. Color blindness results due to lacking of any one types of cone among the three (one detects blue, one that detects red, and one that detects green).

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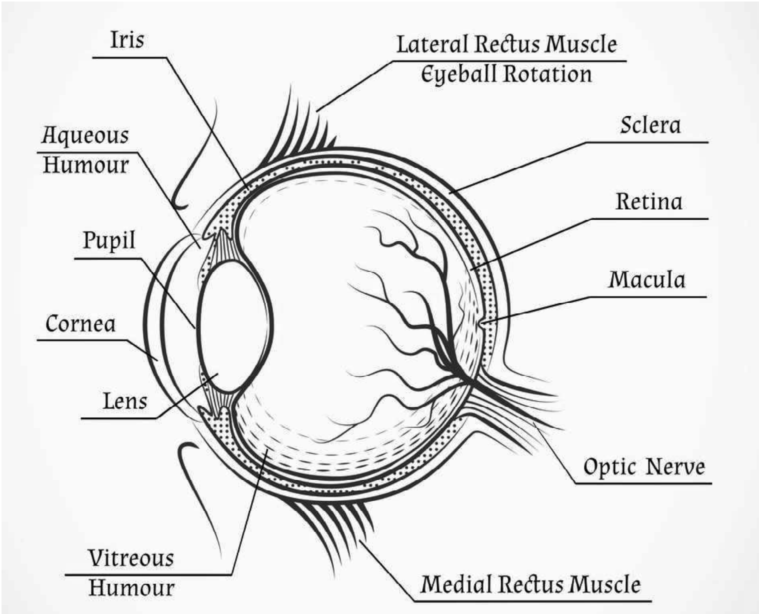

Fig. 4.17 *Structure of Eye: An Organ of Sight*

4.3.2 Organs of Olfaction and Taste

A sense is a biological system used by an organism for sensation, the process of gathering information about the world and responding to stimuli. The ability of an organism to sense and respond to its environment is critical to its survival. The senses of smell and taste combine at the back of the throat. Therefore, if anyone tastes something before smell, the smell lingers internally up to the nose causing to smell it. Both smell and taste use chemoreceptors, which essentially means for sensing the chemical environment. The nose is an olfactory organ which assists to perceive various smells. The mechanism of sense of smell is known as olfaction. The olfactory cells have a propensity to line the roof of the nasal cavity. At one terminal, olfactory cells have cilia that directs into the nasal cavity and at the next terminal of the cell, are the olfactory nerve fibres. As the individual breathes in, the air passes into the nasal cavity and thereafter the chemoreceptors (protein receptors) of olfactory cells can detect subtle differences in chemicals. These chemicals bind to the cilia of olfactory cells, which conduct a nerve impulse that is carried to the brain. The brain then translates these impulses into a meaningful smell. During a cold, (nasal infection/ pneumonia/ COVID-19), the body produces mucus which blocks the sense of smell, therefore, the taste and smell of food gets bland.

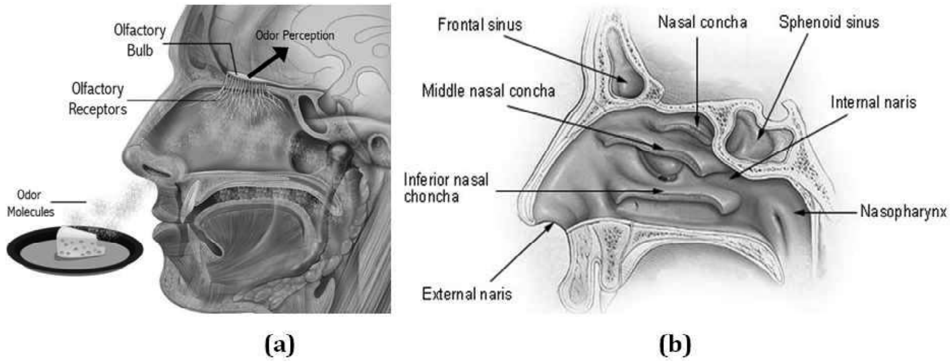

Fig. 4.18 Sense of Olfaction (a) and Structure of Nose (b)

Gustatoreceptors are the senses of taste, which work closely together with the smell. It means without selling something, the individual cannot analyze taste correctly. The taste buds on the tongue contain chemoreceptors that function in a similar manner to the chemoreceptors in the nasal cavity. There are four different types of taste buds present and distributed over tongue to detect different types of tastes like sweet, sour, bitter, and salty. The little bumps on the tongue are called papillae, and the taste buds actually lie down in the grooves between each papilla. Chemicals from food bind to the microvilli of taste buds, generating a nerve impulse that is carried through the sensory nerve fibers and eventually to the brain.

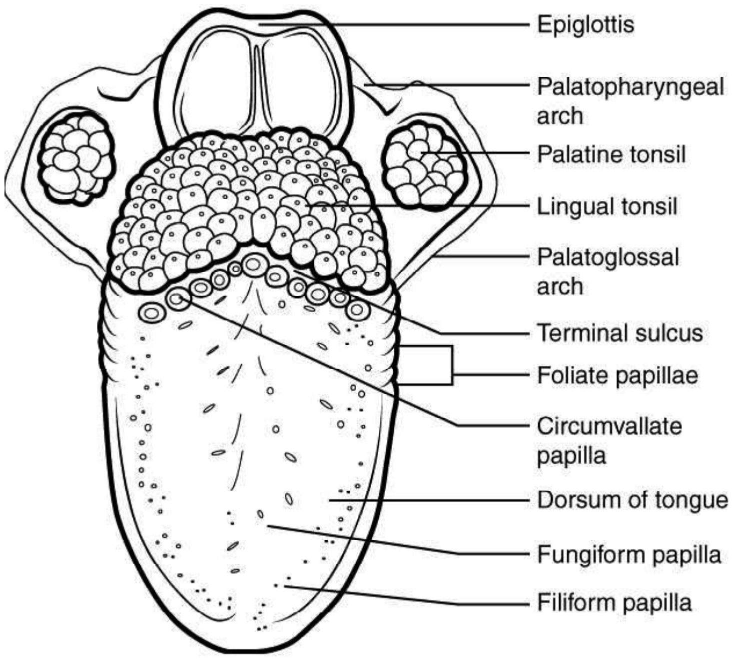

Fig. 4.19 Structure of Tongue: An Organ of Taste

4.3.3 Lateral Line System

The Lateral Line System (LLS) is a system of sense organs found in aquatic vertebrates, used to detect movement, vibration, and pressure gradients in the surrounding water, schooling behavior, predation, and orientation. This is also called as or Lateral Line Organ (LLO) or lateralis system because of the lateral prearrangement of the associated sense organs, so that sensory capacity is achieved by modified epithelial cells, known as hair cells, which respond to dislocation caused by movement. The lateral lines are usually visible as faint lines of pores running along the length on each side, from vicinity of the gill to the base of tail. The hair cells of lateral line conduct these signals into electrical impulses through excitatory synapses and some time have been adapted to function as electro-receptors. The LLS and the inner ear of fish are often grouped together because of many similar functions, ultrastructure and methods of development, so called Octavo-Lateralis System (OLS). Thus lateral line is a sensory system in fish and amphibians made of mechanoreceptors called neuromasts.

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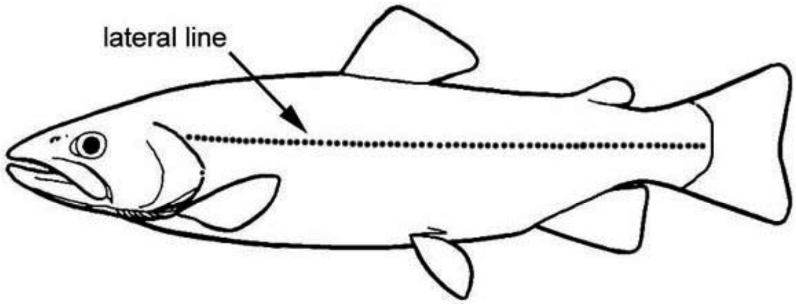

Fig. 4.20 *Schematic Outline of Lateral Line System as a Faint Line of Pores in a Fish*

Structure of Lateral Line System

The chief component of lateral line action and its mechanism is due to the neuromast which is a mechanoreceptive organ that permits the sensing of mechanical changes in water. There are two kinds of neuromasts are found in animals. The first is canal neuromasts which are positioned in the intra-dermal canals, and the second is superficial neuromasts which are to be found in the intra-epidermal canals. The canal neuromasts are capable to detect acceleration of water flow, while superficial or free neuromasts can sense the velocity. Each neuromast consists of receptive hair cells and the tips of hair cells having both glutamatergic afferent and cholinergic efferent connections are covered by flexible jellylike cupula. These hair cells are modified epithelial cells and containing bundles of microvilli (40-50 in numbers) solely acting as mechanoreceptors. The application of mechano-sensitive hairs is homologous to hair cells in the auditory and vestibular system, indicating a close relation among these systems.

The hair cells utilize a system of transduction in order to transmit directional stimulus, generate a steady, tonic rate of firing. As the mechanical movement is transduced through water to neuromast, the cupula bends and is displaced, therefore, variation in magnitude of the stimulus, results in shearing movement and deflection of the hair. The deflection towards the longest hair results in depolarization of the hair cell, augmented neurotransmitter discharge at the excitatory afferent synapse, and a higher rate of signal conduction. On contrary, deflection towards the shorter hair has the opposite effects, hyperpolarizing the hair cell and producing a decreased rate of neurotransmitter release.

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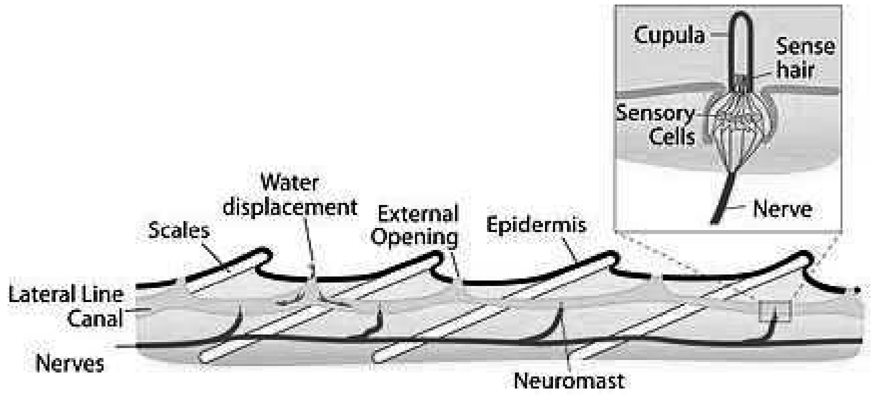

Fig. 4.21 *Structure of Lateral Line System and Magnified Neuromast in Fish*

Physiology of Lateral Line System

The mechanoreceptive hair cells of lateral line structure are incorporated into more complex circuits through their afferent and efferent connections or synapses which utilize glutamate. There are variety of different neuromasts and afferent connections possible, ensuing difference in mechanoreceptive characteristics. For example, a series of experiments on the superficial neuromasts of *Porichthys notatus* revealed that neuromasts can exhibit a receptive specificity for meticulous frequencies of stimulation. A metal ball was vibrated at different frequencies to prevent extraneous stimulation in an immobilized fish. The responses were recorded by using single cell measurements with a microelectrode. The response was used to construct tuning curves, which revealed frequency preferences for two main afferent nerve types. One variety is attuned to collect mechanoreceptive information about acceleration, responding to stimulation frequencies between 30–200 Hz. However, other type is sensitive to velocity information and is most receptive to stimulation below <30 Hz.

The efferent synapses to hair cells are inhibitory in nature and utilize acetylcholine as a transmitter. They are crucial participants in a corollary discharge system designed to limit self-generated interference. When a fish moves, this creates disturbances in water that could be detected by lateral line organ system, potentially interfering with detection of other biologically relevant signals. To prevent this, an efferent signal is sent to hair cell of neuromasts upon motor action, resulting in inhibition that counteracts the excitation resulting from reception of self-generated stimulation. This allows the fish to retain perception of motion stimuli without interference created by its own movements. Once signals transduced from the hair cells are transmitted along lateral neurons, they eventually reach the brain.

Functions of Lateral Line System

The functions of LLS are:

i. The lateral line system permits the detection of movement, vibration and pressure magnitude in contiguous water of an aquatic animal, and providing spatial awareness and ability to navigate in environment. Thus, plays a pivotal action in orientation, predatory behavior, defense, and social schooling.

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ii. The lateral line of predatory fishes might be confused some times and unable to detect social schooling through overlapped complex pattern of simple acoustic and pressure gradients of many closely swimming prey fish.

iii. The lateral line system is necessary to detect vibrations made by prey, and to orient towards the source to begin predatory action. This behavior persists even in blinded fish, but is greatly reduced when lateral line function was inhibited by cobalt chloride application.

4.3.4 Electro Reception or Electroception

The electroreception or electroception is a biological talent to recognize natural electrical stimuli and usually the characteristic feature of aquatic or amphibious animals, because water is a much better conductor than air. The modern research has shown that only the vertebrates but invertebrates (bees) also have capacity to detect the presence and pattern of a static charge on flowers. In vertebrates, the electroreception is an inherited trait which is to say that it was present in common ancestor of all vertebrates. This form of ancestral electroreception is called ampullary electroreception, with the receptive organs themselves called ampullae of Lorenzini. The ampullae of Lorenzini present in cartilaginous fishes (sharks, rays, and chimaeras), lungfishes, coelacanths, paddle fish and aquatic salamanders, and caecilians. Other vertebrates with electroreception like catfish, gymnotiformes, and at least one species of cetacean all have differentially derived forms of electroreception. The ampullary electroreception is passive, and is used predominantly in predation. The two groups of teleost fishes are weakly electric and engage in active electroreception such as Neotropical knife fishes (Gymnotiformes) and African elephant fishes (Notopteroidei). The electroreception is applied in electrolocation (detecting objects) and for electrocommunication.

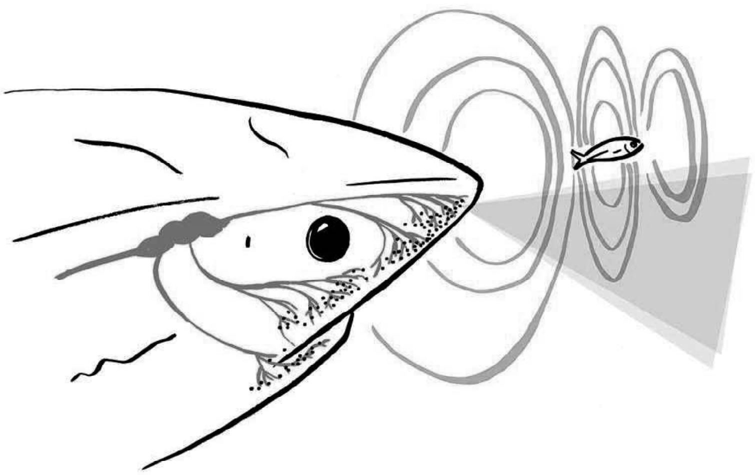

Fig. 4.22 *Schematic Visualization of Electroreception in a Fish*

Electrolocation in Fish

The electroreceptive animals use this type of sense to locate objects around them and play a key role in allocation of ecological niches where animal cannot depend on vision such as in caves, in muddy water and at night. There are many fish use electric fields to detect buried prey and predators so that some shark embryos and pups "freeze" when they detect the characteristic electric signal of their predators. It has been proposed that sharks can use their acute electric sense to detect the earth's magnetic field by detecting weak electric currents induced by their swimming or by flow of ocean currents. There are two types of electrolocation noticed in fishes like active and passive electrolocation.

Active Electrolocation in Fish

In active electrolocation, the animal senses its surrounding environment by generating electric fields and detecting oscillations in these fields using electroreceptor organs. This electric field is generated by means of a specialized electric organ consisting of modified muscle or nerves, so that its frequency and wave structure are specific to species, times and individual (jamming avoidance response). Animals that use active electroreception include the weakly electric fish, which either generate small electrical pulses (pulse-type) or produce a quasi-sinusoidal discharge from the electric organ (wave-type) smaller than one volt. Weak electric fish can discriminate between objects with different resistance and capacitance values, which may help in identifying the object at a range of about one body length.

Passive Electrolocation in Fish

The passive electrolocation is a process where certain species of fish can detect electric fields using specialized electroreceptors to diagnose and allocate the source of an external electric field in its environment creating an electric field. In passive electrolocation, the animal senses the weak bioelectric field generated by other animals and uses it to locate them. A second source of electric fields in fish is the ion pumps associated with osmoregulation at gill membrane which is modulated by the opening and closing of mouth and gill slits. Many fish that prey on electrogenic fish use the discharges of their prey to detect them that evolve more complex or higher frequency signals which are harder to detect. Passive electroreception is carried out solely by ampullary electroreceptors in fish and tuned to low frequency signals below one tens of Hertz.

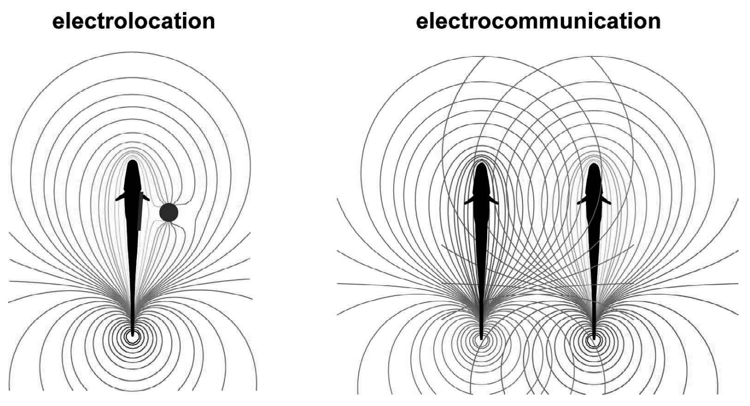

Fig. 4.23 *A schematic Illustration of Electrolocation and Electrocommunication in Fishes*

Electrocommunication in Fish

The electrocommunication is communication method used by weakly electric fishes which using an invisible communicating channel such as electric signaling. In this mechanism of communications, one fish generating electric field and a second individual receiving that electric field with its electroreceptors. The receiving side will interpret the signal frequencies, wave forms, and delay, etc. The best studied species are two freshwater lineages: African Mormyridae and South American Gymnotiformes. The weakly electric fish are the only group that have been identified to carry out both generation and reception of electric fields, than the others adapted to either generate signals or receive them, but not both. The communication between electric fish has been identified mainly to serve the purpose of conveying information in species recognition, courtship and sex recognition, motivational status (attack warning or submission), and environmental conditions as well as territorial displays. Some species of catfish use their electric discharges only in agonistic displays.

Electroreceptors in Fishes

The electroreceptors are voltmeters and electroreceptive sensory cells are hair cells, forming part of octavo-lateral sensory system. Fishes contain mechanoreceptive sensory systems for hearing, maintenance of equilibrium, detection of gravity and rotation of water currents along body. Electroreceptive sensory cells are similar to mechanoreceptive sensory cells of vertebrates; in fact, the ampullae of Lorenzini have long been regarded as mechanoreceptors. Electroreceptors as well as mechanoreceptors are amalgamated by cranial sensory nerves only; unlike their mechanoreceptive counterparts, electroreceptors do not have an efferent innervation.

Tuberous Electroreceptors

The tuberous electroreceptors are found in a few teleosts only, such as, electrogenic Mormyroidei and Gymnotiformes, and perhaps also Siluriformes. Tuberous electroreceptor organs are fired by Electric Organ Discharges (EODs). They are of two functional types: (1) time marker units of high sensitivity and short, fixed latency to a supra-threshold EOD; (2) amplitude coders that are relatively insensitive in absolute terms, encoding minute intensity changes of a fish's own EOD. The first type mainly supports electrocommunication, the second have ability of active object detection. The tuberous electroreceptor organs therefore tend to have bandpass characteristics; some show marked tuning to a certain "best" frequency (frequency of lowest threshold), others are more broadband. Adequate stimuli for tuberous receptors are electric organ discharges.

Ampullary Electroreceptors

The ampullary electroreceptors are exceedingly sensitive to weak electric field and low-frequency stimuli only. The weak stimuli best detected by the primitive ampullary receptors which may also respond best to an externally negative stimulus, underlining their common origin, those found in cartilaginous fishes, nonteleost bony fishes and amphibians. This is in contrast to the few teleosts which possess ampullary receptors responding best to (weak) stimuli of opposite polarity (positive outside). The ampullary electroreceptor cells of nonteleosts always bear a kinocilium at their apico-lumenal face in addition to microvilli while teleosts ampullary receptor cells bear microvilli only. Ampullary electroreceptor cells and their supporting cells make the sensory epithelium lining of ampulla found at the end of a trans-epidermal canal which is approaching outside. The marine fishes usually have longer canals than freshwater fishes, with the receptor opening directly above ampulla. The ampullary organs of elasmobranchs have long been known as "ampullae of Lorenzini".

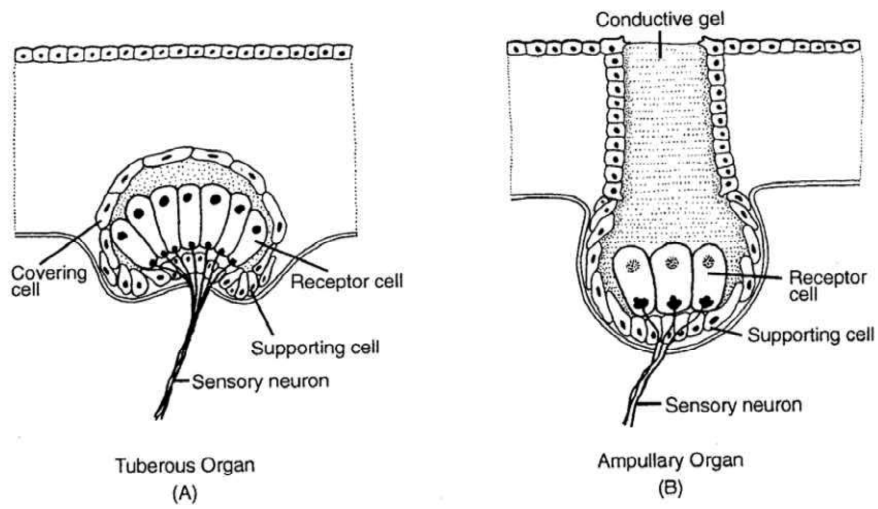

***Fig. 4.24** Schematic Diagram of Tuberous (A) and Ampullary (B) Electroreceptors in Fish*

Functions of Electroreceptors in Fishes

The functions of electroreceptors in fishes are:

i. **Field Detection:** The electroreceptors can be operated either in 'active' or 'passive' mode. The active operating electroreceptors detect the fields generated by fish itself either by its electric organ discharge (as in electric fish), or by its motion through earth's magnetic field (as in elasmobranch and some other fishes) than the passive mode that would be the detection of fields of extraneous origin.

ii. **Prey Detection:** The bioelectric Direct Current (D.C.) and low-frequency fields have been measured from all living marine and freshwater organisms; especially strong fields are generated by wounded organisms. Electrically evoked feeding responses have been observed not only in sharks and stingrays but also in freshwater teleosts, such as catfish or weakly electric fish which all have ampullary, low-frequency electroreceptors. By an attacking fish's motion relative to an electric dipole source, a pure D.C. field is transformed to a low-frequency field, depending on distance from dipole and on swimming speed. The observed threshold sensitivities and attack distances were 5nV/cm and 40cm in marine sharks, and 5μV/cm at 5cm distance in freshwater teleosts.

iii. **Orientation by Environmental Fields:** In Ocean's electric fields are generated by flow of water through vertical component of Earth's magnetic field. However, in freshwater bodies fields of electrochemical, rather than electromagnetic, origin prevail. These environmental fields are potential orientational cues as indicated by behavior of trained animals. These field strengths are well in range of sensitivity of sharks, rays and skates and may inform elasmobranch fishes about their drift with water, or provide them with orientational cues during their movements in familiar territory. Therefore, facts and experiments support the view that electroreceptive fishes may use ambient electric fields for orientation.

iv. **Detection of Communication Signals:** Ampullary electroreceptors clearly have a function in intra and interspecific electric communication. Weakly electric, marine skates communicate by electric organ discharges (EODs) which are monopolar and hence have a high D.C. component to their amplitude spectrum. The ampullary receptors are sensitive to these low-frequency components; there are no other receptors which could mediate these skates' sensitivity for their EODs. Some species' pulse EODs are monopolar; hence, have a high D.C. component like those of skates. But also the biphasic, triphasic, etc., pulse EODs of many mormyrid and gymnotiform weakly electric fishes have low-frequency components of sufficient strength to stimulate these fishes' ampullary receptors. Also, the spectral low-frequency component associated with social "chirping" (brief offs of the EOD) is detected by ampullary receptors and transmitted to the brain.

v. **Magnetic Field Compass:** There are presently two sensory mechanisms by which organisms may orient in Earth's magnetic field. The first is coupling of permanently magnetic material within or outside body of organisms to geomagnetic field. This has been demonstrated in magnetotactic bacteria, and is highly likely in at least some other organisms. The second involves electro-orientation through Faraday's effect. In the putative "active mode" of ampullary electroreceptors in a marine shark, the strength of field at a receptor depends on swimming speed and swimming direction relative to horizontal component of earth's magnetic field. The electromotive force which is induced through the Faraday's effect is oriented perpendicularly to both swimming direction and magnetic field, and is believed to be basis for the magnetic sense of elasmobranchs. This sensory capacity would offer the fish complete compass data.

vi. **Detection of Object Location and Communication Signals:** An electrogenic fish's ampullary electroreceptors may identify its own electric organ discharges (reafference). This is definitely true in extremely sensitive receptors of marine skates and rays, i.e., weakly and strongly electric respectively. It could be, similar to tuberous electroreceptor reafference in weakly electric teleosts, active object detection, as suggested by Baron. Alternatively, ampullary sensory input evoked by a skate's or a ray's own EOD might serve as a reafference, thus, enabling fish to discriminate its own EODs from those of neighbours.

vii. **Reproductive Behavior:** It was only after *Pollimyrus isidori* successfully reproduced in aquaria that the reproductive behavior of a mormyrid could be studied; a breakthrough for the scientific enquiry of electrocommunication.

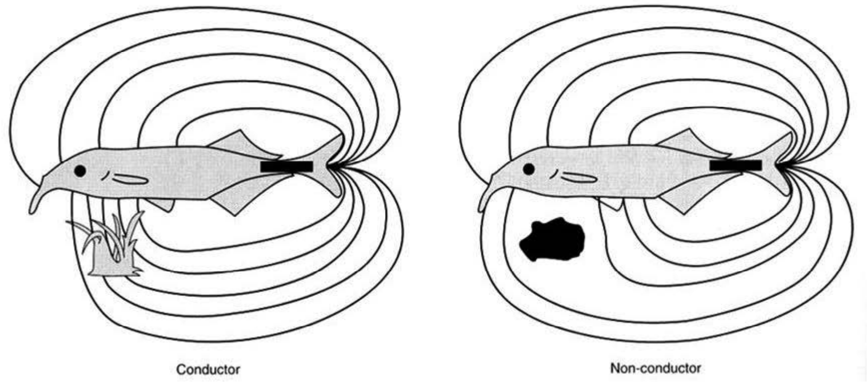

Fig. 4.25 *Electric Field Generated by Fish during Electroreception is Distorted by Nearby Objects: A Good Conductor Such as Living Organism Draws Lines of Force Together in Contrast Non Conductor (Nonliving Matter)*

Mechanism of Electroreception in Fish

The active electroreception evaluates and validates upon tuberous electroreceptors having a movable plug of epithelial cells which connects sensory receptor cells to external environment and are sensitive to high frequency stimuli. However, the passive electroreception however, relies upon ampullary receptors having jelly-filled canal leading from sensory receptors to skin surface and are sensitive to low frequency stimuli. The Mormyrid electric fish from Africa is using tuberous receptors known as Knollen organs to sense electric communication signals. There are number of elasmobranchii rely chiefly on electrolocation in final stages of their attacks, that can be demonstrated by robust feeding response elicited by electric fields similar to those of their prey. The sharks are the most electrically sensitive animals known, responding to direct current (DC) fields as low as 5nV/cm. by ampullae of Lorenzini. A problem with the early submarine telegraph cables was the cable damage caused by sharks because of the electric fields produced by these cables which was sensed by the sharks.

The electric eel (actually a knife fish), other than its capability to produce high voltage electric shocks, uses lower voltage pulses for navigation and prey detection in its turbid habitat. This ability is shared with other gynotiformes. The electrolocating fishes use this skill to detect prey, locate other fish, avoid predators, and navigate by Earth's magnetic field. The electroreceptors probably evolved once or twice early in vertebrate evolution, but the sense was apparently lost in amniotes, and in a large number of the Actinopterygii (ray finned fishes) only to reappear independently in two teleost clades only.

Electrogenic Fishes

Any living tissue can generates electric fields associated with regulation of ionic balance. These electric signals may radiate into environment. In animals, electric fields also arise from normal nerve or muscle-cell activity, and, in most cases, are of low frequency and intensity up to 0.5mV. In certain fishes, however, we find electric organs, consisting of closely packed, orderly arranged groups of cells and solely responsible for production of an electric field outside the body. In most cases, these cells are modified muscle cells. These electric organs are under the exclusive control of the brain. The electric fields range from very weak to very strong (500 Volts or more). These fishes are said to be electrogenic.

In the whole animal kingdom, it is only two classes of Pisces that includes electrogenic members are Chondrichthyes (cartilaginous fishes) and Osteichthyes (bony fishes). Within cartilaginous fishes, only some Batidoidimorpha (rays) have electric organs (weakly electric Rajidae or skates; and strongly electric, Torpedinidae or electric rays). Among bony fishes, only 4 orders comprising electrogenic species are: Mormyroidei (elephant fishes), very few Siluriformes (catfishes), Gymnotiformes (South American knife fishes), and Perciformes (stargazers). All these ectrogenic species are fresh water dwelling except stargazers. The electric organs must have evolved at least six times independently; two times among rays, and four times among teleosts. The electric organs that are discharged for brief periods only during prey attack or defense and its discharges cause discomfort or pain to a human during fish handling and able to "knock a man down" in its natural environment.

The electric organs frequently consist of customized muscle cells, or electrocytes, which are not able to contract but still skilled of producing large action potentials. These electric organs are derived from the most diverse muscles and thus can be occurred almost anywhere in a fish's body. For example, in weakly electric skates these are located in long, extremely slender tail, while in strongly electric rays these organs are part of head region of their flattened, disc-shaped body.

Evolution of Electroreception in Fishes

The electroreception occurred early in evolutionary history with the evolution of an ampullary sensory system that integrated receptors able to detect weak electric signals in surrounding. The sense organs specialized for electroreception has only been found among vertebrates, and around 8,600 species are known to be electroreceptive. The majority of teleosts and amniotes do not have an electroreceptive system, but distribution of electroreception in terms of evolution involves different classes of fish.

i. There is an origin of a common ancestor of current existent vertebrates (close to lampreys and gnathostomes). This ancestor evolved a lateral line that is important in processing sensory information and present in today's hagfishes. Ampullary receptors are ancestral to jawed fish, for lampreys and agnathans were found to have ampullary receptors 400 million years earlier.

ii. There is a loss of electroreception in amniotes. This could be due to fact that air is a poor medium to effectively conduct the electric fields, unlike water.

iii. There is also a loss of electroreception in gars, bowfin, and teleosts (neopterygian fishes). Ampullary receptors are present in all surviving cartilaginous fishes and bony fishes except a few species present in Neopterygii (which include gars, bowfins, and teleosts).

iv. The monotremes and a least three groups of fresh-water teleosts re-evolved electroreception.

v. A group of teleosts, xenomystinae, etc. acquired passive electrolocation with low frequency sensitive ampullary receptors.

vi. Another group of teleosts, Mormyroids, evolved passive electrolocation and active location, as well as a pulse type EODs in active electrolocation.

vii. The silurifiormes and gymnoformes evolved passive electrolocation, and gymnoformes also evolved active electrolocation with a pulse type or wave type EODs.

Check Your Progress

8. Write the names of sense organs.
9. What do you understand by lateral line system?
10. What is the main function of lateral line system?
11. Define electroreceptors.

4.4 NERVOUS SYSTEM: ORIGIN AND COMPARATIVE ANATOMY OF BRAIN

The nervous system is a network of cells called neurons that coordinate actions and transmit signals between different parts of the body. Central to the functioning of the nervous system is an extensive network of specialized cells called neurons. Neurons feature many thin projecting fibers called axons, which penetrate deep into tissues. They are able to communicate with other cells by chemical or electrical means at synapses. Neuronal function is supported by neuroglia, specialized cells which provide nutrition, mechanical support, and protection.

Neuron or Nerve Cell

Structural and functional unit of nervous system is called as neuron or nerve cell. The entire nervous system grouped into three categories: (i) Central Nervous System or CNS; (ii) Peripheral Nervous System or PNS; (iii) Autonomic Nervous System or ANS. The nervous system is made up of highly specialized cells called as neurons. A neuron is composed of three main parts, namely cell body or cyton, dendrite and axon.

(a) Cyton: It contains a well defined nucleus, surrounded by granular cytoplasm called neuroplasm and all the cell organelles like mitochondria, Golgi complex, Nissl's granules, rough endoplasmic reticulum, etc. Only centrosome is absent because nerve cells have lost the ability to divide.

(b) Dendrites: These are branched cytoplasmic projections of cyton known as the dendrons which receive nerve impulses at the branches called dendrites.

(c) **Axon:** It is a very long process and projects from a part of cyton axon hillock. The lower end of the axon is branched and each branch terminates as a bulb like structures called nerve endings which have swollen synaptic knobs or vesicles, which store category of chemicals called neurotransmitters. The axons transmit nerve impulses away from the cell body to a synapse or to a neuromuscular junction.

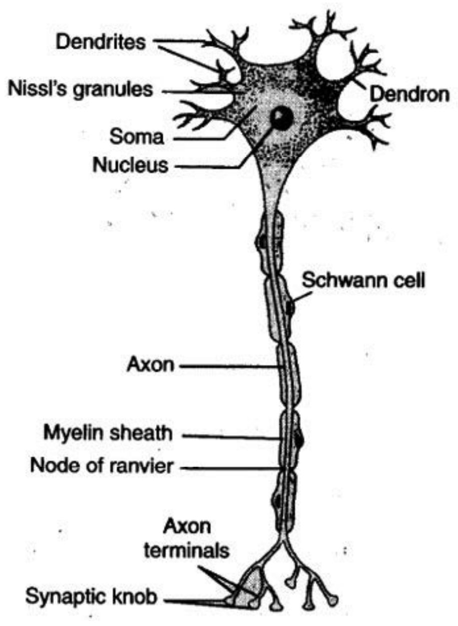

Fig. 4.26 *Structure of Neuron*

Types of Neuron

Scientists have classified neurons into four main groups based on differences in shape:

i. **Multipolar Neurons:** These are the most common neuron in the vertebrate nervous system and their structure most closely matches that of the model neuron: a cell body from which emerges a single long axon as well as a crown of many shorter branching dendrites.

ii. **Unipolar Neurons:** These are the most common invertebrate neuron, feature a single primary projection that functions as both axon and dendrites.

iii. **Bipolar Neurons**: These usually inhabit sensory organs like the eye and nose. Their dendrites ferry signals from those organs to the cell body and their axons send signals from the cell body to the brain and spinal cord.

iv. **Pseudo-Unipolar Neurons:** These are a variant of bipolar neurons that sense pressure, touch and pain, have no true dendrites. Instead, a single axon emerges from the cell body and heads in two opposite directions, one end heading for the skin, joints and muscle and the other end traveling to the spinal cord.

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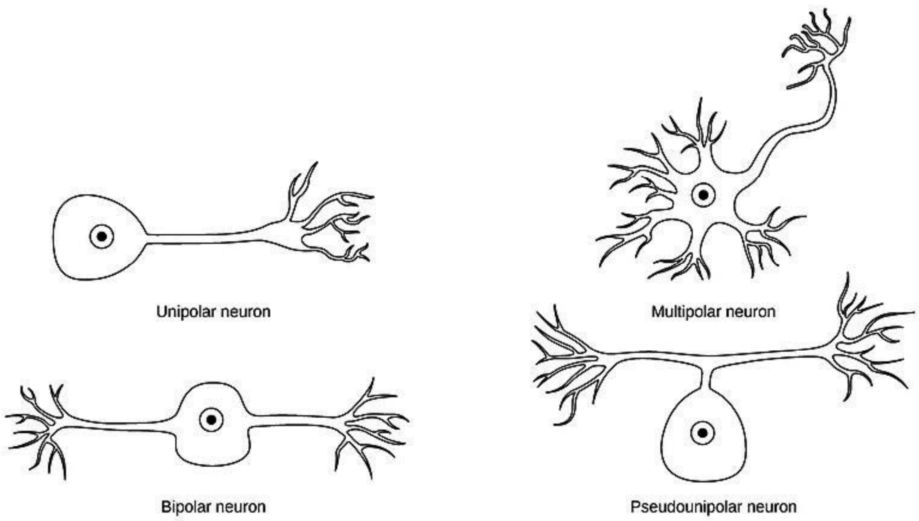

Fig. 4.27 *Types of Neurons in Vertebrates*

4.4.1 Central Nervous System

The Central Nervous System (CNS) is the major neural part of the body comprising the brain, spinal cord, and retina, is the control panel for our bodies responsible for cognition, movement, senses, and emotions.

During ontogenesis or embryonic development of a vertebrate, the mid-dorsal strip of embryonic ectoderm develops a longitudinal thickening, known as a medullary or neural plate. The neural plate slightly invaginates in such a way that its edges rise upwards to form neural folds. The further growth results in merging of neural folds to form a hollow neural tube above the notochord. The cells of the neural tube give raise two kinds of cells, the neuroblasts and spongioblasts. The neuroblasts develop into neurons, while the spongioblasts form the neuroglia and ependymal cells lining the neural canal.

The primordial or newly formed neural tube is approaches by opening at both ends, having a neuropore in front communicating with the exterior, posteriorly the neural tube communicates with the archenteron coelom by a very short neurenteric canal, but both openings become closed shortly. The anterior end of the neural tube enlarges forming the brain, while the remaining neural tube will give rise to the spinal cord. The cavity of the neural tube will become the ventricles of the brain and central canal of the spinal cord.

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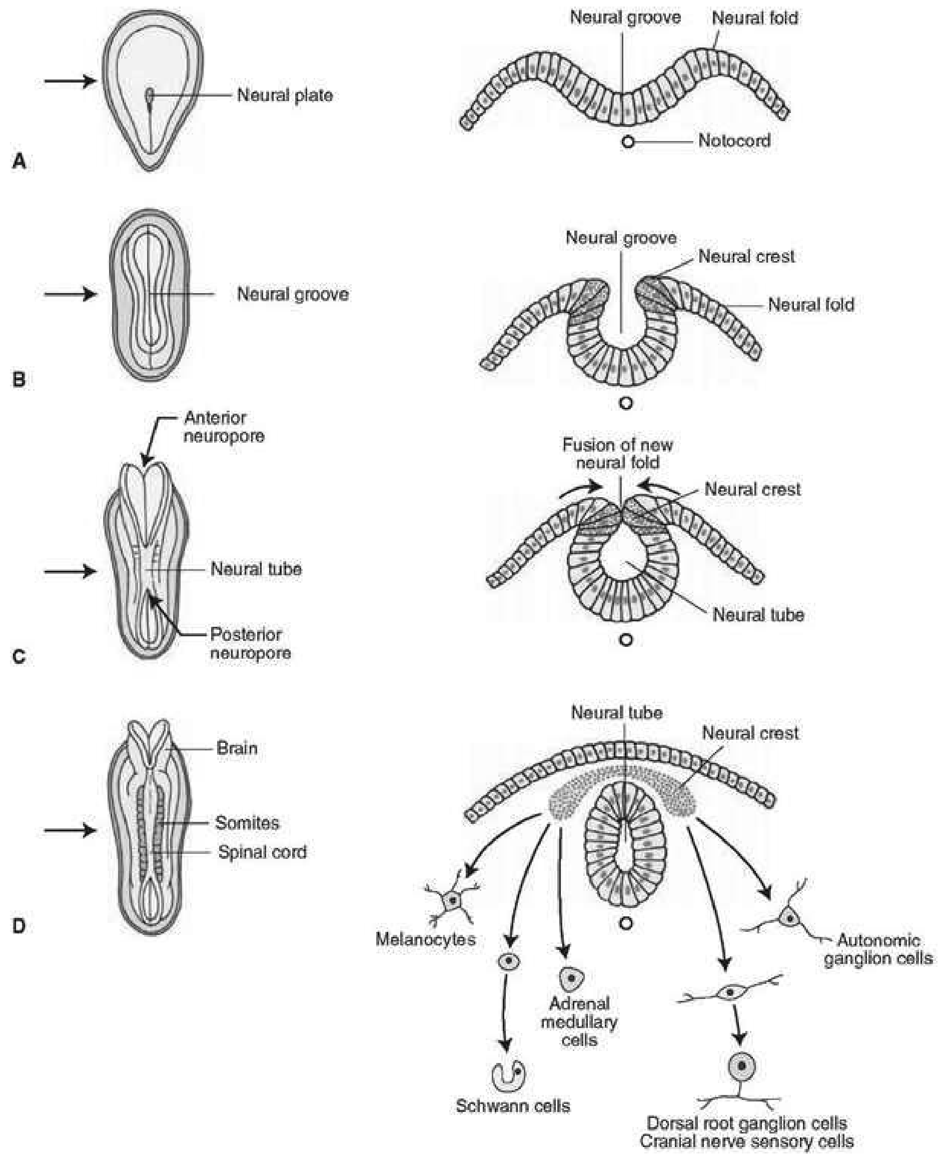

Fig. 4.28 *Origin, Development and Differentiation of Central Nervous System*

Development of Brain

The anterior thickened, enlarged end of the neural tube known as encephalon is the embryonic brain which follows differential growth and acquires two constrictions that separated it into a series of three lobes collectively called the primary cerebral vesicles. The primary cerebral vesicles are a forebrain or prosencephalon, a midbrain or mesencephalon, and a hindbrain or rhombencephalon. This embryonic brain is slightly tilted downwards between the forebrain and midbrain in the region of the mesencephalon and this curvature is known as cranial flexure or cephalic flexure. In later development the cranial flexure is lost in cyclostomes, fishes, amphibians and reptiles, but persists in birds and mammals.

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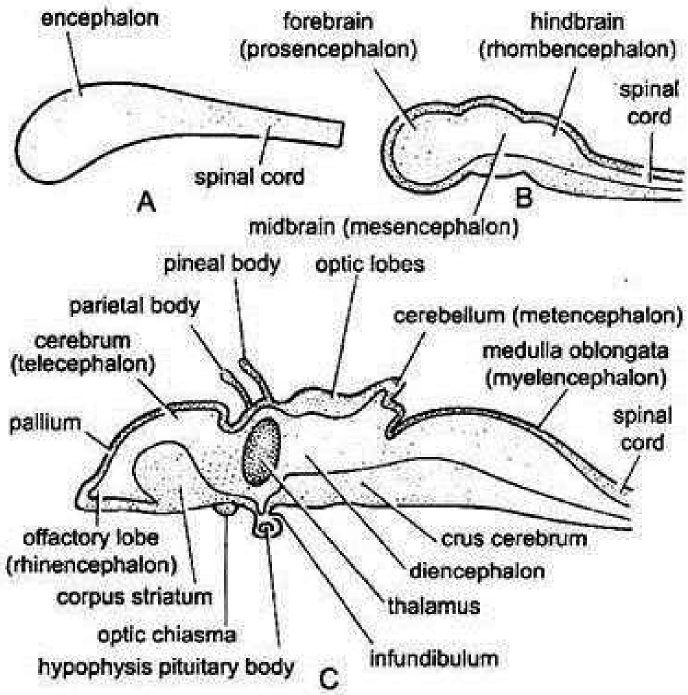

Fig. 4.29 *Diagram Showing the Schematic Development and Different Parts of a Typical Brain (Lateral View)*

Structure of Brain

The brain has two halves or hemispheres: right and left. The right hemisphere controls the left side of the body, and the left hemisphere controls the right side. In most people, the left hemisphere regulates language and speech, and the right hemisphere controls nonverbal, spatial skills. If the right side of the brain is damaged, movement of the left arm and leg, vision on the left, and/or hearing in the left ear may be affected. Injury to the left side of the brain affects speech and movement on the right side of the body. Each half of the brain is divided into main functional sections, called lobes. There are four lobes in each half of the brain: the frontal lobe, temporal lobe, parietal lobe, and occipital lobe. Other important sections of the brain are the cerebellum and the brain stem. Although not usually divided into lobes, the cerebellum and brain stem both have different parts. Each of the brain hemispheres and lobes, cerebellum, and brain stem has specific functions, and they all work together.

The vertebrate's brain is divided in to three parts: forebrain, midbrain and hindbrain. The forebrain or prosencephalon is further sub-divided by a constriction into an anterior telencephalon and a posterior diencephalon. The telencephalon grows beyond and forms paired cerebral hemispheres with cavity, the lateral ventricle. From the antero-ventral part of the telencephalon paired olfactory lobes (rhinencephalon) grow out towards the nose has a cavity, the rhinocoel. The diencephalon or thalamencephalon has an upper epithalamus, a middle thalamus, and a lower hypothalamus. Between the thalami of diencephalon is a third ventricle which communicates with each lateral ventricle by an aperture called a *foramen of Monro*. The midbrain or mesencephalon has a thick roof. Its dorso-lateral walls form two optic lobes (four in mammals). The ventral wall of mesencephalon forms thick crura cerebri, which are tracts of nerve fibres joining the diencephalon with the hindbrain. Passing through the mesencephalon from the third to the fourth ventricle is a narrow iter or aqueduct of Sylvius. The hindbrain or rhombencephalon forms a metencephalon from its anterior dorsal part. The metencephalon enlarges dorsally to give rise to a cerebellum. The surface of the cerebellum has a layer of gray matter, called cerebellar cortex. In lower vertebrates the cerebellum has an extension of the fourth ventricle known as cerebellar ventricle or metacoel. The remaining part of the rhombencephalon forms a myelencephalon, which becomes a thick medulla oblongata having a cavity, the fourth ventricle.

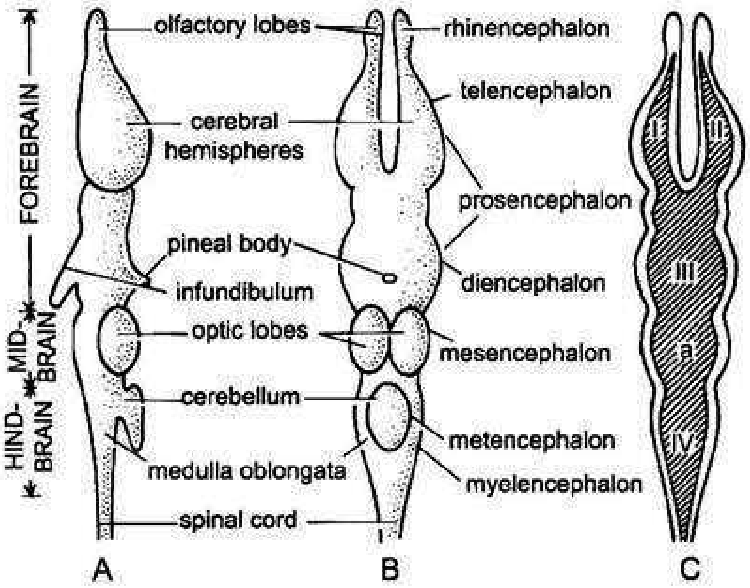

Fig. 4.30 *Schematic Presentation of Brain: Lateral View (A), Dorsal View (B), L.S. Showing Ventricle (C)*

i. **Frontal Lobe:** It is most anterior part right under the forehead. The frontal lobe controls intellectual activities, such as the ability to organize, as well as personality, behavior, and emotional control.

ii. **Parietal Lobe:** Near the back and top of the head above the ears. The parietal lobe controls the ability to read, write, and understand spatial relationships.

iii. **Occipital Lobe:** It is the most posterior at the back of the head. The occipital lobe controls the sight.

iv. **Temporal Lobe:** Side of head above ears situated immediately behind and below the frontal lobes; the temporal lobe controls memory, speech and comprehension.

v. **Brain Stem:** Lower part of brain, leads to spinal cord; the brain stem contains nerve fibers that carry signals to and from all parts of the body. The brain stem also regulates body functions such as consciousness, fatigue, heart rate, and blood pressure. Damage to the brain stem can cause loss of consciousness.

vi. **Cerebellum:** Located at the base of the skull; it is a curved mass of nerve tissues that regulates balance and coordinates fine motor skills; it enables us to move quickly and smoothly.

vii. **Grey and White Matter:** The brain is made up of two types of tissue, grey matter and white matter. Grey matter is involved in analyzing information. White matter conducts information between grey matter areas. The ratio of grey to white matter changes over the lifespan.

Comparative Account of Vertebrate's Brain

This section describes the comparative account of vertebrates' brain.

- **Cyclostomata:** In the brain of cyclostomes, the cerebral hemispheres are hardly indicated with rudimentary ventricles, and two prominent olfactory lobes. The ventral part of diencephalon gives rise to infundibulum of hypophysis as well as the posterior lobe. The cerebellum is inadequately developed due to sluggish and slow moving habit. The medulla oblongata is very well developed in all vertebrates since it serves as a centre for many vital body activities (respiration, heart action, metabolism, etc.).
- **Chondrichthyes:** The telencephalon is primarily olfactory in function and olfactory lobes are large with a rhinocoel in elasmobranchs. The cerebrum is better developed. The diencephalon is narrow with a thin roof having an anterior choroid plexus covering third ventricle. Dorsally the diencephalon has a long-tubular pineal body and the floor of the diencephalon give rise to the stalk or infundibulum of the hypophysis as well as the posterior lobe. The midbrain in fishes is the centre of nervous coordination. The cerebellum is a centre of muscular coordination, is comparatively larger than that of cyclostomes and dipnoans.
- **Osteichthyes:** The brain of bony fishes is more specialized than cyclostomes and cartilaginous fishes. The olfactory lobes are large and each contains a rhinocoel. The cerebral hemispheres are better developed. The diencephalon is small hidden dorsally by the midbrain. Only the pineal body with stalk is present. The parapineal body is not found in modern bony fishes. The pituitary gland is attached with an infundibulum to the ventral side of the diencephalon. The optic lobes and cerebellum are very large than that of elasmobranchs.
- **Amphibia:** The nervous system of amphibians is still basically like that of fishes. The pallium of cerebral hemispheres is invaded for the first time in vertebrates by nerve cells due to which the cerebral hemispheres become enlarged in accordance with more complex activities of locomotion, hibernation, breeding, etc. The olfactory lobes are fused. The diencephlaon is short but optic fibres end in it. The pineal body is found in all amphibians, but only anurans possess a parietal body or a pineal end organ. The optic lobes are large and are the centre of brain activity like fishes. The cerebellum and medulla is very small.
- **Reptilia:** The midbrain is the centre of brain activity all anamniotes, but in reptiles for the first time there is a shift in the nerve centre to the cerebrum. The two long olfactory lobes are larger than that of amphibians. The parietal

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eye is found in *sphenodon* and some modern lizards only. A pair of solid auditory lobes is present. The third ventricle is reduced and forms a narrow cerebral aqueduct. Cerebellum is relatively larger than that of amphibians.

- **Aves:** The brain of birds shows considerable advancements over the earlier tetrapods. The olfactory lobes are extremely small and degenerate because of poor sense of smell. The cerebral hemispheres are very large and cover the diencephalon and optic lobes. The cerebral cortex is smooth. The diencephalon is covered dorsally by the cerebral hemispheres and cerebellum. It has a small dorsal pineal body, an anterior choroid plexus and a narrow third ventricle. The cerebellum is larger than reptiles. A small projection of the fourth ventricle extends into the cerebellum. Cerebellum controls equilibrium and movements in all places during flight.

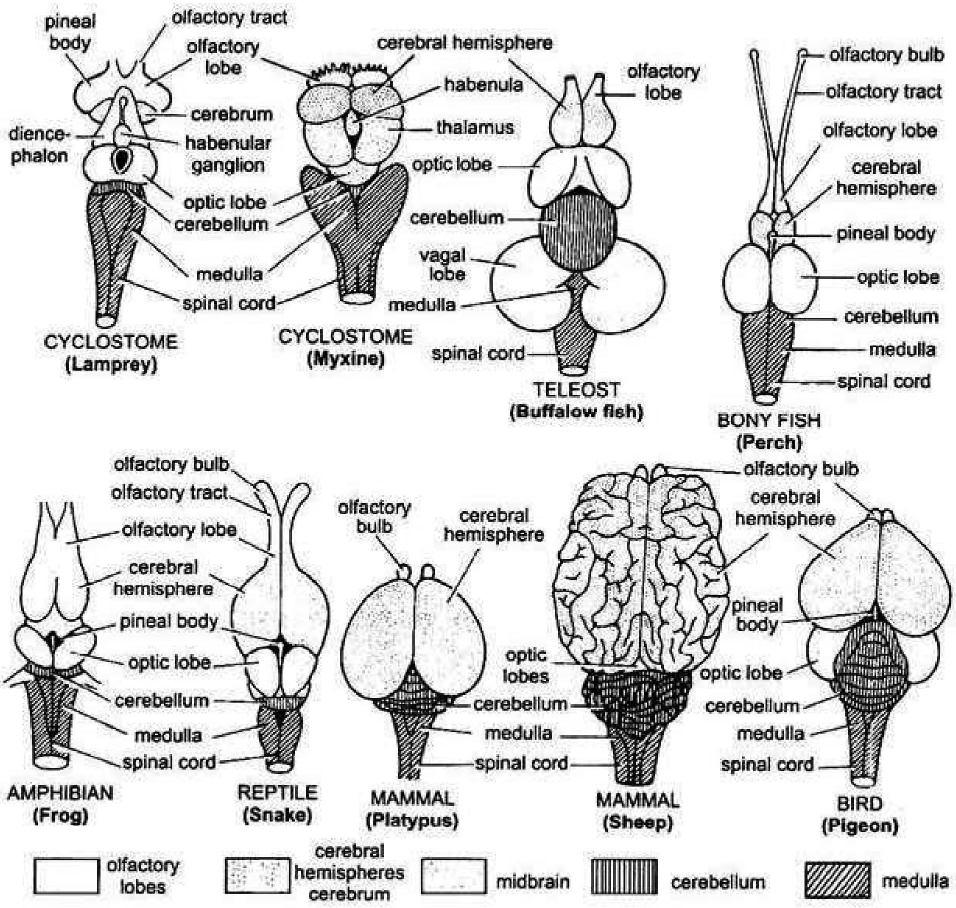

Fig. 4.31 *Comparative Accounts of Modification in Brain of Different Vertebrates*

- **Mammalia:** In mammalia, the brain reaches its highest developmental phase with better integration and mastery over the environment. The cerebral hemispheres are acting as coordinating centres of the brain. The cerebral hemispheres of prototheria are smaller and smooth like reptiles. While in metatheria, these are larger and smooth. But in most eutherians, the cerebral hemispheres are immense, projecting forwards above the olfactory lobes and backwards above the diencephalon and midbrain and divided into lobes. The olfactory lobes are small compared with those of lower vertebrates.

The diencephalon consists of a dorsal epithalamus, a lateral thalamus, and a ventral hypothalamus. A pineal gland is present on the roof of the diencephalon, but it shows no eye-like structure. Thalamus is an important relay centre. The hypothalamus is very important in mammals and consists of four parts. These are the infundibulum forming the stalk and posterior lobe of the pituitary and the optic chiasma.

The hypothalamus controls a great many mammalian functions including blood pressure, sleep, water content, fat and carbohydrate metabolism, body temperature and possibly rhythmic activities such as moulting, migration and pituitary secretion.

The midbrain in mammals is of less importance than in lower vertebrates. The cerebellum is most highly developed in mammals to control the body movement. Beneath the cerebellum is a typical mammalian structure the pons. Besides pons, there is a short tract of transverse fibres, called corpus trapezoideum relaying impulses for sound. The medulla oblongata lies ventrally and is much thickened. The medulla has centre for regulation of digestion, respiration and circulation.

4.4.2 Comparative Account of Peripheral Nervous System

The neural system play a major role in the accountable controlling of the body, both through somatic (voluntary) and autonomic (involuntary) functions. The structures of the nervous system have to be described in detail to understand how many of these functions may possible in complete regulatory operations. There is a physiological perception known as localization of function which states that certain structures are specifically liable for the prescribed functions. The peripheral nervous system consists of nerves connected to or arising from the central nervous system. It has cranial and spinal nerves which over and over again arise in pairs. The cranial nerves emerged out from brain and originated through foramina of the skull. Except the first four pairs of cranial nerves, the rest arise from the medulla oblongata.

Cranial Nerves of Vertebrates

The cranial nerves do not demonstrate a clear metameric arrangement, yet they represent a regular series of segmental dorsal and ventral roots of the segments of the head without joining the both roots together. There are ten pairs of cranial nerves in anamniota (cyclostomes, fishes and amphibians), and twelve pairs in amniota (reptiles, birds and mammals). There is a paired nervous terminalis or number zero nerve arising from the cerebral hemisphere in all vertebrates except birds, it goes to the organ of Jacobson.

Cranial Nerves of Cyclostomata, Pisces, and Amphibia

There are ten pairs of cranial nerves arise from the brain, besides a pair of terminal nerves which are summarized as follows:

i. **First or Olfactory Nerve:** It arises as a number of fibres from each olfactory lobe and innervates the olfactory sac of its side. It is sensory in function.

ii. **Second or Optic Nerve:** The optic nerve arises from the optic thalamus, i.e., on the ventral side of diencephalon. The nerve of each side crosses the others to form the optic chiasma that innervates the retina of the eyes. It is sensory in function.

iii. **Third or Oculomotor Nerve:** It is a slender nerve arising from the ventral surface of the midbrain which further grouped branches to supply the anterior, superior and inferior recti muscles, as well as inferior oblique muscles of the eye-ball. It is motor in function and controls the movements of eye ball, iris and lens.

iv. **Fourth or Trochlear Nerve:** It emerged out from the dorso-Iateral surface of the midbrain, between the optic lobes and the cerebellum, and innervates the superior oblique muscle of the eye ball. It is motor in function and controls the rotation of eye ball.

v. **Fifth or Trigeminal Nerve:** It originates from the antero-lateral side of the medulla oblongata and having a Gasserian ganglion within the cranium. It has classically three main branches: ophthalmicus superficialis, maxillaris, and mandibularis along with one secondarily associated nerve, the ophthalmicus profundus.

vi. **Sixth or Abducens Nerve:** There is a slender nerve arising mid-ventrally from the medulla oblongata and innervates the posterior rectus muscle of the eye ball. It is sensory in function.

vii. **Seventh or Facial Nerve:** It is one of the largest nerve and originates along the lateral region of medulla oblongata in two bundles: The first bundle is a thick broad ophthalmicus superficialis running forward along the upper border of eye orbit. There after along with ophthalmic branch of the fifth nerve approaches to the lateral line receptors and ampullae of Lorenzini on the dorsal side of the snout. On the other hand the second bundle divides into three branches called ramus buccalis, ramus hyomandibularis and ramus palatinus. It is a mixed type of nerve having sensory as well as motor fibres.

viii. **Eighth or Auditory Nerve:** It arises close to the origin of fifth and seventh cranial nerves from the side of the medulla and divides immediately into two branches: the vestibular and saccular. It is sensory in function.

ix. **Ninth or Glossopharyngeal Nerve:** It originates from the ventro-lateral surface of the medulla behind the origin of sixth nerve and runs obliquely backwards to further divides into three branches: pre-trematic or hyoid branch, post-trematic and pharyngeal. This nerve is mixed in function.

x. **Tenth or Vagus Nerve:** The vagus or 10^{th} cranial nerve is the largest and originates as many roots from the postero-lateral side of medulla oblongata behind the ninth cranial nerve and further divides into three branches: branchialis, visceralis and lateralis. An occipital nerve arises behind the vagus and merges to the first two spinal nerves to form a hypobranchial nerve which approaches to muscles in the floor of the buccal cavity. The terminal or pre-olfactory nerve arises from the ventral surface of the cerebrum through the neuropore, runs along the olfactory peduncle and innervate the olfactory septum or nasal septum and external nostrils. The nerve is sensory in function.

The cranial nerves of fishes, are suited to an aquatic mode of life and are related to the gills, lateral line receptors, and ampullae of Lorenzini, for their innervation the trigeminal, facial, glossopharyngeal, and vagus are specialised. In terrestrial or land vertebrates the branches of trigeminal and facial runs to the lateral line receptors and various groups of ampullae of Lorenzini have disappeared. Similarly the branches of the glossopharyngeal and vagus which go to the gills also lost as well as the lateralis branch of the vagus is also faded with the disappearance of lateral line receptors in terrestrial vertebrates

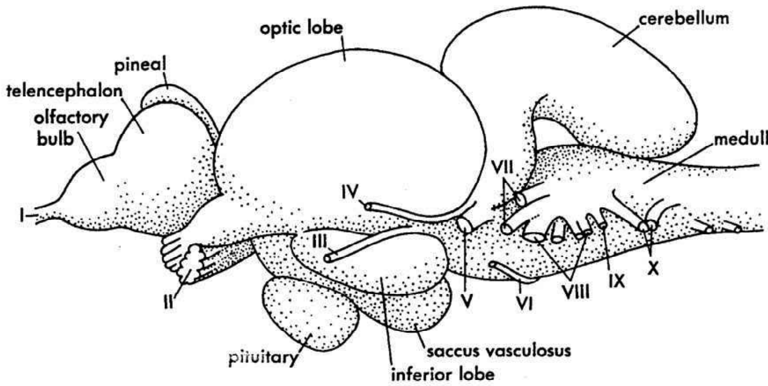

Fig. 4.32 *Origin of Ten Cranial Nerves from Different Parts of Brain in Fishes*

Cranial nerves of Reptilia, Aves, and Mammalia

The twelve pairs of cranial nerves found in Reptilia, Aves, and Mammalia are as follows:

i. **First or Olfactory Nerve:** This is a sensory nerve arising from the anterior end of the olfactory lobe and innervates neurosensory cells of olfactory chamber and conducted impulses to the brain from nasal sac.

ii. **Second or Optic Nerve:** It is a sensory nerve arising from the lateral side of the optic lobe and innervates retina of the eye. The visual impulses are passed to the brain from retina through this nerve.

iii. **Third or Occulomotor Nerve**: This is a motor nerve arising from Crura cerebri of mid brain. It innervates the internal, superior rectus, inferior rectus, anterior rectus and inferior oblique muscles of eye ball.

iv. **Fourth or Trochlear or Pathetic Nerve**: Trochlear nerve is a small motor nerve arising from the dorsal side of the brain between optic lobes and cerebellum innervates the superior oblique muscle of eye ball.

v. **Fifth or Trigeminal Nerve:** This is a mixed nerve arising from antero-lateral parts of medulla oblongata gasserian ganglion at its base. It divides into three branches: (a) axillary nerve passes along the dorsal border of the orbit (between the skull and the eye ball) and innervates the skin of snout with sensory function, (b) axillary nerve runs below the eye ball and supplies to the skin of upper jaw and sensory in behavior, and (c) mandibular nerve runs along the outer side of the lower jaw and innervates muscles and skin with mixed nature.

vi. **Sixth or Abducens Nerve:** It is a small motor nerve arising from the ventral side of medulla oblongata and innervates the external rectus and retractor bulbi muscles of eye ball.

vii. **Seventh or Facial Nerve**: It is a mixed nerve originates from lateral sides of the medulla oblongata just behind the 5th cranial nerve and joins to Gasse-rian ganglion before leaving the skull. It is divided into two branches: (a) palatine nerve: it runs forward underneath the orbit and innervates mucous membrane (roof) of the buccal cavity with sensory nature, and (b) hyomandibualar nerve: it crosses over columellauris of the middle ear and approaches to the muscles of the lower jaw and hyoid apparatus with motor function.

viii. **Eighth or Auditory or Acoustic Nerve**: This is a sensory nerve arising from the lateral sides of medulla and innervates the sensory cells of internal ear.

ix. **Ninth or Glossopharyngeal Nerve:** This is a mixed nerve arising from the lateral sides of medulla behind auditory nerve and approaches to mucous membrane of the tongue, pharynx and muscles of hyoid. It further gives out a insubstantial branch which joins hyomandibular branch of the seventh cranial nerve.

x. **Tenth or Vagus or Pneumogastric Nerve:** This is the largest mixed nerve arising from the side ways of the medulla oblongata having common origin with the ninth nerve. After emerging from skull, the nerve swells and forms a vagus ganglion. The vagus nerve is divided into five branches: (a) cutaneous nerve: it is a sensory nerve innervating the dorsal body wall, (b) cardiac nerve: it is a motor nerve innervating the heart, (c) laryngeal nerve: it is a mixed nerve going to the laryngo-tracheal chamber, (d) pulmonary nerve: it is a motor nerve going to the lungs, and € gastric nerve: it is a mixed nerve innervating the stomach.

xi. **Eleventh or Spinal Accessory:** It arises from medulla and motor in function. Spinal accessory is innervated in the muscles of shoulder and neck.

xii. **Twelfth or Hypoglossal:** It arises from the ventro-posterior end of medulla and motor in function as well as innervated in the muscles of tongue.

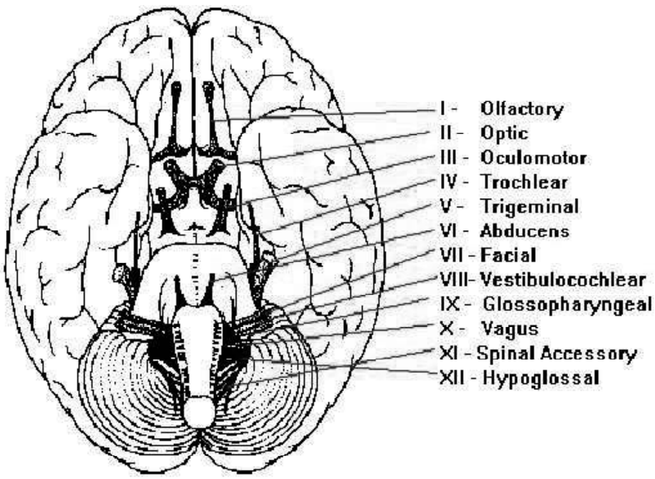

Fig. 4.33 *Origin of Twelve Cranial Nerves from Different Parts of Brain in Fishes*

Spinal Nerves of Vertebrates

The spinal nerves arise from the spinal cord and paired segmental structures emerging through intervertebral foramina of the vertebral column. The number of these spinal nerves corroborated just about to the number of vertebrae. Each spinal nerve is consisting two roots: (a) dorsal root (sensory) connected to the dorsal horn of the gray matter and its ganglion always containing nerve cell bodies of sensory fibers; and (b) ventral root (motor) emerging from the ventral horn of the gray matter with nerve cell bodies of motor fibers located in the brain or spinal cord. During the embryogenesis the dorsal roots arise from neural crests, while the ventral roots originate from the gray matter of the spinal cord. In anamniotes the dorsal roots consisting somatic sensory, visceral sensory and visceral motor fibers. However, in amniotes the dorsal roots having only somatic sensory and visceral sensory fibers. The ventral roots have visceral motor and somatic motor fibers in all groups of vertebrates except in some cyclostomes in which a dorsal and a ventral root of each side unite to form a spinal nerve.

In cyclostomes, the sensory and motor roots do not join together to form a common trunk and remain separate and arises alternately from the spinal cord in lamprey, whereas in hagfishes there may be an incomplete union. In all other fishes the dorsal sensory root and ventral motor root found to be united with each other outside the vertebral column and form a common trunk. On the other hand in amphibians dorsal and ventral roots of the spinal nerves amalgamate in their passage through the intervertebral foramen rather than outside as in most fishes or within the neural canal as in amniotes (reptiles, birds and mammals).

In mammals, complicated plexuses, resulting from the intertwine networking of fibers from the ventral branches of spinal nerves are found to be differentiated into cervical, brachial, lumbar and sacral plexuses. Each spinal nerve divides into three kindling or rami, a dorsal ramus supplying the skin and muscles of the back, a ventral ramus going to body muscles and skin of ventral side, and a communicating ramus communicants or visceral ramus going to the viscera and a ganglion of the autonomic nervous system. Each ramus communicants has two parts, a white ramus with medullated visceral sensory and motor fibers; and a gray ramus (absent in elasmobranchs with non- medullated fibers.

The medullated visceral motor fibers are called preganglionic fibers because they come to an end in autonomic ganglia where they form synapses with non-medullated postganglionic fibers of the gray ramus. These fibers thereafter enter the spinal nerves and pass into the dorsal ventral rami to supply structures under involuntary control. There are 37 pairs of spinal nerves found in rabbit, which further divided into five zones, viz., 8 pairs cervical, 12 pairs thoracic, 7 pairs lumbar, 4 pairs sacral and 6 pair’s caudal nerves.

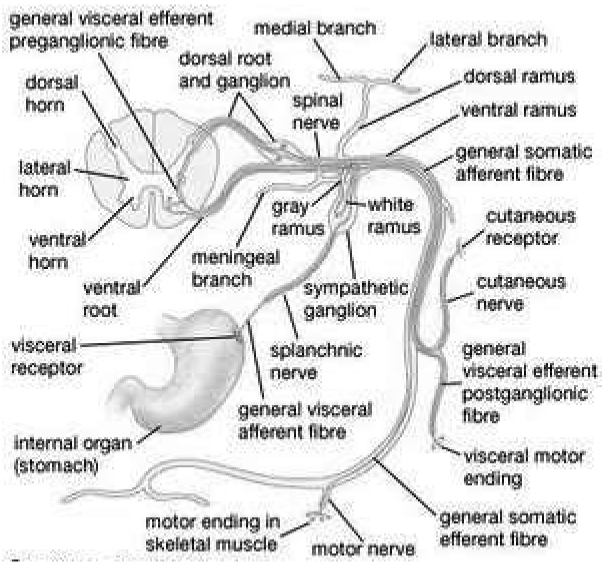

Fig. 4.34 *Stereogram of the Vertebrate Spinal Nerves and Reflex Arcs*

4.4.3 Comparative Account of Autonomous Nervous System

The Autonomous Nervous System (ANS) is so called because it's somewhat independent nature and not under the voluntary control, though it is involuntarily controlled by the nerve centers of the central nervous system. It is also connected to spinal nerves and some pre-vertebral ganglion ramus, cranial nerves. The autonomic nervous system is mainly responsible for controlling the involuntary visceral cardiac and glandular muscles of the body. It is of two types: sympathetic nervous system and parasympathetic nervous system.

Sympathetic Nervous System

In elasmobranchs, an irregular series of sympathetic ganglia lies along the body wall and the nerve fibers of these ganglia connect both spinal cord and smooth muscles of the digestive and circulatory systems. In bony fishes the autonomic nervous system is more advanced i.e., the sympathetic ganglia are prearranged in a chain extending forward to the trigeminal nerve. In amphibians the visceral sensory fibers have their cell bodies in the dorsal root ganglia and their dendrites in the organs which are not under voluntary control such as heart, blood vessels and different parts of alimentary canal. The visceral motor fibers having their cell bodies in the spinal cord forming synapses with neurons whose cell bodies are situated in the sympathetic ganglia. Thus, sympathetic nerves are made of both visceral sensory and visceral motor fibers which whenever stimulated secrete a chemical substance called sympathy which in turn stimulate the organs.

In mammals, there is a pair of ganglionated sympathetic nerves or cords which arise from the brain and pass out the cranium through carotid canals and extend from the neck to the end of the abdomen situated at the lateral sides of the vertebral column and enter the tail as a fine filament. In rabbit, the sympathetic nerve bearing three ganglia in the neck region, ten in the thorax, six in lumbar, four sacral and one caudal, i.e., total 24 ganglia on one side. The ganglia of sympathetic nerves are connected with the ramus communicants of the corresponding spinal nerves, i.e., one ganglion for each spinal nerve. Sympathetic nerves innervate the heart, glands and visceral organs.

NOTES

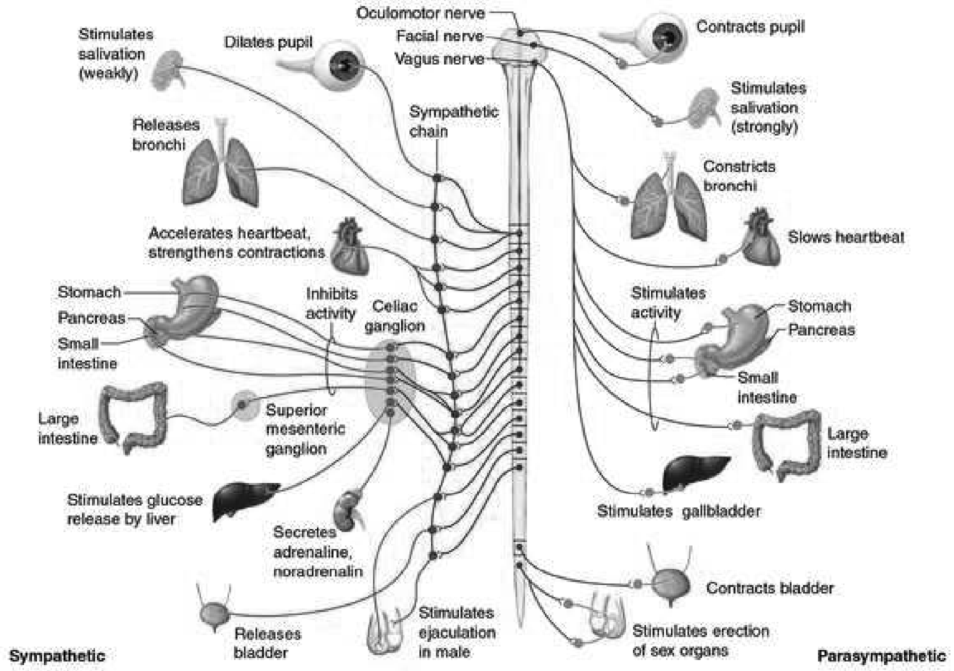

Fig. 4.35 *Autonomic Nervous System of a Mammal*

Parasympathetic Nervous System

The parasympathetic components of autonomic nervous system comprise the cranial outflow. The preganglionic parasympathetic fibers leave the central nervous system from the brain as components of cranial nerves III, VII, IX and X in elasmobranchs similar to that of higher vertebrates. In teleosts, parasympathetic autono-mic fibers are present only in oculomotor (III) and X (vagus). In dipnoans, the cranial autonomic fibers are present only in vagus (X) in *Protopterus* and *Lepidosiren* while the *Neoceratodus* oculomotor and vagus are given out from the cranial outflow.

The parasympathetic system of amphibians includes parasympathetic nerves and ganglia. The fibers of parasym-pathetic nerves come from cranial and spinal nerves; while parasympathetic ganglia are situated in the organs innervated by parasympathetic nerves. Their preganglionic fibers are very long and extend from the central nervous system to a ganglion in or near the organ which they innervate. Here they are connected to the short postganglionic fibers.

Parasympathetic nervous system mammals is formed by the fibers of III, VII, IX nerves and X cranial nerves and form from 2nd, 3rd and 4th sacral nerves. Ganglia of parasysmpathetic nerves lie in the head neck and sacral regions. They innervate all those organs which are innervated by the sympathetic nerves. The III cranial nerve runs to the ciliary ganglion in the orbit and from these nerve fibers supply to the muscles of the iris. The parasympathetic fibers from the VII and X cranial nerves supply to the lacrimal gland, salivary gland, lungs, heart, liver and different parts of alimentary canal. The parasympathetic nerve fibers of the sacral region unite to form pelvic ganglia on each side and the nerve fibers from this ganglion supply to the bladder, kidney, rectum and gonads.

Working Mechanism of Autonomic Nervous System

The sympathetic and parasympathetic nervous systems work independently but opposite to one another. Thus, each visceral organ innervated by a sympathetic fibre stimulates the organ to start the function and parasympathetic fibre inhibits or slows down the function of that organ.

For example, sympathetic stimulation causes increased heartbeat, rise in blood pressure, bronchial dilation, peripheral vascular contraction, sweat gland activity, dilation of pupil, contraction of arrestor pili, inhibition of saliva, contraction of certain sphincters, splendid contraction and increased blood-sugar content.

In short the animal exhibits symptoms of fear or anger and is made ready to fight or flight. Sympathetic fibers are adrenergic or sometimes (as in sweat glands) cholinergic. Opposite to sympathetic action, parasympathetic stimulation leads to dilation of blood vessels (except intrinsic coronary circulation of heart), increased salivary secretion, constriction of bronchi, increased peristalsis, relaxation of sphincter, constriction of pupil. Parasympathetic fibers are cholinergic.

Check Your Progress

12. What do you understand by nervous system?
13. Define central nervous system.
14. What are the main parts of a vertebrate's brain?
15. What is the main function of hypothalamus?
16. What is the main function of autonomous nervous system?

4.5 ANSWERS TO 'CHECK YOUR PROGRESS'

1. The urinogenital or urogenital system in vertebrates is the group of organs concerned with sexual reproduction and elimination of nitrogenous waste as urinary excretion.
2. During embryogenesis, the kidneys originate from the lateral plate, which transforms and differentiates into the nephric ridges and buds into blocks or knobs of tissue called nephrotomes.
3. There are three major regions of the kidney, renal cortex, renal medulla, and the renal pelvis. The outer granulated layer is the renal cortex.
4. In most vertebrates there is a bag-like urinary bladder serving as storage or temporary reservoir for urine which is derived as an enlargement of the terminal parts of mesonephric ducts.
5. The excretion is a physiological process of eliminating waste products of metabolism and other materials that have no use in body of an organism.

NOTES

6. The foremost major function of the urinary system is the process of excretion and elimination nitrogenous metabolic wastes from the body and homeostasis.
7. The foremost function of the reproductive system is to ensure existence, survival and sustenance of the species in environment.
8. The sense organs are the organs that respond to external stimuli by conveying impulses to the sensory nervous system.
9. The Lateral Line System (LLS) is a system of sense organs found in aquatic vertebrates, used to detect movement, vibration, and pressure gradients in the surrounding water, schooling behavior, predation, and orientation.
10. The lateral line system permits the detection of movement, vibration and pressure magnitude in contiguous water of an aquatic animal, and providing spatial awareness and ability to navigate in environment. Thus, plays a pivotal action in orientation, predatory behavior, defense, and social schooling.
11. The electroreceptors are voltmeters and electroreceptive sensory cells are hair cells, forming part of octavo-lateral sensory system. Fishes contain mechanoreceptive sensory systems for hearing, maintenance of equilibrium, detection of gravity and rotation of water currents along body.
12. The nervous system is a network of cells called neurons that coordinate actions and transmit signals between different parts of the body.
13. The Central Nervous System (CNS) is the major neural part of the body comprising the brain, spinal cord, and retina, is the control panel for our bodies responsible for cognition, movement, senses, and emotions.
14. The vertebrate's brain is divided in to three parts: forebrain, midbrain and hindbrain.
15. The hypothalamus controls a great many mammalian functions including blood pressure, sleep, water content, fat and carbohydrate metabolism, body temperature and possibly rhythmic activities such as moulting, migration and pituitary secretion.
16. The autonomous nervous system is mainly responsible for controlling the involuntary visceral cardiac and glandular muscles of the body. It is of two types: sympathetic nervous system and parasympathetic nervous system.

4.6 SUMMARY

- The urinogenital or urogenital system in vertebrates is the organs concerned with reproduction and urinary excretion. It is also called genitourinary system.
- The major function of the reproductive system is to ensure survival of the species.
- The overall purpose of the reproductive system is to produce sex cells, bring egg and sperm cells together, provide for nourishment of the embryo or fetus until hatching or birth, and to release young from the maternal body.

- The principal function of the urinary system is to maintain the volume and composition of body fluids within normal limits.
- Kidneys are the primary adult excretory organs and work in association with auxiliary structures such as the gills, lungs, skin, parts of the digestive system and salt glands.
- The nervous system is the major controlling, regulatory, and communicating system in the body. It is the center of all mental activity including thought, learning, and memory.
- In vertebrates it consists of two main parts, the Central Nervous System (CNS) and the Peripheral Nervous System (PNS). The CNS consists of the brain and spinal cord. The Peripheral Nervous System (PNS) is the connection between the central nervous system and the rest of the body.
- The PNS can be broken down into the Autonomic Nervous System (ANS), which controls bodily functions without conscious control, and the sensory-somatic nervous system, which transmits sensory information from the skin, muscles, and sensory organs to the CNS and sends motor commands from the CNS to the muscles.
- The kidneys originate from lateral plate mesoderm that differentiates into the nephric ridges which buds into blocks of tissue called nephrotomes, which differentiate into nephrons or renal tubules or kidney tubules, the structural and functional units of the kidney.
- A kidney tubule or uriniferous tubule, i.e., nephron has three parts: (i) A ciliated peritoneal funnel near the proximal end of the tubule which opens into the splanchnocoel by a nephrostome or coelomostome (often the peritoneal funnel itself is called a nephrostome), (ii) A convoluted ciliated tubule opening into a longitudinal collecting duct, and (iii) A Malpighian body or renal corpuscle.
- The gonads begin as a thickening of coelomic epithelium, which forms a genital ridge. The central part of the genital ridge forms the functional gonad.
- Spermatogenesis proceeds through mitotic division of sperm-forming cells or spermatogonia, to form primary spermatocytes. These cells then undergo one meiotic division to form secondary spermatocytes, and then another division to form spermatids, that later mature and transform to become motile spermatozoa.
- The ovaries are generally masses of connective tissue within an outer germinal epithelium. In the ovary are ova in various stages of development formed from germinal epithelium.
- The ovaries are never connected with the kidneys, nor are they connected with their ducts in most vertebrates; hence, ova pass into the coelom after being discharged.
- The duplex uterus is doubled, and is found in monotremes, marsupials, elephants and rodents.

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- The bipartite uterus is y-shaped externally and divided internally (ungulates, carnivores)
- The bicornuate uterus is y-shaped but has no internal partition (some ungulates, whales).
- The simplex uterus has only one uterine chamber (primates).
- The nervous system is made up of highly specialized cells called as neurons. A neuron is composed of three main parts, namely cell body or cyton, dendrite and axon.
- The Central Nervous System (CNS), comprising the brain, spinal cord, and retina, is the control panel for our bodies responsible for cognition, movement, senses, and emotions.
- During ontogenesis of a vertebrate embryo, the mid-dorsal strip of ectoderm develops a longitudinal thickening, known as a medullary or neural plate. The neural plate slightly invaginates but its edges grow upwards to form neural folds.
- The anterior thickened, enlarged end of the neural tube known as encephalon is the embryonic brain. It undergoes differential growth and acquires two constrictions, which divide it into a series of three lobes, the primary cerebral vesicles. The primary cerebral vesicles are a forebrain or prosencephalon, a midbrain or mesencephalon, and a hindbrain or rhombencephalon.
- The vertebrate's brain is divided in to three parts: forebrain, midbrain and hindbrain.
- The nervous system is responsible for controlling much of the body, both through somatic (voluntary) and autonomic (involuntary) functions. The peripheral nervous system consists of nerves connected to or arising from the central nervous system. It has cranial and spinal nerves.
- There are ten pairs of cranial nerves in amanita (cyclostomes, fishes and amphibians), and twelve pairs in amniota (reptiles, birds and mammals). There is a paired nervus terminalis or number zero nerve arising from the cerebral hemisphere in all vertebrates except birds, it goes to the organ of Jacobson.
- The spinal nerves arise from the spinal cord. They are also paired segmental structures emerging through intervertebral foramina of the vertebral column. Their number corresponds approximately to the number of vertebrae present.
- Each spinal nerve is formed by two roots: (a) dorsal root (sensory) attached to the dorsal horn of the gray matter. The dorsal root has always a ganglion containing nerve cell bodies of sensory fibers, and (b) ventral root (motor) arising from the ventral horn of the gray matter. The nerve cell bodies of motor fibers are always located in the brain or spinal cord.
- The autonomic nervous system is so called because it is partly independent and not under voluntary control, though it is involuntarily controlled by the nerve centers located in the central nervous system. It is also connected to spinal nerves and some prevertebral ganglion ramus, cranial nerves.

- The autonomic nervous system is mainly responsible for controlling the involuntary visceral cardiac and glandular muscles of the body. It is of two types: sympathetic nervous system and parasympathetic nervous system.
- The sympathetic and parasympathetic nervous systems work independently but opposite to one another.
- Each visceral organ innervated by a sympathetic fiber stimulates the organ to start the function and parasympathetic fiber inhibits or slows down the function of that organ.
- Bowman's capsule is dilated end of a kidney tubule that surrounds a knot of capillaries.
- Corpus luteum is hard yellowish body that develops from an ovulated follicle and acts as an endocrine gland.
- Cremasteric pouch are layers of the body wall that suspend the testes, or the scrotal wall apart from the skin.
- Glomerulus is ball-like network of capillaries that is surrounded by Bowman's capsule at the proximal end of a renal tubule.
- Gubernaculum is cord of tissue that extends between the embryonic testis of mammals and the developing scrotum and guides the descent of the testes.
- Holonephros is the hypothetical ancestral kidney that develops from all of the nephrotome.
- Loop of Henle is that portion of the renal tubule of mammals and some birds that loops into the medulla of the kidney, and is essential for establishing the interstitial salt gradient needed for the production of concentrated urine.
- Metanephros is the adult kidney of amniotes, which develops from the caudal part of the mesomere.
- Opisthonephros is the adult kidney of most anamniotes; kidney tubules are concentrated caudally.
- Pronephros is the first formed kidney of a vertebrate embryo, which lies dorsal to the pericardial cavity and forms the archinephric duct before it atrophies.
- Rete cords are minute cords in the embryo that reconnect the primary sex cords and the cranial mesonephric tubules; they contribute to the sperm passages in males and regress in females.
- Retroperitoneal is pertaining to structures that lie dorsal to the peritoneal cavity.
- Seminiferous tubules are tubules within the testes that produce sperm.
- Sertoli cells are epithelial cells of the seminiferous tubules that play a role in the maturation of sperm.
- The lateral line system is a system of tactile sense organs, unique to aquatic vertebrates from cyclostomes and fishes to amphibians that serve to detect movements and pressure changes in the surrounding water.

- Lateral line system is made up of a series of mechanoreceptors called neuromasts (lateral line organs) arranged in an interconnected network along head and body.
- The lateral line system allows fish to detect direction and rate of water movement.
- In sharks and rays, some neuromasts have been evolutionarily modified to become electroreceptors called ampullae of Lorenzini that can also detect Earth's electromagnetic field, and sharks apparently use these electroreceptors for homing and migration.
- Electroreception is the ability to detect weak naturally occurring electrostatic fields in the environment.
- Electroreception facilitates the detection of prey or other food sources and objects and is used by some species as a means of social communication.
- The electroreception is present in all classes of lower, aquatic vertebrates (fishes and some amphibians), but not invertebrates.
- There are two types of neuromasts, canal neuromasts which are located in the intradermal canals, and the superficial neuromasts which are located in the intraepidermal canals. Canal neuromasts are able to detect water flow acceleration, while superficial or free neuromasts can detect velocity.
- Electroreception is used in electrolocation (detecting objects) and for electrocommunication.
- In active electrolocation, the animal senses its surrounding environment by generating electric fields and detecting distortions in these fields using electroreceptor organs. This electric field is generated by means of a specialized electric organ consisting of modified muscle or nerves.
- In passive electrolocation, the animal senses the weak bioelectric field generated by other animals and uses it to locate them. These electric fields are generated by all animals due to the activity of their nerves and muscles.
- Electrocommunication is the communication method used by weakly electric fishes. Weakly electric fishes are a group of animals that utilize a communicating channel that is 'invisible' to most other animals: electric signaling.
- Ampullary electroreceptors are exceedingly sensitive to weak electric field low-frequency stimuli, only.
- The tuberous electroreceptors are found in a few teleosts only: in the electrogenic Mormyroidei and Gymnotiformes, and perhaps also Siluriformes. Tuberous electroreceptor organs are fired by Electric Organ Discharges (EODs).
- Sense organs are specialized organs that help to perceive the world around us. They are an integral part of our lives and it is the only way that enables us to perceive the environment.

- There are five sense organs, namely: Eyes, Ears, Nose, Tongue, and Skin,
- Mechanism of seeing or sight through eyes called ophthalmoception. However, the process of hearing of sound by ears known as audioception. On the other hand, tongue aid to detect the taste and flavors through gustaoception
- Skin is the largest organ of our body. It is related to the sense of touch. The sense of touch is also referred to as tactioception.

4.7 KEY TERMS

- **Excretion:** The excretion is a physiological process of eliminating waste products of metabolism and other materials that have no use in body of an organism.
- **Gonads:** The gonads are cytogenous paired sex glands present separately in individual sex (dioecious), like testes and ovaries in human males and females respectively with the exception of the hermaphrodite cyclostomes and some bony fishes.
- **Sense Organs:** The sense organs are the organs that respond to external stimuli by conveying impulses to the sensory nervous system.
- **Lateral Line System:** The Lateral Line System (LLS) is a system of sense organs found in aquatic vertebrates, used to detect movement, vibration, and pressure gradients in the surrounding water, schooling behavior, predation, and orientation.
- **Electrocommunication:** The electrocommunication is communication method used by weakly electric fishes which using an invisible communicating channel such as electric signaling.
- **Electroreceptors:** The electroreceptors are voltmeters and electroreceptive sensory cells are hair cells, forming part of octavo-lateral sensory system.
- **Nervous System:** The nervous system is a network of cells called neurons that coordinate actions and transmit signals between different parts of the body.
- **Neurons:** Structural and functional unit of nervous system is called as neuron or nerve cell.

4.8 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short Answer Questions

1. Write a short note on the modification of male gonad and genital ducts in vertebrates.
2. What is the structure of LLS?

3. What are the different types of neurons?
4. Give a comparative account of ANS.

Long Answer Questions

1. Discuss the structure and evolution of kidneys in vertebrates.
2. Describe the electroreception in fishes in detail.
3. Evaluate and compare the vertebrates' brain.
4. Explain the cranial nerves of reptilian, aves, and mammalia.

4.9 FURTHER READING

Kardong, Kenneth. 2012. *Vertebrates: Comparative Anatomy, Function, Evolution*. Delhi: McGraw-Hill Education.

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