MZON - 12

தமிழ்நாடு திறந்தநிலைப் பல்கலைக்கழகம்

எல்லோருக்கும் எப்போதும் கல்வி

M.Sc. ZOOLOGY – FIRST YEAR

COMPARATIVE ANATOMY OF CHORDATA AND VERTEBRATA

SCHOOL OF SCIENCES

TAMIL NADU OPEN UNIVERSITY

577, ANNA SALAI, SAIDAPET, CHENNAI - 600 015

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Curriculum Design	**Dr. T. Ravimanickam** Associate Professor School of Science Tamil Nadu Open University, Chennai – 15	**Dr. S. Vinod Kanna** Assistant Professor School of Science Tamil Nadu Open University, Chennai – 15
Course Writer	**Dr. P. Sekar** Assistant Professor Government Institute of Advanced Study in Education, Saidapet, Chennai - 15	
Content Editor	**Dr. T. Ravimanickam** Associate Professor School of Sciences Tamil Nadu Open University, Chennai – 15	
Course Coordinator	**Dr. T. Ravimanickam** Associate Professor School of Sciences Tamil Nadu Open University, Chennai – 15	

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No.577, Anna Salai, Saidapet, Chennai - 600 015. Tamil Nadu.

Professor K.Parthasarathy
Vice Chancellor

08.01.2022

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At this momentous juncture, I wish you all bright and future endeavours.

With warm regards,

(K. PARTHASARATHY)

Email:tnouvc@gmail.com
:drkpsbard@gmail.com
Ph: 044-24306633 / 24306634
Fax:91-44-24356767
URL:www.tnou.ac.in

MZON-12: COMPARATIVE ANATOMY OF CHORDATA AND VERTEBRATA

SCHEME OF LESSONS

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Unit 4 Origin and classification of vertebrates

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Unit 22 Nervous system: Comparative anatomy of the brain in relation to its functions

Unit 23 Comparative anatomy of spinal cord and Nerves-Cranial, Peripheral and Autonomous nervous system

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MZON-12: COMPARATIVE ANATOMY OF CHORDATA AND VERTEBRATA

SYLLABUS

Block V: Sense organs

Unit 1

Origin of Chordates

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the origin of chordates
- Classify the chordates
- Explain various theories of origin.
- Illustrate the larval lineage for origin of chordates.

OVERVIEW

This unit deals with the origin of chordates. Under this unit, we will learn about the creation of the phylum chordate using various theories like, echinoderm origin, hemichordate origin, urochordate origin, cephalochordate origin and combined origin. And we will also focus on the larval lineage for origin of chordates and origin of free-swimming vertebrates.

1.1. INTRODUCTION

Origin and ancestry of vertebrates has long been of particular interest to zoologists. Origin of chordate was one of the important events in the history of chordate as it was the beginning of evolution of more advanced chordates like horses and humans. It is the story of origin from a primitive invertebrate like creatures to early chordates. Though first fossil of the first vertebrate the ostrachoderm was discovered from the Ordovician period but it might have originated in late Cambrian period. As early chordates were soft bodied, their fossil records are not preserved. Hence, to trace their ancestry, we have to find out the similarity among different deuterostomes to trace the origin of chordates. Some structural features shared by them such as bilateral symmetry, antero-posterior body axis, triploblastic coelomate condition, etc., may be because of their common ancestry. Over the years, several hypotheses have been proposed to explain the origin of vertebrates.

1.2. Creation of the Phylum Chordata

The phylum Chordata was named (attributed) by William Bateson (1885), it was already in common use by 1880. In 1866, Ernst Haeckel mentioned a taxon include tunicates, cephalochordates, and vertebrates. Attributed

Chordates evolved from some deuterostome ancestor (echinoderms, hemichordates, pogonophorans etc.,) as they have similarities in embryonic development, type of coelom and larval stages. Fossils of the earliest vertebrates are known from the Silurian-Devonian period, about 400 million years ago. The following theories have been given to explain the origin of chordates:

1.2.1. Echinoderm Origin

The theory was given by Johannes Muller (1860), and is based on the comparative studies of larval stages of echinoderms and hemichordates. Tornaria larva of hemichordates resembles echinoderm larvae such as Bipinnaria, Auricularia, Dipleurula and Doliolaria, which all possess ciliary bands and apical tuft of cilia. Johannes Muller, W. Garstang and DeBeers proposed that echinoderm larvae gave rise to chordates by neoteny. Also, like chordates, echinoderms are also deuterostomes and possess mesodermal skeletal elements.

The discovery of fossil echinoderms called Calcichordata from Ordovician period (450 mya) 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 Ca 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.

1.2.2. Hemichordate Origin

Romer (1959) suggested that ancestral deuterostomes were sedentary tentacle feeders whose 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.* By some mutation pharyngeal gill slits evolved in these ancestors, which made the pharynx sieve-like to trap planktons as the water current passed through it. Extant pterobranchs possess both ciliated arms and pharyngeal gill slits. Tornaria larva of hemichordates shows phylogenetic relationship with echinoderm larvae and hemichordates also show affinities with chordates.

1.2.3. Urochordate Origin

W. Garstang (1928) and N.J. Berrill (1955) reported 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. Garstang (1928) suggested that chordates evolved from some sessile filter feeding urochordate by the larval stage evolving into adult by neoteny and by losing the sedentary adult stage.

1.2.4. Cephalochordate Origin

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.

1.2.5. Combined theory

E.J.W. Barrington (1965) combined all the above theories and proposed that the common ancestor of echinoderms and chordates was a sessile ciliary arm feeder that lived in the plankton-rich environment of the Cambrian. Modern Crinoidea (Echinodermata), Pogonophora and Pterobranch hemichordates evolved from a similar ancestor by retaining the original mode of feeding, perhaps because they continued to inhabit the same environment as occurred in ancestral days. However, pharyngotremy (perforation of pharynx with gill slits) must have evolved in a large number of groups at that time, which must have been much more superior method of food gathering by filtering water through pharynx as compared to ciliated arm feeding. Hence, the sedentary Protoascidians of that time lost ciliated arm feeding and adopted pharyngeal filter feeding as the only method of food gathering. Sometime later, when the plankton population in water declined, free-swimming tailed larva of these urochordates did not metamorphose and became a neotenic adult, since free-swimming mode was superior in food searching at a time of food scarcity. Cephalochordate-like ancestors evolved by perfection and expansion of chordate characters that were already present in the ascidian tadpole larva. We already have fossils of such primitive chordates, e.g., *Pikaia gracilens* from mid-Cambrian.

1.3. Larval Lineage for Origin of Chordates

N. J. Berrill (1955) has suggested in his book, “The Origin of Vertebrates”, the following larval sequence:

All chordates possess 5 similar morphological (synapomorphies), or primary characteristics, at some point during their larval or adulthood stages that distinguish them from all other taxa.

Echinoderm – Bipinnaria

↓

Hemichordate – Tornaria

↓

Protochordate – Ascidian tadpole

↓

Permanently free swimming chordate.

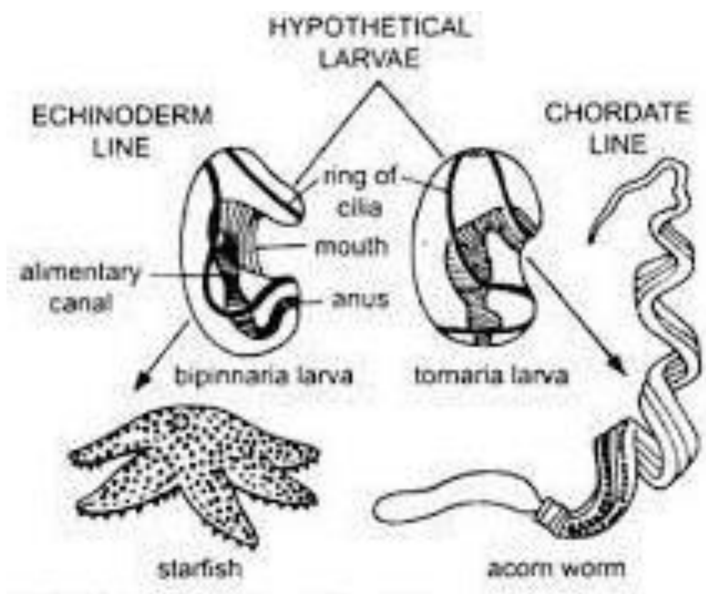

Fig. 1. Similarity of larval forms of echinoderms and hemichordates which indicates the idea that both the larval forms share the same ancestor.

1.4. Origin of Free-Swimming Vertebrates

In contrast to protochordates (hemichordates, urochordates, and cephalochordates), vertebrates are actively-feeding, predatory organisms that move by lateral undulation of an elongate body.

Cephalochordates are having the derived feature of an elongated body as adults, but are still (primitively) filter feeders; that is, they feed while motionless, moving food-laden water by means of cilia on their gill bars.

Hemichordates and most of the urochordates are also filter-feeders, moving water through their gill slits, but are sessile as adults. When ascidian tunicates metamorphose, the notochord is resorbed. However, that ascidian and larvacean urochordates have a free-swimming larval stage (with a notochord); ascidians metamorphose to sessile adults, but larvaceans become sexually mature as movable "larvae."

These observations have led workers to suggest that the freely-swimming mode of locomotion of vertebrates (and cephalochordates) evolved by retaining the form of the larvae of the "ancestors" (hemichordates and urochordates) as the form of the adults of the descendants (cephalochordates and vertebrates). This general phenomenon is called paedomorphosis: the evolutionary retention of larval features of the ancestors as the adult features of the descendants.

Let us sum up

Under this unit, we studied about the origin of chordates. We also focused on the creation of phylum chordates through various theories like echinoderm origin, hemichordate origin, urochordate origin, cephalochordate origin and combined theory of origin. We also studied about the larval lineage for origin of chordates and origin of free-swimming vertebrates.

Check your Progress

1) The phylum chordata was named by __________.
2) Johannes muller gave the comparative studies of larval stages of __________ and ___________.
3) The discovery of fossil echinoderms called as _________.
4) The extant pterobranchs possess both ________ and _________.
5) In the ascidian tunicates metamorphose, the __________ is resorbed.

Glossaries

1. Diapsid : It is a group of amniote tetrapods that develope two holes.
2. Bipedal : Using only two legs to walk
3. Marsupials : A mammal that belongs to the infraclass methatheria

Suggested readings

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Origin of chordata https://youtu.be/RuPCP5DaC7A

Answers to check your progress

1) Willian bateson
2) Echinoderm and hemichordate
3) Calcichordata
4) Ciliated arms and pharyngeal gill slits
5) Notochord

Unit 2

CONCEPT OF PROTOCHORDATA AND THE NATURE OF VERTEBRATE MORPHOLOGY

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Classify the phylum chordate

- Explain the various groups of species present in the phylum chordate
- Describe the characteristic features of each groups of phylum chordate.

OVERVIEW

This unit deals with the phylum chordate. Under this unit we will study about the classification of phylum chordate and study about the external structure and characteristic features of species of each group like amphibian, reptile, aves and mammals.

2.1. INTRODUCTION

Protochordate is an informal category of organisms to describe the invertebrates that are closely related to vertebrates. The Chordates are identified by the presence of a notochord. On the contrary, the Protochordates lack a true notochord.

A notochord is the primitive beginning of the backbone found in the embryonic stage. These are only found in the organisms belonging to phylum Chordata. Humans belong to this phylum and possess a notochord at their embryonic stage.

A notochord arises from the mesoderm and protects the body of the chordates at the embryonic stage. Whereas, a vertebral column extends from the neck to tail and protects the backbone in adult chordates.

The study of development and comparisons of the adult structures of the several groups of protochordate animals reveals something of their interrelationships and origin. The hemichordates are perhaps closer to the echinoderms than to the chordates, but these groups appear to have been derived from a bilaterally symmetrical dipleurula ancestor, not from a sessile pterobranch-like form. The origin of the chordates is speculative but the idea of a prototunicate stage is rejected. The tunicate is viewed as a highly modified end product, with fewer similarities to the ancestral form than amphioxus. Amphioxus is quite suggestive of the vertebrate, yet it is more like the tunicate in the details of its embryology and along with that rather extreme peripheral group is best thought of as constituting a subphylum, the Acraniata (Malcolm Jollie, 1973)

Protochordata is divided into the following three sub-phyla:

- Hemichordata

- Urochordata
- Cephalochordata

2.2. Phylum Chordata

General Characters of Phylum Chordata

(1) All are free-living with no fully parasitic forms. Some are Aquatic, aerial or terrestrial

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

(3) A post anal tail usually projects beyond the anus at some stage and may or may not persist in the adult.

(4) Exoskeleton often present; well developed in most vertebrates.

(5) Body wall triploblastic with 3 germinal layers: ectoderm, mesoderm and endoderm.

(6) Coelomate animals having a true coelom, enterocoelic or schizocoelic in origin.

(7) A skeletal rod, the notochord, present at some stage in life cycle.

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

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

(10) Digestive system complete with digestive glands.

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

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

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

(14) Sexes separate with rare exceptions.

Table. 2.1. Difference between lower and higher Chordate animals

Acrania (Protochordata) or Lower Chordata	Craniata (Euchordata) or Higher Chordata
Exclusively marine, small-sized chordates	Aquatic or terrestrial, mostly large sized vertebrates
No appendages, cephalization and exoskeleton	Usually 2 pairs of appendages, well-developed head and exoskeleton present
Coelom enterocoelic, budding off from embryonic archenteron.	Coelom schizocoelic, arising by splitting of mesoderm
Notochord persistent. No skull, cranium and vertebral column	Notochord covered or replaced by a vertebral column. Skull and cranium well developed.
Phyrynx with permanent gill clefts. Endostyle present	Phraryngeal gill clefts persist or disappear Endostyle absent
Heart chamber less when present. No. red blood corpuscles in blood	Heart made of 2, 3 or 4 chambers. Blood contains RBC
Kidneys protonephridia	Kidneys meso– or metanephric
Sexes separate or united. Reproduction asexual as well as sexual. Gonoducts usually absent	Sexes separate. Only sexual reproduction, Gonoducts always present
Development indirect with a free-swimming larval stage	Development indirect or direct, with or without a larval stage
Division I. Agnatha	**Division II. Gnathostomata**
True jaws absent	True jaws present
Paired appendages absent	Appendages paired (pectoral & pelvic)

Inner ear with 2 semi-circular canals.	Inner ear with 3 semi-circular canals
Notochord persistent in adults	Notochord persists or replaced by vertebrae

2.3. Classification of Chordata

Phylum chordata can be divided into two groups: Acrania (Protochordata) and Craniata (Euchordata) having contrasting characters.

2.3.1. ACRANIA (Protochordata)

- (Gr. *a*, absent; kranion, head, or, Gr. protos, first; chorde, cord)
- All marine, small, primitive or lower chordates.
- Lacking a head, a skull or cranium, a vertebral column, jaws and brain.
- About 2,000 species.
- The Acrania is divided into three subphyla: *Hemichordata, Urochordata* and *Cephalochordata,* chiefly on the character of notochord present.

Subphylum I. Hemichordata

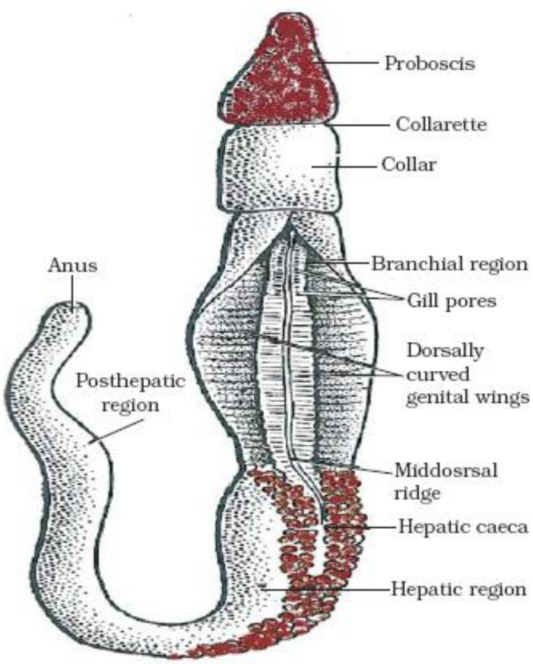


Fig.2.1. Balanoglossus

- (Gr. *hemi,* half; *chorde,* cord).
- Body divided into 3 regions: Proboscis, collar and trunk.
- Notochord doubtful, short, confined to proboscis and non–homologous with that of chordates.
- Class 1. Enteropneusta
- (Gr. *enteron,* gut; *pneustos,* breathed). Body large and worm-like.
- Gill slits numerous.
- Intestine straight.
- Acorn or togue worms.
- 70 species.
- Balanoglossus, Saccoglossus.

Class 2. Pterobranchia

- (Gr. *pteron,* feather; *branchion,* gill).
- Body small and compact.
- Gill-slits one pair or none.
- Intestine U–shaped. Pterobranchs.
- 20 species.
- Cephalodiscus, Rhabdopleura.

Subphylum II. Urochordata or Tunicata

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

Class 1. Ascidacea

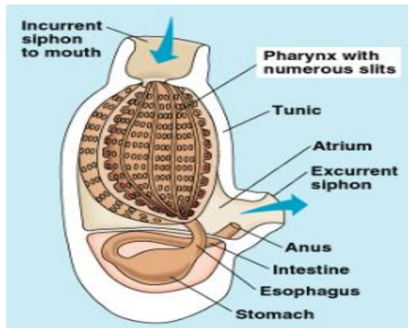


Fig. 2.2. Structure of Ascidacea

- Sessile tunicates with scattered muscles in tunic.
- Solitary, colonial or compound.
- Gill-clefts numerous.
- Ascidians or sea squirts.
- 1,200 species.
- *Herdmania, ciona, Molgula.*
- Retrogressive metamorphosis present in Herdmania.

Class 2. Thaliacea

Fig. 2.3. Species of Thaliacea

- Free-swimming or pelagic tunicates with circular muscles in tunic.
- Sometimes colonial.
- Salps or chain tunicates.
- 30 species.
- Salpa, Doliolum, Pyrosoma.

Subphylum III. Cephalochordata

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

Class Leptocardii

- Body fish-like, segmented with distinct myotomes and numerous gill-slits.
- Free swimming and burrowing.
- Lancelets.
- 30 species.
- Branchiostoma (=Amphioxus), Asymmetron.

2.2.2. CRANIATA (Euchordata)

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

Subphylum IV. Vertebrata

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

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

Division I. Agnatha

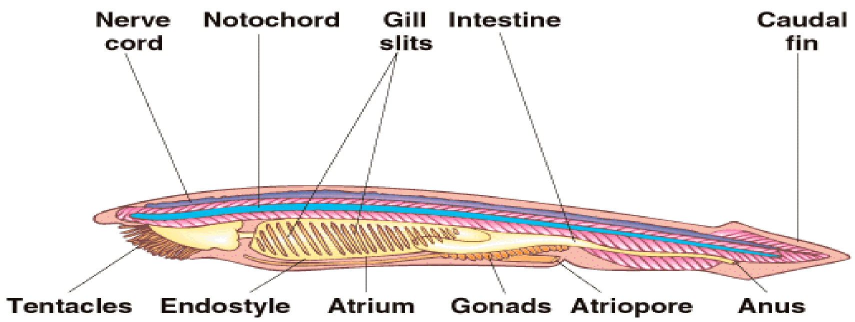


Fig. 2.4. Structure of Agnatha

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

Class 1. Ostracodermi

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

Class 2. Cyclostomata

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

Division II. Gnathostomata

- (Gr. gnathos, jaw; stoma, mouth).

- Jawed vertebrates having true jaws and paired limbs.
- For convenience, some taxonomists further divide Gnathostomata division into two super classes.
- All the fishes like aquatic gnathostomes are placed in the superclass Pisces, whereas all the four-footed terrestrial gnathostomes in the superclass Tetrapoda.
- Their contrasting features are as follows:

Superclass 1. Pisces	*Superclass 2. Tetrapoda*
Exclusively aquatic gnathostome vertebrates.	Aquatic or terrestrial. Some arboreal and aerial
Paired limbs, if present, as fins.	Paired pentadactyle limbs present
Median fins present	Median fins absent
Skin usually moist and scaly	Skin usually dry and conified
Respiration aquatic, by gills	Respiration aerial, by lungs
Sense organs functional in water	Sense organs functional in air.
It consist of fishes only.	It consist of classes Amphibia, Reptilia, Aves and Mammals.

Superclass: Pisces

Class 1. Chondrichthyes (Cartilaginous Fishes)

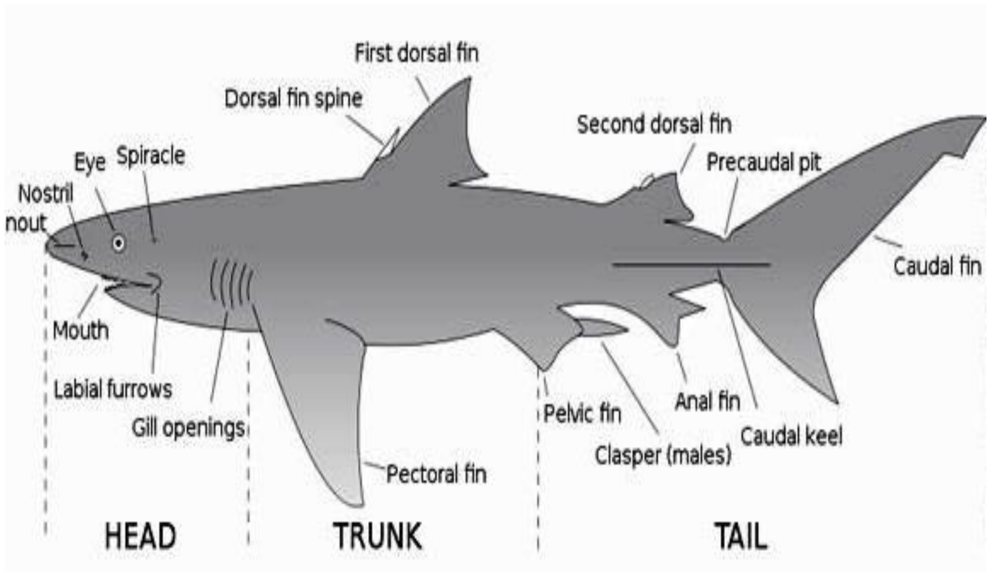


Fig. 2.5. External feature of Cartilaginous Fish

General Characters of Chondrichthyes

(1) Mostly marine and predaceous.

(2) Body fusiform or spindle shaped.

(3) Fins both median and paired, all supported by fin rays. Pelvic fins bear claspers in male. Tail heterocercal.

(4) Skin tough containing minute placoid scales and mucous glands.

(5) Endoskeleton entirely cartilaginous, without true bones (Gr. chondros, cartilage + ichthys, fish). Notochord persistent. Vertebrae complete and separate. Pectoral and pelvic girdles present.

(6) Mouth ventral. Jaws present. Teeth are modified placoid scales. Stomach J-shaped. Intestine with spiral valve.

(7) Respiration by 5 to 7 pairs of gills. Gill-slits separate and uncovered. Operculum absent. No air bladder and lungs.

(8) Heart 2–chambered (1 auricle and 1 ventricle). Sinus venosus and conus arteriosus present. Both renal and portal systems present. Temperature variable (poikilothermous).

(9) Kidneys opisthonephric. Excretion ureotelic. Cloaca present.

(10) Brain with large olfactory lobes and cerebellum. Cranial nerves 10 pairs.

(11) Olfactory sacs do not open into pharynx. Membranous labyrinth with 3 semicircular canals. Lateral line system present.

(12) Sexes separate. Gonads paired. Gonoducts open into cloaca. Fertilization internal. Oviparous or ovoviviparous. Eggs large, yolky. Cleavage meroblastic. Development direct, without metamorphosis.

2.3.3. Classification of Chondrichthyes

(a) Subclass I. Selachii: (Gr., selachos, a shark)

(1) Multiple gill slits on either side protected by individual skin flaps.

(2) A spiracle behind each eye.

(3) Cloaca present.

(4) Examples:

- True sharks. About 250 living species.
- Dogfishes (Scoliodon, Chiloscyllium, Mustelus, Carcharinus)
- Spiny dogfish (squalus) seven gilled shark (Heptanchus)
- Zebra shark (stegostoma), hammer-headed (Sphyrna), whale shark (Rhineodon). Skates and rays. About 300 species. Skate (Raja), stingray (Trygon), electric ray (Tropedo), eagle ray (Myliobatis), guitar fish (Rhinobatus), sawfish (Pristis)
- Electric organ are found in Torpedo

(b) Subclass 2. Holocephali: (Gr., holos, entire + kephale, head)

(1) Single gill opening on either side covered by a fleshy operculum.
(2) No spiracles, cloaca and scales.
(3) Jaws with tooth plates.
(4) Single nasal opening.
(5) Lateral line system with open groove.
(6) Examples: Rat fishes or chimaeras. About 25 species. Hydrolagus (= Chimaera).

Fig.2.6. Chimaeras Fish

Class 2. Osteichthyes (Bony fishes)

General Characters of Osteichthyes

(1) Inhabit all sorts of water-fresh, brackish or salt; warm or cold.
(2) Body spindle-shaped and streamlined.
(3) Fins both median and paired, supported by fin rays of cartilage or bone. Tail usually homocercal.
(4) Skin with many mucous glands, usually with embedded dermal scales of 3 types; ganoid, cycloid or ctenoid. Some without scales. No placoid scales.
(5) Endoskeleton chiefly of bone (Gr., osteon, bone + ichthyes, fish). Cartilage in sturgeons and some other. Notochord replaced by distinct vertebrae Pelvic girdle usually small and simple or absent. Claspers absent.
(6) Mouth terminal or sub terminal. Jaws usually with teeth. Cloaca lacking, anus present.
(7) Respiration by 4 pairs of gill on body gill arches, covered by a common operculum on either side.
(8) An air (swim) bladder often present with or without duct connected to pharynx. Lung-like in some (Dipnoï).
(9) Ventral heart 2-chambered (1 auricle + 1 ventricle). Sinus venosus and conus arteriosus present. Aortic arches 4 pairs. Erythrocytes oval, nucleated. Temperature variable (poikilothermous).

(10) Adult kidneys mesonephric. Excretion ureotelic.
(11) Brain with very small olfactory lobes, small cerebrum and well developed optic lobes and cerebellum. Cranial nerves 10 pairs.
(12) Well-developed lateral line system. Internal ear with 3 semicircular canals.
(13) Sexes separate. Gonads paired. Fertilization usually external. Mostly oviparous, rarely ovoviviparous or viviparous. Eggs minute to 12 mm. Cleavage meroblastic. Development direct, rarely with metamorphosis.

2.3.4. Classification of Osteichthyes

(a) Subclass I. Sarcopterygii: **(Gr., sarcos, fleshy + pterygium, fin)**

(1) Paired fins leg-like or lobed. With a fleshy, bony central axis covered by scales.
(2) Dorsal fins 2. Caudal fin heterocercal with an epichordal lobe.
(3) Olfactory sacs usually connected to mouth cavity by internal nostrils or choanae, hence the previous name of subclass, choanichthyes (Gr., choana, funnel + ichthyes, fish).
(4) Popularly called fleshy or lobe-finned, or air breathing fish. Divided into 2 super orders or orders: Crossopterygii and Dipnoi.

Order 1. Crossopterygii

(Gr., crossoi, a fringe + pteryx, fin)

Fig. 2.7. Lobe-Finned Fish

(1) Paired fins lobate. Caudal fin 3–lobed.
(2) Premaxillae and maxillae present.
(3) Internal nares present or absent. Spiracles present.
(4) Air bladder vestigial.
(5) Example– Primitive fleshy-finned extinct fishes.Single living genus Latimeria.

Order 2. Dipnoi

(Gr., di, double + pnoe, breathing)

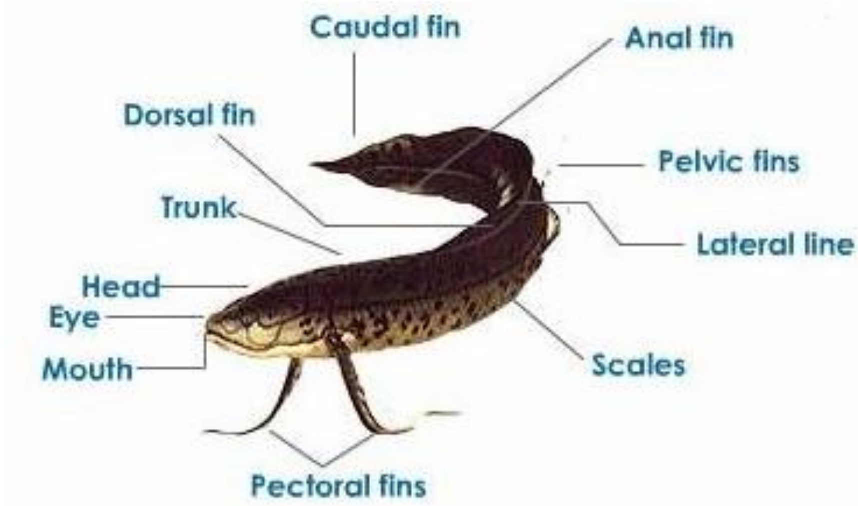


Fig. 2.8. External feature of Lung-fish

(1) Median fins continuous to form diphycercal tail.
(2) Premaxillae and maxillae absent.
(3) Internal nares present and spiracles absent.
(4) Air bladder single or paired, lung-like
(5) Examples – Lung fishes. Only 3 living genera: Epiceratodus (Neoceratodus), Protopterus and Lepidosiren

(b) Subclass II. Actinopterygii

(Gr., actis, ray + pteryx, fin)

(1) Paired fins thin, broad, without fleshy basal lobes, and supported by dermal fin rays.
(2) One dorsal fin, may be divided.
(3) Caudal fin without epichordal lobe.
(4) Olfactory sacs not connected to mouth cavity.
(5) Popularly called ray-finned fishes. Divided into 3 infraclasses or superorders: Chondrostei, Holostei and Teleostei.

Superorder A. Chondrostei

(Gr., chondros, cartilage + osteon, bone)

Fig. 2.9. Gulf Sturgeon

(1) Mouth opening large.
(2) Scales usually ganoid.
(3) Tail fin heterocercal.
(4) Primitive ray-finned fish or cartilaginous ganoids.
(5) Examples – Acepenser (Sturgeon), Polyodon (paddlefish)

Superorder B. Holostei

(Gr., holos, entire + osteon, bone)

(1) Mouth opening small.
(2) Ganoid or cycloid scales.
(3) Tail fin heterocercal.
(4) Intermediate ray-finned fish, transitional between Chondrostei and Teleostei.
(5) Examples –Lepisosteus (garpike)

Superorder C. Teleostei

(Gr., teleos, complete + osteon, bone)

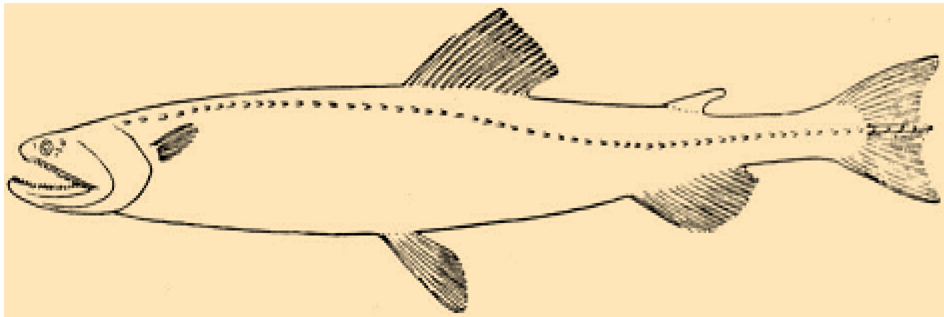


Fig.2.10. Teleostei fish

(1) Mouth opening terminal, small.
(2) Scales cycloid, ctenoid or absent.
(3) Tail fin mostly homocercal.
(4) A hydrostatic swim bladder usually present.
(5) Advanced or modern ray-finned fishes
(6) Examples – *Harpodon* (Bombay duck), *Cyprinus* (carp), *Labeo rohita* (rohu), *Catla*, *Botia*, *Carassius* (Goldfish), *Clarius* (Magur), Heteropneustes or Saccobranchus (singhi), *Wallago* (lachi), *Mystus* (tengra), *Electrophorus* (electric eel) *Anguilla* (freshwater eel), Muraena (moray) *Hemirhamphus* (half beak), *Belone* (garfish), *Hippocampus* (sea horse), *Syngnathus* (pipe fish), *Fistularia* (flute fish) *Ophiocephalus* or *channa* (snake head) *Amphipbnous, Symbranchus* (eels). *Mastacembelus, Macrognathus, Pterois* (scorpion fish), *Pleuronectes, Synaptura, Solea, Echeneis or Remora* (sucker fish), (porcupine fish), *Tetrodon* (globe fish).

2.4. Class Amphibian

The development of a muscular limb with defined joints and digits (tetrapod) is first seen in the amphibians. Also, for the first time an atlas allows the head can move up and down separately from the trunk. Modern amphibia have eggs with no shells or membranes which are laid in water, usually have paired lungs, have mucous glands to keep them moist and poison glands for protection. Amphibia tend to reduce bones, lose scales and are small. They can be divided into three groups, Urodela (salamanders and newts), Anura (frogs and toads) which lack an adult tail and undergo the most dramatic metamorphosis from aquatic tadpoles, and the Gymnophiona (caecilians or apodans) which have no trace of limbs or girdles and are burrowers.

Fig. 2.11. Species of class Amphibia

2.5. Class Reptilia

Reptiles are the first amniotes, having eggs with extra embryonic membranes, which allow the embryo to develop on land. As we will see in the skull lab, a lot of the relationships are based on the holes in the skull called fenestrae, which are filled with jaw muscles and on the position of the temporal arches. Many reptile groups, for example the dinosaurs, are extinct. The Sauropsids, which includes the dinosaurs, contains the modern day reptiles and led to the birds. Another group, the Synapsids, produced the extinct therapsid reptiles and led to modern mammals.

Modern reptiles with no temporal fossa (anapsid) are the Parareptilia (turtles). Most modern reptiles have two temporal fossae (diapsid) and include snakes, lizards, legless lizards, crocodiles, alligators and the birds. A second neck bone, the axis, allows greater mobility of the head and most reptiles have long necks with many cervical vertebrae.

Fig.2.12. Species of class Reptiles

2.6. Class Aves

Birds are specialized diapsid reptiles, which are second only to fish in number of vertebrate species. Their closest relatives are the crocodiles; both lay shelled eggs and have similar musculature and bones, including a wishbone. Birds are warm blooded, have feathers and complex lungs. Birds usually have wings for flying and hollow, air-filled bones which keep them light. They also have beaks and walk on two legs (bipedal).

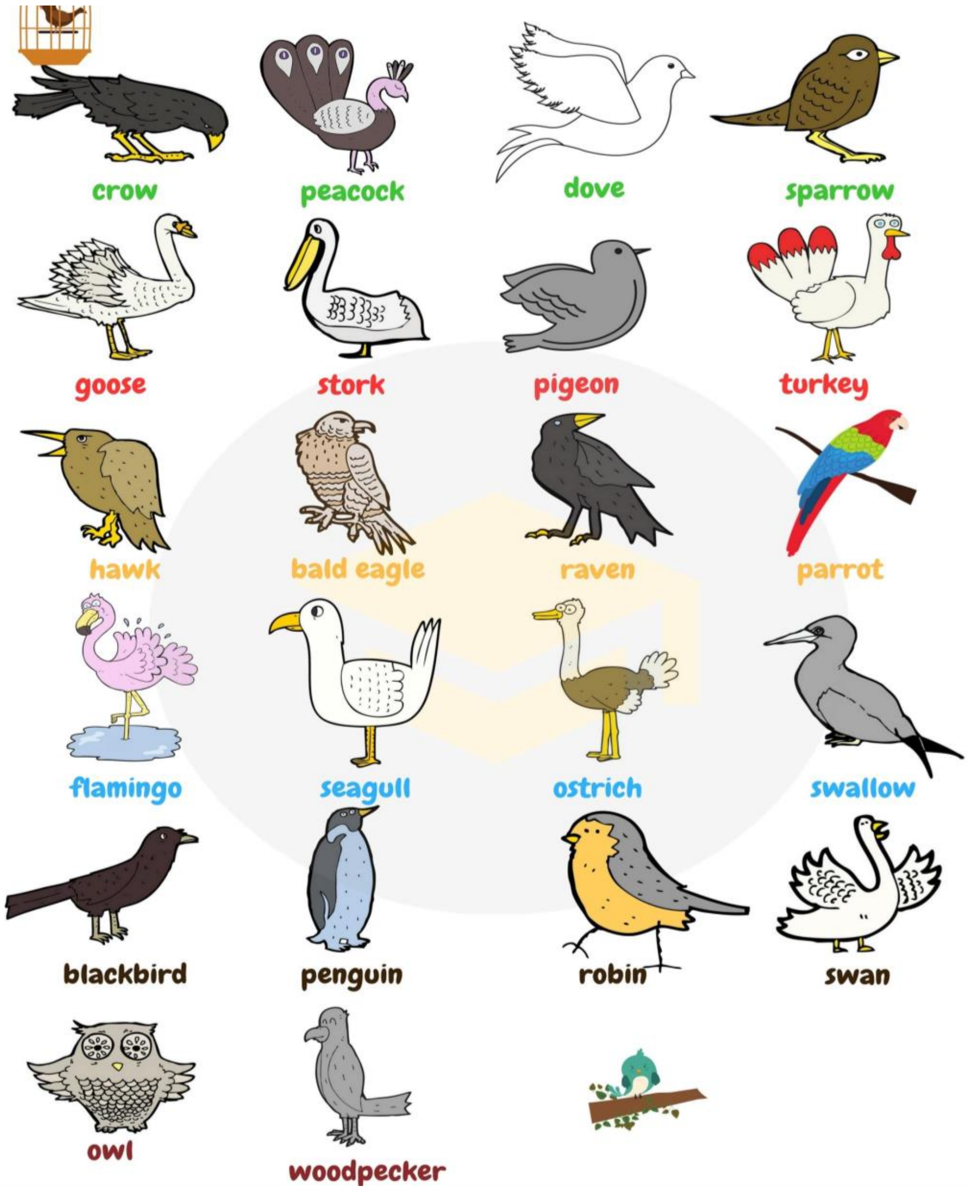


Fig.2.12. Species of class Aves

2.7. Class Mammalia

The mammalian skull, like that of the therapsid reptiles has only the lower temporal fossa and thus is a synapsid skull. Mammals are warm-blooded, have hair and mammary glands. They also have sebaceous (oil) glands and sweat glands. They have anucleate red blood cells. Mammals have three bones in the middle ear and most mammals have large brains. The lower jaw is composed of a single bone, the dentary, which forms a joint with the squamosal bone. Although the dentaries are paired structures, they are often fused into a single structure by the mandibular symphysis.

There are three groups of living mammals. The monotremes include the duckbill platypus and spiny anteater. They are amniotes with a primitive, shelled egg. Another group of mammals, represented by the opossum and best known by the kangaroo, are the Monotheria (marsupials). These animals have a simple placenta and young born at a very early stage, which crawl into a pouch and suckle there until they are larger. Most modern mammals are Eutheria (placentals), with the fetus connected to a complex placenta in the uterus enabling it to develop considerably before it is born.

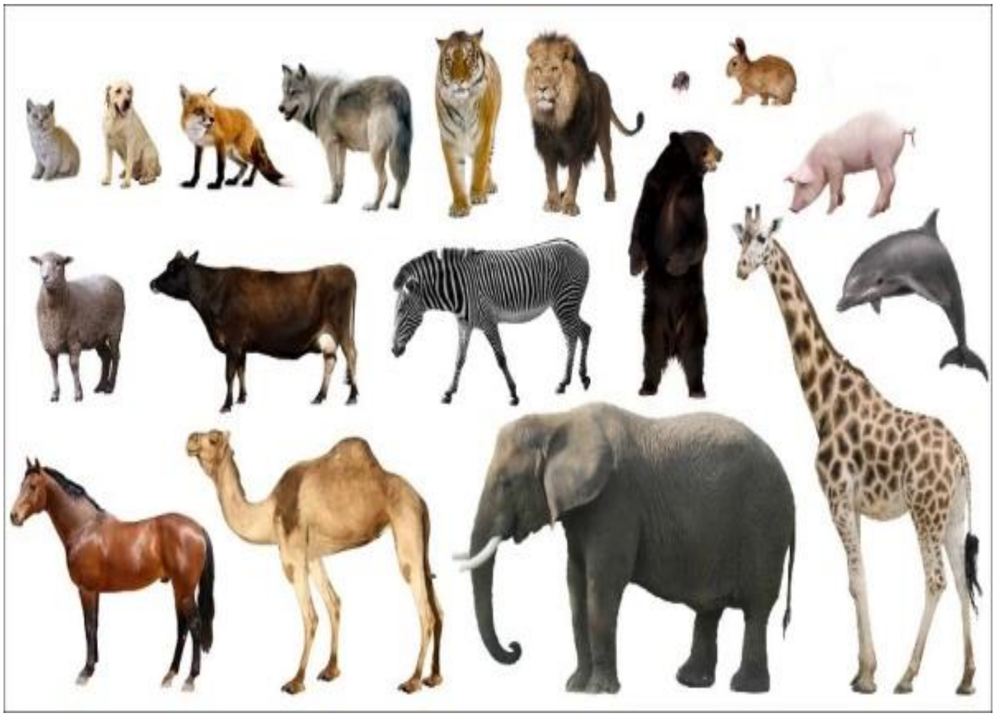


Fig.2.13. Species of class Mammalia

Let us sum up

Under this unit, we studied about the phylum chordate. In this unit we focused on the classification of chordates based on their external features, characteristics and salient features of species of each of species in this phylum such as, protochordates, craniates, Chondrichthyes, amphibians, reptiles, aves and mammals.

Check your Progress

1) The chordates are identified by the presence of ___________.
2) Prochordata is divided into ___________, ___________ and ___________.
3) The acraniata and craniata are divisions of ___________.
4) Modern reptile with no temporal fossa is known as ___________.
5) The mammals have ___________ red blood cells.

Glossaries

1. Marsupials : A mammal that belongs to the infraclass methatheria
2. Nemetology : Division of zoology that studies roundworm
3. Carnicology : Study of crustaceans

Suggested readings

1. **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.
2. **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.

Weblink

Concept of prochordata https://youtu.be/c4r2yf9t6V0

Nature of vertebrate morphology
https://youtu.be/PvDAKV0OPAM?list=TLPQMDkxMTIwMjLe0S0s1p4a0Q

Answers to check your progress

1) Notochord
2) Hemichordate, urochordata and cephalochordate
3) Chordata
4) Parareptile
5) Anucleated

UNIT 3

Definition, Scope and Relation to Other Disciplines. Importance of the Study of Vertebrate Morphology

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Define the chordates
- List out the characteristic features of chordates
- Understand the important study of vertebrate morphology.

OVERVIEW

In this unit we will study about the definitions of chordates, characteristics of chordates and importance of study of vertebrate morphology.

3.1. INTRODUCTION

The phylum Chordata consists of both invertebrate and vertebrate **chordates**. It is a large and diverse phylum. It includes about 60,000 species. Chordates range in length from about a centimeter to over 30 meters (100 feet). They live in freshwater, marine, terrestrial, and aerial habitats. They can be found all over the world.

3.2. Definition of Chordata

A chordate is an animal of the phylum Chordata. All chordates possess some primary characteristics, at some point during their larval stage or adulthood that distinguish them from all other taxa.

Any of a phylum (Chordata) of animals having at least at some stage of development a notochord, dorsally situated central nervous system, and gill slits and including the vertebrates, lancelets, and tunicates (Merriam Webster Dictionary)

Scientific name	- Chordata
Kingdom	- Animalia
Higher classification	- Deuterostome
Rank	- Phylum
Super phylum	- Deuterostomia
Subkingdom	- Eumetazoa

3.2.1. Characteristics of Chordates

Chordates have three embryonic cell layers. They also have a segmented body with a coelom and bilateral symmetry. Chordates have a complete digestive system and a closed circulatory system. Their nervous system is centralized. There are four additional traits that are unique to chordates.

Post-anal tail: The tail is opposite the head and extends past the anus.

Dorsal hollow nerve cord: The nerve cord runs along the top, or dorsal, side of the animal. (In non-chordate animals, the nerve cord is solid and runs along the bottom).

Notochord: The notochord lies between the dorsal nerve cord and the digestive tract. It provides stiffness to counterbalance the pull of muscles.

Pharyngeal slits: Pharyngeal slits are located in the pharynx. The pharynx is the tube that joins the mouth to the digestive and respiratory tracts.

A Chordate model

The following figure is a typical model of chordate.

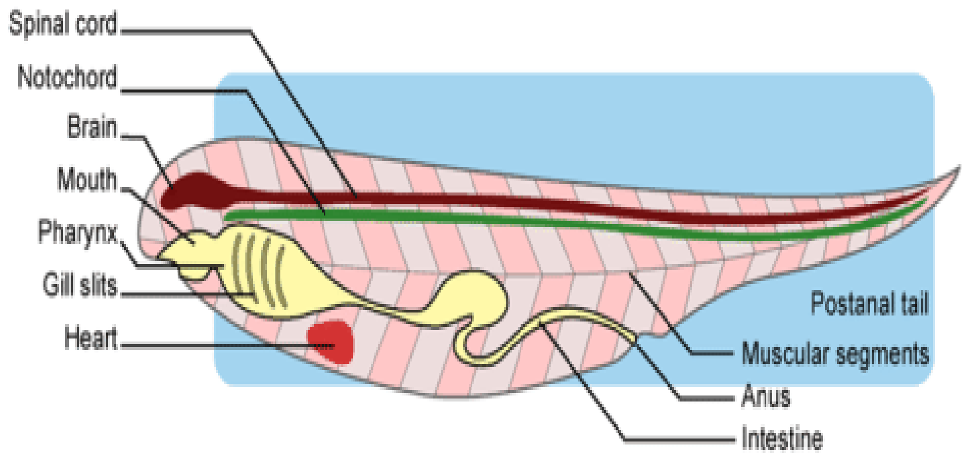


Fig.3.1: Body Plan of a Typical Chordate.

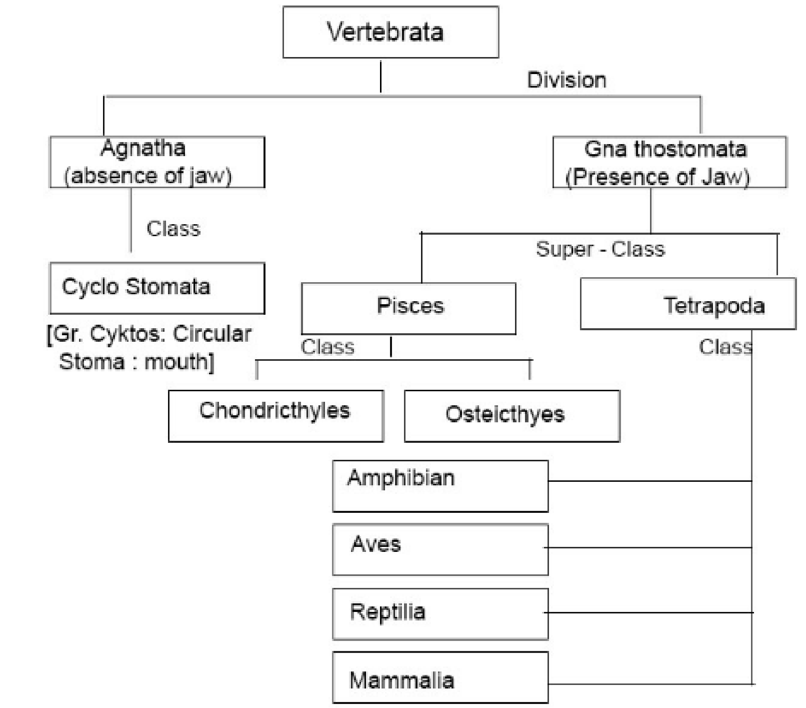
The body plane of a chordate includes a post-anal tail, notochord, dorsal hollow nerve cord, and pharyngeal slits, ventral heart, close circulation, RBC, post-anal tail, hepatic portal system etc., are very important features of chordates. On the basis of position of notochord, phylum Chordata is divided in to four subphylum:

Hemichordata: Notochord at heart region (Ex. Balanoglossus)

Urochordata: Notochord at tail Notochord region (Ex. Hardmania)

Cephalochordata: Notochord extends from head to tail (Ex. Branchiostoma)

Vertebrata or Craniata: Notochord is found in the embryonic stage and replaced by the vertebral column in adult. Brain encloses within the cranium.



3.3. Interrelationships with other discipline

Interrelationships are when each discipline has a relationship with the other discipline. The discipline need to communicate closely with one another. While each department has its own goals, these goals actually help the human being to understand the whole concept of the living being.

The branch of biology that deals with animals and animal life, including the study of the structure, physiology, development, and classification of animals.

Another related field is medicine. In particular, it is a branch of zoology that deals with the diseases and treatment of humans.

A closely related field is veterinary medicine. In particular, it is a branch of medicine that deals with the diseases and treatment of non-human animals.

Table.3.1. Some of the closely related field of Zoology are mentioned here under:

Branches of Zoology	**Definition**
Anatomy	Study of internal structure of animals
Anthrozoology	Study of past, present and future interactions between animals and human beings
Archaeozoology or Zooarchaeology	Study of dead animals
Arachnology	Branch of biology that deals with the study of spiders, scorpions or other arachnids
Bionics	Study of mechanical systems like living organisms and parts of living organisms
Carnicology	Study of Crustaceans
Cetology	Study of marine mammals [Dolphins, Whales, Porpoises, etc.,]
Cytology or Cell Biology	Study of cell structure and its functions
Ecology or Environmental Biology	Relationship between the organisms and their surrounding environments
Embryology or Developmental Biology	Study of egg, fertilization, embryos and fetuses.
Entomology	Study of insects
Ethology	Study of the behavior of animals
Evolution or Evolutionary Biology	Study of origin of animals and their adaptation
Genetics	Study of heredity and variations

Geology	Study of earth and life as shown by fossils in rocks
Herpetology	Study of reptiles and amphibians
Histology	Study of anatomy of cells and tissues of animals
Histopathology	The study of changes in tissues caused by disease.
Ichthyology	Study of Fishes
Mammalogy	Study of Mammals
Malacology	Study of animal forms with shells [Snails, Octopus, Slugs, etc.,]
Morphology	Study of form and specific structures of animal organisms
Nematology	Division of zoology that studies roundworms
Neonatology	Study of newborn animals till the age of two months
Ornithology	This branch of zoology concerns the study of birds.
Paleontology	Study of fossils and extinct animals
Pathology	Study of bodily fluids in laboratory like blood, urine, tissues, etc., to diagnose diseases
Physiology	Animal physiology (deals with the physiological processes in animals)
Primatology	Study of primates [apes, gorillas, monkeys, prosimians, etc.,]

Protozoology	Study of protozoa or the unicellular organisms
Taxonomy	This field studies, groups and formulates nomenclature rules of animals on the basis of common characteristics.
Toxicology	The scientific study of poisons
Zoography (Descriptive Zoology)	Study of animals and their respective habitats
Zoogeography	Study of geographical distribution of animal species
Zoometry	Study of measurement including size and length of animal parts
Zootomy	Study of animal anatomy

3.3. Importance of study of vertebrate morphology

Vertebrate Morphology provides a comprehensive discussion about various vertebrate morphology. The structure and function concept at the level of organs and organ systems is fundamental to an understanding of comparative evolutionary morphology. For example: Amphibians, reptiles, mammals, and birds evolved after fish.

Let us sum up

Under this unit, we studied about the various definitions of chordates, characteristic of chordates and importance of study of vertebrate morphology.

Check your Progress

1) In urochordata the notochord is present in the ___________ region.
2) The tube that joins the mouth to the digestive and respiratory tracts is known as ___________.
3) The segmented body of the chordates is usually ___________ symmetry.
4) The ___________ runs along the top, or dorsal side of the animal.

5) In __________ the notochord found in the embryonic stage is replaced by the vertebral column in adult.

Glossaries

1. Ethology : Study of behaviour of animals
2. Zootomy : Study of animal anatomy

Suggested readings

1. **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.
2. **ROMER, A.S** (1974), The Vertebrate Body, W.B. Saunders, London.

Weblink

Importance of study of vertebrate morphology
https://youtu.be/bzsNGlm0eFc

Answers to check your progress

1) Tail
2) Pharyngeal slits
3) Bilateral
4) Nerve cord
5) Craniata

UNIT – 4

Origin and Classification of Vertebrates

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the origin of vertebrates
- Explain the characteristics of vertebrates

- Classify the vertebrates based on its characteristic features.

OVERVIEW

Under this unit, we will study about the origin of vertebrates. We will also focus on the characteristic features of each groups of vertebrates and study about the classification of each groups, such as jawless fishes, cartilaginous fishes, bony fishes, amphibians, reptiles, aves and mammals.

4.1. INTRODUCTION

Vertebrates and invertebrates are evolved from a common ancestor. But today, from an evolutionary perspective, vertebrates are considered to be the top forms of life on earth. Their complex anatomy and physiology provide a significant advantage over invertebrates in the natural world. The vertebrates, which derive their name from vertebrae, the series of bones that make up the vertebral column, or backbone.

4.2. Origin of vertebrates

For more than 150 million years, vertebrates were restricted to the oceans, but about 365 million years ago, the evolution of limbs in one lineage of vertebrates set the stage for these vertebrates to colonize land. There they diversified into amphibians, reptiles, birds, and mammals. There are approximately 52,000 species of vertebrates, a relatively small number compared to, say, and the one million insect species on Earth. But what vertebrates lack in species diversity they make up for in disparity, varying enormously in characteristics such as body mass. Vertebrates include the heaviest animals ever to walk on land, plant-eating dinosaurs as massive as 40,000 kg. They also include the biggest animal ever to exist on Earth, the blue whale, which can exceed a mass of 100,000 kg. On the other end of the spectrum, a fish discovered in 2004 is just 8.4 mm long and has a mass roughly 100 billion times smaller than that of a blue whale (Alison Loomis, 2007).

The very first vertebrates are thought to have evolved 525 million years ago (*Shu et al.* 1999). That vertebrate is thought to have been Myllokunmingia. But other evidence points towards Pikaia gracilens as the very first vertebrate and the ancestor to all modern vertebrates.

Conway Morris and Caron (2012) published an exhaustive description based on all 114 of the known fossil specimens; they discovered new and unexpected characteristics that they recognized as primitive features of the first chordate animals. On the basis of these findings, they constructed a new scenario for chordate evolution. Subsequently, Mallatt and Holland reconsidered Conway Morris and Caron's description, and concluded that many of the newly recognized characters are unique, already-divergent specializations that would not be helpful for establishing Pikaia as a basal chordate (Mallatt, J and Holland, N. D, 2013).

Meaning

Vertebrate animals possess a vertebral column and/or notochord at any point in their life span.

One of the ways life is classified through the presence or absence of the vertebrate. Vertebrates and invertebrates evolved from a common ancestor that was speculated to have lived around 600 million years ago.

Evidence of true vertebrates began to appear 525 million years ago and ever since then, vertebrates have branched off into a long lineage that includes armored fish and giant sauropods to woolly mammoths and modern man.

4.3. Characteristics of Vertebrates

A vertebrate is an animal that has all of the following characteristic features at some point in its life:

- A stiff rod running through the length of the animal (it could either be the vertebral column and/or notochord)
- Humans and all other vertebrates possess a notochord as an embryo and it eventually develops into the vertebral column.
- A bundle of nerves run above the vertebral column (spinal cord) and the alimentary canal exists below it.
- The mouth is present at the anterior portion of the animals or right below it.
- The alimentary canal ends in the anus, which opens to the exterior. The tail extends after the anus.

4.4. Classification of Vertebrates

Vertebrates are classified into 7 classes based on their anatomical and physiological features. They are:

Animals that possess a backbone is classified as a vertebrate. There are a large number of vertebrates currently existing on earth and they are classified into 7 classes based on their physiological and anatomical features.

4.5. 7- classes of vertebrates

Vertebrates have been classified based on their anatomical and physiological characteristics into 7 groups. They are as follows:

1. Class Agnatha
2. Class Osteichthyes
3. Class Chondrichthyes
4. Class Amphibia
5. Class Reptilia
6. Class Aves
7. Class Mammalia

4.5.1. Jawless fishes (Class: Agnatha)

These are very primitive fishes that have not changed much from fossil records for millions of years. They have a jawless, circular mouth with rows of small sharp which aid in holding and feeding on other fishes. Most members of this class are parasites and scavengers.

4.5.2. Cartilaginous fishes (Class: Chondrichthyes)

As the name suggests, this class is characterized by the cartilaginous skeleton. Members include sharks, rays, skates and sawfish. Some sharks such as the massive Greenland shark can live for several centuries. A specimen that was tagged in 2016 was found to be at least 273 years old.

4.5.3. Bony fishes (Class: Osteichthyes)

This class of fishes is characterized by their skeleton which is composed primarily of bone rather than cartilage (such as sharks). Class Osteichthyes is also the largest class of vertebrates today.

4.5.4. Amphibians (Class: Amphibia)

Amphibians include ectothermic tetrapods such as frog toads and salamanders. The distinguishing feature that separates amphibians from reptiles is their breeding behavior. Most amphibians need a body of water to breed as their eggs are shell-less. Furthermore, they undergo metamorphosis where the young ones transform from fully-aquatic larval form (with gills and fins) to terrestrial adult form.

4.5.5. Reptiles (Class: Reptilia)

Reptiles include tetrapods such as snakes, crocodiles, tuataras and turtles. The characteristic feature of reptiles is that they are ectothermic in nature. Snakes are still considered tetrapods though they have no visible limbs. This is due to the fact that snakes evolved from ancestors that had limbs.

4.5.6. Birds (Class: Aves)

From a biological perspective, birds are dinosaurs (more aptly called avian dinosaurs). This class of organisms are characterized by feathers, toothless beaks and a high metabolic rate. Furthermore, members of class Aves lay hard-shelled eggs.

4.5.7. Mammals (Class: Mammalia)

This class of organisms have the ability to regulate their body temperature irrespective of the surrounding ambient temperature. Therefore, mammals are called endothermic animals and it includes humans and platypuses.

Let us sum up

Under this unit, we study about the origin of vertebrates, characteristic features of vertebrates and classified the vertebrates into following groups such as jawless fishes, cartilaginous fishes, bony fishes, amphibians, reptiles, aves and mammals.

Check your Progress

1) The vertebrates are classified into ___________ classes based on their anatomical and physiological features.
2) ___________ are jawless, circular mouthed fishes.
3) ___________ is characterized by cartilaginous skeleton.
4) ___________ is a class of fishes characterized by their skeleton which is composed of bone.
5) ___________ undergoes metamorphosis, where the young ones transform from fully aquatic to larval forms to terrestrial adult forms.

Glossaries

1. Notochord : it extends throughout the entire length of the future vertebral column, and reaches as far as the anterior end of the midbrain.

2. Cartilage : Cartilage is a non-vascular type of supporting connective tissue that is found throughout the body.

Suggested readings

1. **ROMER, A.S** (1979), Hyman's Comparitive Vertebrate Anatomy, III Ed., The University of Chicogo Press, London.
2. **WEICHERT, C.K** (1965), Anatomy of the Chordates, McGraw Hill Book Co., New York.

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Origin of vertebrates https://youtu.be/nqoqxA8p_AM

Classifications of vertebrates https://youtu.be/mRidGna-V4E

Answers to check your progress

1) 7 classes
2) Agnatha
3) Chondrichthyes
4) Osteichthyes
5) Amphibians

Unit 5

Vertebrate Integument and its Derivatives

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the integuments of vertebrates

- List out the derivatives of vertebrate integuments
- Explain the structure and functions of each integuments.

OVERVIEW

In this unit, we will study about the vertebrate integuments and its derivatives. Under this unit, we will focus on the various integuments of the vertebrates such as keratinoid structures, nail, horns, baleen, feathers, hair, glands, dermal bone, teeth, claws and hoofs and their structures and functions.

5.1. INTRODUCTION

The chordate skin (integument) is a compound organ, made up of two major layers of tissues of epidermis and the dermis. The epidermis is the outermost layer. It is separated from the dermis by the basal membrane (basal lamina and reticular lamina).

The epidermis is derived from somatic ectoderm, the exterior-most covering of the chordate body. It provides protection against the invasion of microorganisms, provides flexibility in motion, and seals in moisture. It also gives rise to a variety of differentiated structures such as feathers, hair, horns, claws, nails and glands.

5.12. Epidermal Derivatives of the Integument

5.2.1. Keratinoid Structures

New epidermal cells are formed continuously in the lower layers of the epidermis. In terrestrial vertebrates, new epidermal cells push more superficial ones to the stratum corneum, the outer-most epithelial layer. In the process of self-destruction, these exterior epidermal cells accumulate protein products called keratin. Keratinized or cornified skin serves to prevent water escape and to protect against friction and direct mechanical stimulation (e.g., calluses in humans). The production of all of the following structures involves keratinization: Epidermal Scales: a continuous layer of repetitious thickenings of the stratum corneum; you cannot dissect an individual epidermal scale out of the skin! These scales may be shed entirely (moulting) or in small flakes. Examine preserved specimen of snake skin and dried specimens of bird legs and feet.

5.2.2. Nails

Keratinized epithelial cells are produced at the nail base and push the existing nail forward. They provide protection from mechanical injury and stabilize skin for better grasping. Found only in primates.

5.2.3. Horns

A tough, cornified layer of the integument covers horns. Their core, however, is bone, which is of dermal origin. Horns are found in bovines (cattle, antelope, sheep, goats, bison, and wildebeest). They are retained year-round and grow throughout the animal's lifetime.

5.2.4. Baleen

Found in some whales, baleen is a series of keratinized plates that arise from oral epithelium. These sheets hang from the palate along its length and act as a sieve.

5.2.5. Feathers

Feathers are believed to have evolved from reptilian scales. Columns of epidermal cells project into the skin initially to form an invagination called the feather follicle. Later growth results in a projection out of the skin of a keratinized epidermal sheath with an inner feather shaft. These columns then separate and develop into barbs. Feather growth is initiated by dermal papillae, which die in the grown feather to form feather pulp. Examine the dried specimens. Note the quill (calamus), which attaches to the body and extends as a rachis. From the rachis project many veins with barbs and barbules to hold them together.

5.2.6. Hair

Just as in feathers, there is an initial ingrowth of epidermal cells to form the hair follicle, followed by an outward growth of keratinized cells to form the hair shaft. Dermal papillae cells of the outer edge die and form the core substance of hair follicles. Note the similarities between hair and feathers both in development and in general anatomy. They both possess dermal papillae, shafts, an inner pulp and columns of specialized keratinized cells. Hair is characteristic of mammals.

5.2.7. Glands

Specialized to secrete specific products (oil, sweat, milk, etc.), these structures are derived by an in folding of the epidermis. In many cases they retain a connection to the stratum corneum whereby their secretions can be released at the skin surface.

5.2.8. Dermal Bone

Once present in some extinct fish - Ostracoderms had a complete head shield, while Placoderms had a broken head shield and body armor. Now dermal bone is present in turtle dermal bone, antlers, and in the dermal armor of armadillo. In antlers the velvet is epidermal in origin and shapes and provides blood to the dermal bone. Once grown, the velvet is shed and only the bone remains. Antlers are found in deer, elk, moose and their relatives, often only in males. They are shed annually.

5.2.9. Teeth

Teeth are composed of three main parts. Enamel, the hardest substance in the body, covers the tooth surface. It is epidermal in origin.

5.2.10. Claws

One of the long curved nails on the end of an animal's or a bird's foot. That uses them for holding or picking things up.

5.2.11. Hoofs

The hard part of the foot of ungulates animals like horses and some other animals.

Let us sum up

Under this unit, we studied about the vertebrate integuments and its derivatives, we also focused on the various integuments of the vertebrates such as keratinoid structures, nail, horns, baleen, feathers, hair, glands, dermal bone, teeth, claws and hoofs and their structures and functions.

Check your Progress

1) The chordate skin is made up of 2 layers of tissues known as __________ and __________.
2) In the keratinoid structure the exterior epidermal cells accumulate protein products called __________.
3) __________ is a series of keratinized plates that arise from oral epithelium.
4) The column of epidermal cells project into the skin initially to form an invagination called the __________.

5) The long-curved nails on the end of the animal is known as __________.

Glossaries

1. Tetrapod : tetrapod means four feet, they are a group of vertebrates that includes amphibians, reptiles, birds, and mammals.

2. Integument : a tough outer protective layer, especially that of an animal

Suggested readings

1. **NEWMAN, N.H** (1961), Phylum Chordate, The University of Chicago Press, Chicago.
2. **WATERMAN, A.J** (1971), Chordate Structure and Function, The Macmillan Company.

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Integuments and derivatives of vertebrates https://youtu.be/jHsd4o_L_lg ,

Answers to check your progress

1) Epidermis and dermis
2) Keratin
3) Baleen
4) Feather follicles
5) Claws.

Unit 6

Development, General Structures and Functions of Skin and its Derivatives

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the skin development in vertebrates
- Illustrate the functions of integuments in vertebrates
- Explain the structure of mammalian skin
- List out the different kinds of epidermal glands.

OVERVIEW

In this unit, we will study about the development, general structure and functions of skin and its derivatives. We will also focus on the skin development, functions of integuments in vertebrates, structure of mammalian skin, derivatives and different types of epidermal glands.

6.1. INTRODUCTION

Skin of vertebrate consists of epidermis and dermis, both of which are having diverse functions. Skin epidermis starts to stratify during embryogenesis. It plays vital role in protecting the organism from water loss and environmental insults during postnatal life. The dermis is a connective tissue that is separated with the epidermis by a deposition of extracellular matrix called the basement membrane. During skin development, many skin appendages are also induced. Those include epidermal appendages such as feather follicles, hair follicles, sebaceous glands and sweat glands and dermal appendages such as the arrectorpili muscle. More stem cell populations are characterized in these appendages recently. In addition, considerable progress has been made in identifying molecules and pathways that regulate development and regeneration of skin and its appendages.

6.2. Skin Development

- During chick skin development, feathered areas are formed in the skin with high-cell density of dermal cells and naked areas are formed in low-cell density regions.
- Feather and hair development begins from thickening of epidermis and condensation of dermal cells, which is associated with the interaction among morphogens such as FGFs (fibroblast growth factor and BMPs (bone morphogenetic proteins).
- The mechanism by which feather buds are arranged in a periodic pattern on the skin and branching formation within each bud might be explained by reaction–diffusion model, one of the mathematical models.
- Feather follicles are differentiated from feather buds with the invaginated epidermis and the feathers have an ability of regeneration throughout lifetime owing to feather stem cells.
- Development and regeneration of hair follicle involve reciprocal epidermal and dermal cell interactions.
- Sequential activation of molecules including *Wnt-Eda-Shh et al.* is required for hair follicle development.

- Secondary hair germ cells first response, followed by bulge stem cell activation during hair regeneration.
- Regenerative hair cycling is regulated by epigenetic, micro-environment and macro-environment factors.

The integument or skin in mammals as well as in all vertebrates is continuous with the mucous membrane of mouth, rectum, urinogenital organs, nostrils and eyelids. The skin is made up of two distinct and embryo-logically different layers. The outer layer is epidermis and it is ectodermal in origin and the inner layer is dermis which is mesodermal in origin. The two layers are separated by a basement membrane (Fig. 6.1)

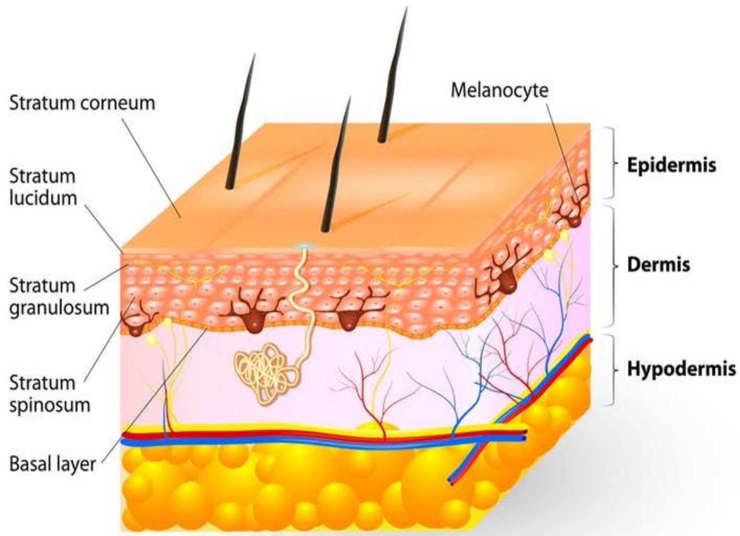

Fig. 6.1: The layers of Human skin

The outer layer or the epidermis is again divided into a number of distinct strata. The innermost layer of the epidermis is called stratum germinativum or Malpighian layer. This layer is made up of tall and columnar cells arranged perpendicular to the dermis. The cells divide mitotically and continually. The new cells thus formed tend always to reach the surface and, on their sojourn, become flattened and show poor stain ability. The layer formed by these flat cells is known as transitional layer. The outermost layer of the epidermis is called stratum corneum or horny layer. The cells of this layer are flat and dead. The chief constituent of these cells is keratin which is a very hard, tough and insoluble protein. The epidermis in certain parts of the body of man is a bit different. In the thick skin on the soles of the feet and palms of the hands the transition from Malpighian layer to corneal layer is not so abrupt. The transitional layer in these parts of the body is further subdivided into an inner stratum granulosum and an outer stratum lucidum. The thickness of the epidermal part of the skin remains fairly constant because the rate of proliferation of the stratum germinativum is nearly equal to the loss of corneal cells. The dermis or corium is thicker than the epidermis and is made up of connective tissue fibers, smooth muscle fibers, blood vessels, nerves and glands. In whales and seals the fat forms a thick layer, called blubber which acts as food reservoir and also helps in maintaining body temperature. The pigments of the skin or melanin in mammals never remain confined in specialized cells but they remain in the cells of the deepest layer of the epidermis (Tariqul Islam Goldar)

6.3. Functions of the Integument in Vertebrates:

1. Protection:
    - ii) The integument or skin protects the body from the entry of foreign bodies and prevent from the mechanical injuries.
    - iii) The hard dermal and epidermal scales that protect the skin from surface abrasion and also the soft tissues which lie beneath it.
    - iv) Hair, bristles and spines are employed for offensive and defensive purposes.
    - v) The impervious integument helps the body from loss of water.

2. Thermoregulation: The integument of warm-blooded animals regulates the body temperature. Feathers of birds, sweat glands and blubber of mammals help in the regulation of body temperature. Deep covering of the hairs help in the conservation of heat, especially during winter.

3. Storage of food: In whales, seals and sea cows, a sub- dermal fat layer forms a thick layer, called blubber, which acts as food storage.

4. Excretion: The integument of some aquatic vertebrates (e.g., aquatic amphibians) serves as an organ for excretion. During ecdysis the waste material which is stored in the corneal layer of the skin is shed. Sweat of the sweat glands aids in removing nitrogenous wastes from the body.

5. Respiration: The moist skin of common eel, mud skippers and swamp eels help in respiration. The skin of amphibians is moist and highly glandular that help air in contact with the skin to be interchanged and thus performs accessory respiration. In plethodontid salamanders, the lungs are absent, so rely totally on cutaneous respiration.

6. Secretion: The skin acts as an organ of secretion. The different glands are located in the skin those help the vertebrates in different ways for survival.

Fishes possess numerous mucous glands in the skin that secrete abundant mucous. The slimy mucus of the fish on the skin reduces resistance during swimming. The poison glands of fishes, amphibians and snakes are used for protection and predation. Mammary glands, scent glands, and sebaceous glands are present in the skin and serve different functions.

7. Locomotion: Various types of integumentary derivatives sub-serve different types of locomotion's. The fins of fishes, web in aquatic amphibians, terrapins and aquatic birds, scales or scutes in snakes, adhesive pads in climbing lizards, feathers in birds and patagium in flying lizards help in different modes of locomotion.

6.4. Structure of Skin Mammalia:

- The skin (Fig. 6.2) is elastic and waterproof and is much thicker than in other vertebrates, especially the dermis is very thick and tough and is used for making leather.

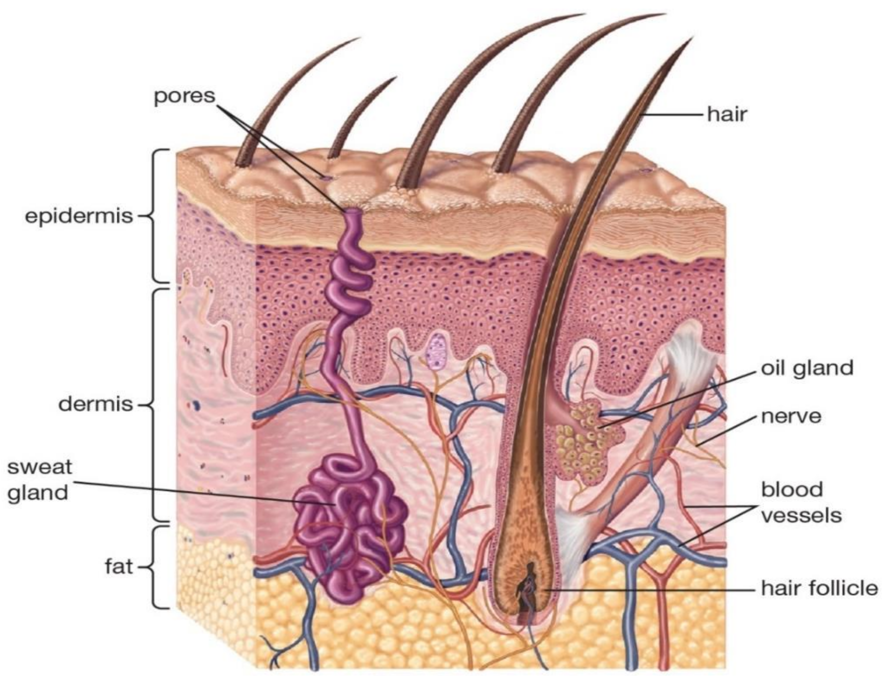

Fig.6.2. Structure of Skin Mammalia

- The epidermis is thickest in mammals and is differentiated into five layers- stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum germinativum or Malpighian layer.
- The outer layer of stratum corneum containing keratin, its cells lose their nuclei, but the cells are not dead as believed before.

- They secrete several hormones, one of which represses the mitotic activities of the Malpighian layer.
- In places of friction, such as soles and palms, the stratum corneum is very thick.
- Stratum corneum is variously modified in various mammals to form epidermal scales, bristles, hairs, claws, nails, hoofs and horns etc.
- Below the stratum corneum is a refractive stratum lucidum in certain regions only.
- The stratum lucidum is now known as a barrier layer because the electron microscope has shown that its cells become compact and closely united to form a region which prevents passage of substances into or out of the body.
- Stratum lucidum contains a chemical known as eleidin.
- Keratohyalin and eleidin are intermediate products in the formation of keratin.
- Below this is a stratum granulosum which is having darkly-staining granules of keratohyalin.
- Below the stratum granulosum is a stratum spinosum whose cells are held together by spiny intercellular bridges, each bridge has two arms in close contact, one arm arising from each cell.
- Lastly there is a stratum germinativum or Malpighian layer which rests on a thin basement membrane.
- The Malpighian layer forms new cells continuously which move towards the surface and become flat and keratinised till the stratum corneum has flat, cornified cells made only of keratin.
- This layer is sloughed off continuously and replaced by new cells.
- There are no mucous glands in the epidermis of mammals.
- The keratin from the epidermis at ends of digits forms claws, nails or hoofs.
- The dermis is best developed in mammals.
- The upper part of the dermis in contact with the epidermis is the papillary layer which is made of elastic and collagen fibers with capillaries in between.
- It is thrown into folds to form rows of dermal papillae, especially in areas of friction. The greater lower part of the dermis is a reticular layer having elastic and collagen fibers.

- In both layers there are blood vessels, nerves, smooth muscles, certain glands, tactile corpuscles, and connective tissue fibres extending in all directions.
- Below the dermis the subcutaneous tissue has a layer of fat cells forming adipose tissue which helps to maintain body heat.
- In making leather only the dermis is used. Dermal scales are not found in mammals except armadillos.
- In the lowest layer of the epidermis are pigment granules but there are no pigment-bearing chromatophores in mammals.
- In man some branching dendritic cells or melanoblasts lie between the epidermis and dermis, they contain pigment.
- The epidermis forms hairs, sudorific glands, sebaceous glands and mammary glands.
- Hairs form an epidermal covering.
- Shafts of hair project above the skin and their roots are embedded in hair follicles, into each of which opens a branching sebaceous gland.
- Hairs form an insulating layer which prevents a loss of body heat, thus, hairs keep up the body temperature.
- Sebaceous glands are out pushings of the wall of hair follicle and produce an oily substance which keeps the hair supple and prevents its wetting in water.
- It also lubricates the skin. In the dermis are present coiled sudorific or sweat glands, which occur all over except lips and glans penis.
- Mammary glands are modified sebaceous glands, but in monotremes they are modified sudorific glands.
- They are functional only in females for producing milk for the young. Mucous glands are not found in mammals.

6.5. 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.

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

1. Epidermal Glands: Epidermal glands are formed from the Malpighian layer of the epidermis. They arise from the epidermis and often penetrate the dermis.

According to their structure they are unicellular or multicellular, tubular or alveolar and simple or compound (branched) glands. These are lined by cuboidal or columnar cells.

(a) Unicellular glands are single modified cells found among other epithelial cells, they are present in amphioxus, cyclostomes, fishes and larvae of amphibians. Unicellular glands are known as mucous cells or goblet cells. They secrete a protein mucin which combines with water to form mucus which lubricates the surface of the body.

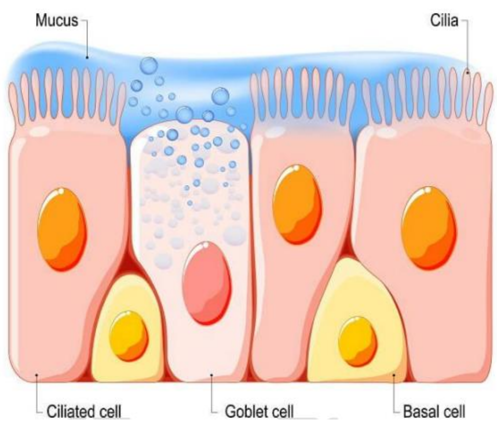

Fig. 6.3: Mucus and Goblet cells

Other unicellular glands are granular cells and large beaker cells of cyclostomes and fishes, they also secrete mucus

(b) Multicellular glands are of two types:

1. Tubular glands 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.

2. Tubular glands may become coiled at the base deep in the dermis, e.g., sweat or sudoriferous glands of mammals,

3. Tubular glands may divide into many tubules which are then called compound tubular glands, e.g., mammary glands of females and of males in monotremes and primates, etc., and gastric glands in stomach.

4. Alveolar or saccular glands are multicellular down growths of the Malpighian layer into the dermis, having a tubular duct whose terminal

parts form a rounded expansion to become flask-shaped, e.g., mucous and poison glands of amphibians.

5. 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.

6.5.1. Kinds of Epidermal Glands:

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

Integumentary Derivative:

1. Glands: A large variety of epidermal glands is present in the skin of mammals. These glands are tubular or alveolar in nature and are always multicellular.

The principal glands are:

A. Sudorific or sweat glands:

- These are long and coiled tubular glands.
- The lower part of the gland lies embedded in the dermis and the upper part are constituted by a duct which opens to the outside through a pore.
- The distribution of sweat glands in different mammals is not uniform.
- In case of man the sweat glands are more numerous on palm, sole and arm pits.
- In cat, dog and rat sweat glands are found in the sole of the feet.
- In rabbits the glands are found around the lips.
- The ruminants have sweat glands located on the muzzle and on the inter-digital fold of skin.
- In hippopotamus the pinna houses the sweat glands. Sweat glands are absent in Tachyglossus, Mus, Talpa, Cetacea and Sirenia.
- The sweat is watery in appearance but its colour is red in certain mammals like hippopotamus and Macropus.

Functions:

1. The secretion of sweat glands is known as sweat.
2. Sweat aids in removing nitrogenous wastes and helps in the regulation of body temperature.

3. The ciliary glands (glands of Moll) are modified apocrine sweat glands that are found on the margin of the eyelid. They are next to the base of the eyelashes, and anterior to the Meibomianglands within the distal eyelid marginand similar to the case with wax- secreting glands in the external ear passage.

B. Sebaceous glands:

- The glands are alveolar in nature and are generally associated with the hair.
- But they occur in hairless parts of the body, i.e., around the genital organ, tip of the nose and border of lips, independently.
- These glands are absent in Pangolin, Cetacea and Sirenia.

Functions:

1. The secretion of the gland is known as sebum. It is oily in nature and helps in keeping the body oily.
2. Meibomian glands in the eyelids are modified sebaceous glands. It secrets an oily film on the surface of the eyeball.
3. Scent glands too are modified sebaceous glands.
4. The secretion of scent glands is sex attractants. They are situated on the different parts of the body.
5. In the deer family scent glands are located near the eyes. In carnivores scent glands are found near the anus.
6. The pigs and goats have scent glands in between their toes.

Let us sum up

Under this unit, we studied about the development, general structure and functions of skin and its derivatives. We also focused on the skin development, functions of integuments in vertebrates, structure of mammalian skin, derivatives and different types of epidermal glands.

Check your Progress

1) The dermis is a connective tissue that is separated with the epidermis by a deposition of extracellular matrix called the __________.
2) The mechanism by which feather buds are arranged in a periodic pattern on the skin and branching formation within each bud might be explained by __________.
3) The outer layer or the epidermis is again divided into a number of __________.

4) The greater lower part of the dermis is a reticular layer having __________ and __________.
5) The multicellular glands are of 2 types, they are __________ and __________.

Glossaries

1. Integument : a tough outer protective layer, especially that of an animal

2. Cornified : it is a slow, coordinated process in space and time that allows the formation of a dead cells layer to create a physical barrier for the skin.

Suggested readings

1) **COLBERT, H. EDWIN** (1989), Evolution of the Vertebrates, II Ed., Wiley Eastern Limited, New Delhi.
2) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.

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Development of skin of vertebrates
https://www.notesonzoology.com/vertebrates/skin-of-vertebrates-structure-embryonic-origin-and-functions/4016

Structure and functions of skins of derivatives
https://www.embibe.com/exams/skin-derivatives/#:~:text=Skin%20performs%20various%20functions%20like,Hair%20serves%20a%20protective%20function

Answers to check your progress

1) Basement membrane
2) Reaction–diffusion model
3) Distinct strata
4) Elastic and collagen fibers
5) Tubular gland and Alveolar gland

Unit 7

Glands, Scales, Horns, Claws, Nail, Hoofs, Feathers and Hairs Skin derivatives and appendages

STRUCTURE

Glossaries

Suggested readings

Weblink

Answers to check your progress

OBJECTIVES

After completing this unit, the students will be able to

- Explain the various types of skin glands
- List out the derivatives of vertebrates
- Explain the variations among the vertebrates
- Illustrate the structure of skin.

OVERVIEW

In this unit, we will study about the glands, scales, horns, claws, nails hoofs, feathers and hair skin derivatives and appendages. Under this unit, we will focus on the skin glands, pigment, epidermal scales, claws nails and hooves, horns and antlers, feathers and hairs, dermal derivatives, variations among vertebrates like cyclostomes fishes, amphibians, reptiles, birds and mammals, skin structure, hair and glands of vertebrates.

7.1. INTRODUCTION

In vertebrates, the notable changes that have taken place during the course of evolution is the development of a variety of glands, pigmentary structures, scales, claws, nails, horns, feathers, and hairs as adaptations to their changing environments.

7.2. Skin glands

The glands of the skin are all exocrine, that is, they secrete their products, usually through ducts, to the epidermal surface. They may be unicellular, as are the goblet cells of fishes, or multicellular, as are the sweat glands of humans. Some multicellular glands are tubular and extrude their secretion into a central space or lumen; some, like the oil-producing sebaceous glands of mammals, form their product by complete breakdown of the cells, a method of secretion known as holocrine. Glands may consist of tubes or sacs, and they may be singular, clustered, or branched; some even contain units of more than one type. They may secrete their product continuously, periodically, or only once (fig. 7.1)

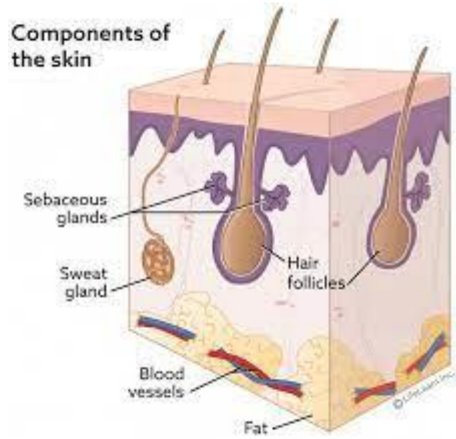

Fig. 7.1: Sweat Glands of Humans

Mucous glands secrete a protein called mucin, which with water forms the substance known as mucus; this slimy material serves to lubricate the body, thus lessening friction and aiding locomotion in swimming animals. Serous glands produce a watery secretion; sweat glands of mammals are of this type. Sebaceous glands secrete oil, ceruminous glands secrete wax, mammary glands secrete milk, poison glands secrete various toxins, and scent glands secrete a variety of odoriferous substances. Further, certain epidermal glands may be modified into light-producing structures called photophores, seen in the skin of many deep-sea fishes.

7.3. Pigment cells

In fishes, pigment is produced in branched cells known as chromatophores, which can be found in both epidermis and dermis. Rapid color change, by which some fishes can adapt to a change of background, is brought about by redistribution of the pigment within the cell boundaries. Slow, long-term changes involve alterations in the numbers of cells or in the amount of pigment they contain.

Chromatophores are also present in amphibians and reptiles, but not in birds or mammals, which possess pigment cells called melanocytes. Melanocytes are found mainly in the epidermis, though they occur elsewhere. They also are branched, or dendritic, and their dendrites are used to transfer pigment granules to adjacent epidermal cells. A number of different pigments are produced in the different vertebrate groups, but in mammals only brown eumelanin and yellow or red phaeomelanin are important. Pigment cells chromatophores and melanocytes alike are influenced by melanocyte-stimulating hormones of the pituitary (fig. 7.2).

7.4. Epidermal scales

Epidermal scales are horny, tough extensions of the stratum corneum. Well developed in reptiles, they are also common on exposed skin in birds and mammals. Such scales are periodically molted or shed gradually along with the rest of the stratum corneum. Epidermal scales are absent in fishes, but dermal, or bony, scales are abundant. Claw like epidermal scales are present in certain amphibians, including a few toads, certain burrowing, wormlike caecilians, and the salamander *Hynobius*. The so-called horns of the horned lizard are specialized epidermal scales; and the rattle of rattlesnakes is a series of dried scales loosely attached to each other, the last one always remaining despite molting of the rest of the stratum corneum. Epidermal scales cover the bony scales of the carapace (top) and plastron (bottom) of turtles' shells. The beak of turtles is composed of a modified epidermal scale covering the jawbone.

(a)

(b)

(c)

Fig. 7.2. Epidermal scales: a. Ant eater, b. Lizard, c. Crocodile

Bills of birds are similarly constructed. In birds, epidermal scales are confined to the lower legs, feet, and base of the bill. The spurs of some birds are bony projections covered with a scale like sheath. The skin of the webs in aquatic birds is also scaly. In mammals, except for a few cases, epidermal scales are largely restricted to the tails and paws. The overlapping horny plates of the pangolin are modified epidermal scales.

7.5. Claws, Nails, and Hooves

In many animals, hardened corneal growths occur at the end of the digits, growing parallel to the skin surface. True claws—found in reptiles, birds, and mammals consist of a dorsal scale like plate (unguis) covering a ventral plate (subunguis), the whole capping the bony tip of a digit. Nails found only in mammals consist of a broad and flattened unguis, with the subunguis reduced to a vestige under the outer tip. Hooves, the characteristic feature of the hoofed mammals, or ungulates are exaggerated nails, with the unguis curved all around the end of the digit and surrounding the subunguis. (fig. 7.4)

Fig. 7.4. Claws

Fig. 7.5. Nails

Fig. 7.6. Hooves

7.6. Horns and antlers

Horns are hardened corneal projections of several types. Except for certain lizards, horns are found only in mammals. The keratin fiber horn is unique to the rhinoceros. It consists of a cone of keratinized cells that grows from an epidermis covering a cluster of dermal bumps (papillae). The fibers, somewhat resembling thick hair, grow from the papillae, and cells between the papillae produce a cement that binds the fibers together.

Hollow horns are found in cattle, sheep, buffalo, goats, and other ruminants. In certain species only the males display them. Such horns consist of an extension of the frontal bone, a permanent part of the cranium covered by a horny layer. The horn of the pronghorn antelope is unique in that the horny covering is shed periodically and a new one is formed from the epidermis that persists over the bony extension.

Antlers, which are characteristic features of the deer family, are not integumentary derivatives at all. Fully developed antlers are solid bone, without any epidermal covering. The young antlers, however, are covered with skin having a velvety appearance. When the antler is fully developed, the drier skin cracks and is rubbed off by the animal. Antlers in giraffes are small and remain permanently covered. (fig. 7.7)

Fig. 7.7. Horns

7.7. Feathers and hair

Birds and mammals display remarkable elaborations of the epidermis in the form of feathers and hair, respectively. These distinctive features are dealt with below (see bird; mammal).

Fig. 7.8. Furs

Fig. 7.9. Hairs

Fig. 7.10. Feathers

7.8. Dermal derivatives

Dermal scales are found almost exclusively in fishes and some reptiles. They are bony plates that fit closely together or overlap and form the dermal skeleton. Highly developed dermal scales are seen in turtles, where the bony plates form a rigid dermal skeleton that is attached to the true skeleton. In other reptiles, dermal scales are small and localized on parts of the body, as in crocodilians, certain lizards, and a few snakes.

Birds lack dermal scales, and only a single living mammal the armadillo displays them. Associated with the evolutionary tendency toward elaboration of epidermal extensions in birds and mammals, there has been a corresponding reduction in dermal derivatives. The membrane bones of the skull, the mandible (lower jaw), and the clavicles (collarbones) are the remaining vestiges of dermal plates in these groups.

Fig. 7.11. Armadillo - Dermal plates

Fig. 7.12. Whale – Baleen

Fig. 7.13. Bat - Webbed wings

Fig. 7.14. Bird – Beak

7.9. Variations among vertebrates

The vertebrates belong to the phylum Chordata and are closely related to a small, fishlike, almost transparent invertebrate called amphioxus. Amphioxus represents chordate integument at its simplest: an epidermis, consisting of one layer of columnar or cuboidal epithelial cells and scattered mucous cells, covered by a thin cuticle, and a thin dermis of soft connective tissue. Beginning with the simplest vertebrates, the cyclostomes (lampreys and hagfishes), and the integument becomes complex and pigmented; in successive evolutionary stages a wide array of derivatives appears among the various classes of vertebrates.

7.9.1. Cyclostomes

In the lamprey the surface of the skin is smooth, with no scales. The epidermis consists of several cell layers that actively secrete a thin cuticle. Gland cells that produce slime are mixed with the epidermal cells, as in most aquatic vertebrates. The dermis is a thin layer of connective tissue fibers interwoven with blood vessels, nerves, muscle fibers, and chromatophores.

7.9.2. Fishes

Fishes have a more or less smooth, flexible skin dotted with various kinds of glands, both unicellular and multicellular. Mucus-secreting glands are especially abundant. Poison glands, which occur in the skin of many cartilaginous fishes and some bony fishes, are frequently associated with spines on the fins, tail, and gill covers. Photophores, light-emitting organs found especially in deep-sea forms, may be modified mucous glands. They may be used as camouflage or to permit recognition, either for repulsion to delimit territory or for attraction in courtship.

Also formed within the skin of many fishes are the skeletal elements known as scales. They may be divided into several types on the basis of composition and structure. Cosmoid scales, characteristic of extinct lungfishes and not found in any fishes today, are similar to the ganoid scales of living species. Placoid scales (or denticles) are spiny, tooth like projections seen only in cartilaginous fishes. Ganoid scales, sometimes considered a modification of the placoid type, are chiefly bony but are covered with an enamel-like substance called ganoin. These rather thick scales, present in some primitive bony fishes, are well developed in the gars.

Cycloid scales appear to be the inner layer of ganoid or cosmoid scales. Found in carps and similar fishes, they are thin, large, round or oval, and arranged in an overlapping pattern; growth rings are evident on the free edges. Ctenoid scales are similar to cycloid, except that they have spines or comb like teeth along their free edges; these scales are characteristic of the higher bony fishes—perches and sunfishes, for example, some fishes, such as catfishes and some eels, have no scales.

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The dominant modern fishes, teleosts, are characterized by bony scales covered with skin. The epithelium of a trout's epidermis provides the animal with an inert covering of keratin. The scales lie in the dermis as thin, overlapping plates with the exposed part bearing the pigment cells. The scale is deposited in a series of annual rings, since its growth occurs rapidly in spring and summer and rarely in winter.

7.9.3. Amphibians

Most modern amphibians lack horny scales or other protective devices. An exception is seen in the caecilians, a small group that has fishlike scales similar to those possessed by ancient and extinct forms. The amphibian epidermis has five to seven layers of cells formed from a basal stratum germinativum. At the skin surface, in contact with the external environment, the cells are keratinized to form a stratum corneum, which is best developed in amphibians that spend most of their time on land. The cells of this horny layer are not continuously shed but are periodically molted in sheets. Molting is controlled by the pituitary and thyroid glands but is unaffected by sex hormones. The wartiness of toads results from local thickenings.

Some amphibian families have disk like pads on their digits for adherence to underlying surfaces. During the breeding season the males of anurans (frogs and toads) and urodeles (salamanders and newts) develop nuptial pads on some digits of the forelimbs, which facilitate firm gripping of the females; the pads are induced to form by androgenic (male) hormones.

The dermis is two-layered, having an outer and looser stratum spongiosum and an inner stratum compactum. Although some amphibians have external gills or internal lungs, for many the skin is a vital respiratory organ, and the dermis is richly supplied with blood vessels and lymph spaces. Chromatophores are located just below the junction of the dermis with the epidermis. The numerous mucous and poison glands originate from nests of epidermal cells that grow down into the dermis.

7.9.4. Reptiles

In the evolutionary sense, reptiles are the first truly terrestrial vertebrates, since they have dispensed with an aqueous environment for their larval development. Their main problem is to prevent desiccation by water loss through the skin. This is solved by the possession of a thick stratum corneum in which waxes are arranged in membrane like layers between the keratinized cells. Reptilian scales are overlapping folds of skin, each scale having an outer surface, an inner surface, and a hinge region. All the epidermal and dermal surfaces of each scale are continuous with those of the next scale.

The shape and size of the scales vary in the different families and with the mode of life. Maximum flexibility of the skin is achieved in some forms by reduction of the scales to small, non-overlapping granules. Among desert dwellers there is a tendency for some scales, particularly those on the head and tail, to be enlarged to form spines. Burrowing and secretive forms have a slippery body surface because of the presence of smooth, highly polished scales. The skin is often reinforced by bony plates, which lie beneath the superficial scales (though corresponding with them in size and shape); these plates may form a continuous protective armor. Other defensive, or sometimes offensive, devices associated with the skin and scales are the occasional development of horns or fringing folds that break up the animal's outline and coloring.

The colors of reptiles are produced by both melanocytes in the epidermis and three types of chromatophores in the dermis: melanophores, which contain melanin; xanthophores, which contain yellow pigments; and iridophores, which contain reflecting platelets of colorless guanine. The pattern may be fixed, for concealment by camouflage, or the chromatophores may provide for rapid colour change.

Reptilian skin possesses glands, but they are usually small. Most are holocrine; some are tubular. Lizards and snakes have small glands that are related to the sloughing cycle, and all groups of reptiles appear to communicate by scent glands. For example, chelonians (turtles and tortoises) have glands in the throat, inguinal, and axillary regions, and snakes have saclike scent glands at the base of the tail.

Fig. 7.15. Turtle - Dermal plates

Fig. 7.16. Spikes

7.9.5. Birds

The avian epidermis is thin, delicate, and clothed in feathers, except on the obviously naked areas of the legs, feet, beak, comb, and wattle. On the legs and feet, and sometimes elsewhere, the cornified layer is thickened to form scales of several types. The dermis, also thin, consists mostly of a network of connective tissue fibres and muscle fibres that help to adjust the feathers. In larger birds, such as the ostrich, the skin is thick enough to allow it to be processed into leather. The scales resemble those of reptiles in possessing layers containing beta keratin and alpha keratin.Feathers, which consist of beta keratin, are considered to have evolved from reptilian scales. They are periodically molted, and other keratinized structures such as the bill and claws may be molted as well. Pigment is primarily restricted to feathers and scales. Specialized nerve endings are present throughout the skin. Various holocrine and tubular glands have been observed, but nearly all are small and inconspicuous. The exception is the holocrineuropygial gland, or preen gland, which is located on the back just in front of the tail and secretes oil for grooming the feathers. It is largest in aquatic birds.Feathers are unique to birds. Those of adults are admirably engineered to be lightweight yet strong. They are of three basic types, each associated with certain functions. Contour feathers (including the flight and tail feathers) define the body outline and serve as aerodynamic devices; filoplumes (hair feathers) and plumules (down feathers) are used principally as insulation, to conserve body heat. Colours and patterns in feathers serve as protective coloration or for sexual display.

Fig. 7.17. Birds- Tallons

In most birds contour feathers are not uniformly distributed over the surface of the body but are arranged in feather tracts (pterylae) separated from one another by regions of almost naked skin (apteria). The only exceptions are the ostrich like birds, the penguins, and the South American screamers, in which the even distribution of plumage has probably been secondarily acquired. Feather tracts differ in arrangement in different species and hence are useful in the classification of birds.

The wing tract includes the flight feathers proper (remiges) and their coverts (tectrices). The remiges include the primaries, arising from the "hand" and digits and attached to the hand's skeleton; the secondaries, arising from the forewing and attached to the ulna; and the tertials (when present), arising from the upper wing and attached to the humerus. The tectrices cover the bases of the remiges, overlapping and decreasing in size toward the leading edge of the wing.

The spinal (dorsal) tract extends the whole length of the bird, excepting the head, along and on both sides of the spinal column. In gallinaceous birds this tract may be subdivided from front to back (though not separated by apteria) into the regions of the hackle, the cape, the back, and the saddle. Each region is distinguished by the form and pattern of its constituent feathers.

On the ventral surface of the bird are paired breast tracts, with a ventral tract between them. The tail tract includes the tail feathers (rectrices) and their coverts. Other tracts cover the head, base of the wings and legs.

A contour feather of an adult bird tends to be almost bilaterally symmetrical. It consists of a tapering central shaft, the rachis, to which are attached a large number of tapering parallel barbs. These in turn carry many minute elongated barbules on both their distal and proximal faces. The distal barbules bear tiny hooklets (hamuli) that fit into grooves on the proximal barbules of the next higher barb. In this way the barbules overlap and interlock to form the coherent web or vane of the feather. Barbules in the basal portions of feathers are long, delicate threads and do not bind successive barbs together; consequently, this part of the feather is fluffy.

The filoplumes, which arise at the bases of contour feathers, are inconspicuous hair like feathers bearing a small tuft of barbs at their apexes. Filoplumes appear to be present in all birds, but only in certain species do they project beyond the contour feathers—on the thighs of cormorants, for example.

Plumules are present in young birds before they develop the adult plumage. In adults the plumules are generally scant and are concealed by contour feathers; however, in many birds, such as gulls and ducks, they form a thick, insulating under covering comparable to the underfur of seals. Their barbs do not form coherent vanes but are long, loose, soft and fluffy. Their structure is much simplified, and a rachis may be entirely lacking. In herons and some hawks the tips of the plumules disintegrate into a fine scaly powder that becomes distributed over the plumage, providing protection against wetting and giving it a peculiar sheen; accordingly, these specialized down feathers are called powder down.

Feathers get their colors from a number of pigments. Melanin is responsible for black, gray, brown and related tints; yellow or reddish brown granules of phaeomelanin and dark brown granules of eumelanin are transferred to the epithelial cells of the feather from melanocytes. Some feathers are colored bright yellow, vivid red, green, violet or blue by carotenoids and other rare pigments. Cosmetic coloration of the feathers by the secretion of the preen gland is exploited by pelicans. Not all coloration requires pigments. The striking white of sea gulls and swans is a “structural color” produced by the reflection of light by irregularly distributed air-filled cavities. Blue, green and violet can also be structurally produced, as for example, in kingfishers and parrots.

7.9.6. Mammals

An important distinguishing character of mammals is their hair. They also possess many other horny derivatives of the epidermis, including nails, claws, hooves, quills, and horns. All mammalian hard keratin, as well as the soft keratin of the stratum corneum, is of the alpha type. Bony dermal plates are found in the armadillo. Antlers, too, are made of bone and derived from the dermis, but they have an epidermal covering—the velvet—when newly grown.

Fig. 7.18. Teeth of Mammals

7.10. Skin structure

The mammalian epidermis has several layers of cells, known as keratinocytes, which arise by cell division in a basal stratum germinativum. This rests on a basement membrane closely anchored to the surface of the dermis. Newly formed cells move outward, and at first form part of the prickle cell layer (stratum spinosum), in which they are knit together by plaque like structures called desmosomes. Next, they move through a granular layer (stratum granulosum), in which they become laden with keratohyalin, a granular component of keratin. Finally, the cells flatten, lose their nuclei and form the stratum corneum. The dead cells at the skin surface are ultimately sloughed or desquamated. In thick, glabrous skin lacking hair follicles, such as that on human palms and soles, a clear layer, called the stratum lucidum, can be distinguished between the stratum granulosum and the stratum corneum.

The important barrier to outward loss of water or inward passage of chemicals lies in a compact zone of the lower stratum corneum. There the spaces between the layers of the cornified cells are tightly packed with lipid (waxy) platelets that have been produced inside so-called membrane coating granules within the underlying epidermal cells. As well as the clear horizontal stratification of the epidermis, a vertical organization is also apparent, at least in non-glabrous skin, in the sense that the ascending keratinizing cells appear to form regular columns.

In the basal layer, groups of keratinocytes are each associated with a single dendritic (branching) pigment cell to form "epidermal melanocyte units". In addition to keratinocytes and melanocytes, the mammalian epidermis contains two other cell types: Merkel cells and Langerhans cells. Merkel cells form parts of sensory structures. Langerhans cells are dendritic but unpigmented and are found nearer the skin surface than melanocytes. After a century of question about their purpose, it is now clear that they have a vital immunologic function.

The dermis forms the bulk of the mammalian skin. It is composed of an association of connective tissue fibers, mainly collagen, with a ground substance of mucopolysaccharide materials (glycosaminoglycans), which can hold a quantity of water in its domain. Two regions can be distinguished an outer papillary layer and an inner reticular layer. The papillary layer is so called by reason of the numerous microscopic papillae that rise into the epidermis, especially in areas of wear or friction on the skin. These papillae, not to be confused with the "dermal papillae" of the hair follicles (see below), are arranged in definite patterns beneath epidermal ridges. In humans these external ridges are responsible for the fingerprints, or dermatoglyphs. The reticular layer has denser collagen than the papillary layer, and it houses the various skin glands, vessels, muscle cells and nerve endings.

Fig. 7.19. Spikes

7.11. Hair

In evolution, the overriding importance of hair is to insulate the warm-blooded mammals against heat loss. Hairs have other uses, however. Their function as sensory organs may indeed, predate their role in protection from cold. Large stiff hairs (vibrisae), variously called whiskers, sensory hairs, tactile hairs, feelers and sinus hairs are found in all mammals except humans and are immensely helpful to night-prowling animals. Vibrissae are part of a highly specialized structure that contains a mass of erectile tissue and a rich sensory nerve supply. These specialized hairs are few in number, their distribution being confined chiefly to the lips, cheeks and nostrils and around the eyes; they occur elsewhere only occasionally. Human eyelashes consist of sensory hairs that cause reflex shutting of the eyelid when a speck of dust hits them.

Hair may also be concerned in sexual or social communication, either by forming visible structures, like the mane of the lion or the human beard or by disseminating the product of scent glands, as in the ventral gland of gerbils or the human axillary organ. Hair is important as well in determining the coloration and pattern of the mammalian coat, serving either as camouflage or as a means of calling attention to the animal or a specific part of its body.

In essence, each hair is a cylinder of compacted and keratinized cells growing from a pit in the skin—the hair follicle. The follicle consists mainly of a tubular indentation of the epidermis that fits over a small stud of dermis the dermal papilla at its base. Indeed, it is formed in the embryo by just such as interaction between its constituents, the epidermis growing inward as a peg that ultimately invests a small group of dermal cells.

The epidermal components of an active hair follicle consist of an outer layer of polyhedral cells, forming the outer root sheath, and an inner horny stratum, the inner root sheath. This inner sheath is composed of three layers known respectively as Henle’s layer (the outermost), consisting of horny, fibrous, oblong cells; Huxley’s layer with polyhedral, nucleated cells containing pigment granules; and the cuticle of the root sheath, having a layer of downwardly imbricate scales (overlapping like roof tiles) that fit over the upwardly imbricate scales of the hair proper. The outer root sheath is surrounded by connective tissue. This consists internally of a vascular layer separated from the root sheath by a basement membrane—the hyaline layer of the follicle. Externally, the tissue has a more open texture corresponding to the deeper part of the dermis that contains the larger branches of the arteries and veins.

A small muscle, the arrectorpili, is attached to each hair follicle, with the exception of the small follicles that produce only fine vellus hairs. If this muscle contracts, the hair becomes more erect and the follicle is dragged upward. This creates a protuberance on the skin surface, producing the temporarily roughened condition that is popularly called gooseflesh.

The hair shaft is composed chiefly of a pigmented, horny, fibrous material, which consists of long, tapering fibrillar cells that have become closely impacted. Externally, this so-called cortex is covered by a delicate layer of imbricated scales forming the cuticle. In many hairs the center of the shaft is occupied by a medulla, which frequently contains minute air bubbles, giving it a dark appearance. The medullary cells tend to be grouped along the central axis of the hair as a core, continuous or interrupted, of single, double, or multiple columns.

The cuticular scales of mammalian hairs are predominantly of the overlapping, imbricate type, with edges that are rounded, minutely notched, or flattened. They vary in size, shape and edge structure and are distinctive for each species. Among the higher primates, for example, those of chimpanzees are slightly oval, those of gorillas and humans have shallowly notched edges, and those of orangutans have edges that are deeply notched.

In many deer the cortical substance can hardly be distinguished; almost the entire hair appears to be composed of thin-walled polygonal cells. In the peccary the cortical envelope sends radial projections inward, the spaces between being occupied by medullary substance; and this on a large scale, is the structure of the porcupine's quills.

One of the most remarkable mammalian hairs is that of the Australian duckbill or platypus, where the lower portion of the shaft is slender and wool like, while the free end terminates as a flattened, spear-shaped, and pigmented hair with broad imbricate scales. In the three-toed sloth a microscopic alga grows between the cuticular scales of the hairs and appears to be symbiotic; its presence gives a curious greenish gray hue to the coat of the sloth and helps to disguise the animal among the trees.

The activity of hair follicles is cyclic. After an active period (known as anagen), the follicle passes through a short transition phase (catagen) to enter a resting phase (telogen). In this process, cell division ceases and the dermal papilla is released from the epidermal matrix, which becomes reduced to a small, inactive, secondary germ. The base of the hair expands and becomes keratinized to form a “club”, which is held in the follicle until the next cycle begins. A new period of anagen starts with cell proliferation of the secondary germ, which then extends inward to reinvest the dermal papilla. After the new hair is formed, the old club hair is shed or molted. The events of early anagen are in effect, a reenactment of the early development of the hair follicle.

The final length of any hair depends mainly on the duration of anagen and varies between body sites and from animal to animal. Hairs on the back of a rat take three weeks to grow fully, whereas the follicles on the human scalp may be continuously active for three years or more.

The cyclic activity of hair follicles is the mechanism by which mammals molt; it thus enables animals to alter their coats as they grow or as they adjust to changing temperature-control or camouflage requirements. In some mammals molting takes place in a pattern, so that the follicles act in synchrony in a particular area of the body. In the human scalp the follicles are out of step with each other, and there is continuous loss of club hairs.

7.12. Glands

The skin glands of mammals are of three major types. Associated with hair follicles are oil-secreting sebaceous glands as well as tubular glands, which produce an aqueous secretion. Sebaceous glands are termed holocrine because their secretion involves complete disintegration of their cells, which are constantly replaced. Tubular or merocrine glands extrude their secretion into a central lumen. The tubular glands of the hair follicle are usually classified as apocrine because it is believed that in some glands at least, secretion involves a breaking off of part of the gland cells. A second type of merocrine gland not associated with hair follicles, is termed eccrine because the cells remain intact during secretion. Eccrine glands occur in hairy skin only in humans and some primates; but the footpad glands, which increase friction and thus prevent slipping in many mammalian species are of a similar type.

A major function of skin glands is the production of odors for sexual or social communication. Many species in all but a few mammalian orders have specialized aggregations of glandular units for this purpose. These occur in almost every area of the body. Some like the chin and anal glands of the rabbit, contain only tubular units; others like the abdominal gland of the gerbil, are purely sebaceous; still others, like the side glands of shrews, contain batteries of both holocrine and tubular units.

In some large mammals an important function of merocrine glands is temperature control. Horses and cattle, for example, have apocrine glands for this purpose, but the superbly effective cooling system of humans is served by eccrine sweat glands.

Let us sum up

Under this unit, we studied about the glands, scales, horns, claws, nails hoofs, feathers and hair skin derivatives and appendages. We also focused on the skin glands, pigment, epidermal scales, claws nails and hooves, horns and antlers, feathers and hairs, dermal derivatives, variations among vertebrates like cyclostomes fishes, amphibians, reptiles, birds and mammals, skin structure, hair and glands of vertebrates.

Check your Progress

1) The pigments that are produced by the fishes are known as __________.
2) Pigment cells chromatophores and melanocytes alike are influenced by __________ of the pituitary.
3) __________ is the mammal that displays dermal scales.
4) __________ is the scale that appears in the inner layer of ganoid or cosmoid scales.
5) The dermis is two-layered which is composed of outer __________ and inner __________.

Glossaries

1. Cartilage : Cartilage is a non-vascular type of supporting connective tissue that is found throughout the body.

2. Tetrapod : tetrapod means four feet, they are a group of vertebrates that includes amphibians, reptiles, birds, and mammals.

3. Integument : a tough outer protective layer, especially that of an animal

4. Cornified : it is a slow, coordinated process in space and time that allows the formation of a dead cells layer to create a physical barrier for the skin.

Suggested readings

1) **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.
2) **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.

Weblink

Glands, scales, horns, claws, nails, hoofs, feathers and hair or vertebrates
https://www.zoology.ubc.ca/~millen/vertebrate/Bio204_Labs/Lab_2__Integument..html

Answers to check your progress

1) Chromatophores
2) melanocyte-stimulating hormones
3) armadillo
4) Cycloid
5) looser stratum spongiosum and stratum compactum

Unit 8

Circulatory System

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the circulatory system
- Differentiate the different types of circulatory system
- Illustrate the circulatory system in fishes

- Describe the heart in various species of vertebrates

OVERVIEW

In this unit, we will study about the circulatory system. Under this unit, we will focus on the different types of circulatory systems such as closed and open type of circulatory system, body fluid, chambers of heart, heart of hemichordates, chordates, circulatory system in fish and heart of fish.

8.1. INTRODUCTION

In all animals, except a few simple types, circulatory system transports nutrients, respiratory gases, and metabolic products throughout a living body, permitting integration among the various tissues. The process of circulation includes the intake of metabolic materials, the transport of these materials throughout the body, and the return of harmful by-products to the environment.

8.2. Circulatory System Structure

The circulatory system is effectively a network of cylindrical vessels of arteries, veins and capillaries that emanate from a pump, the heart. In all vertebrate organisms, as well as some invertebrates, this is a closed-loop system in which the blood is not free in a cavity. Circulatory systems may be open (mixed with the interstitial fluid) or closed (separated from the interstitial fluid).

8.3. Type of Circulatory System

Some invertebrates including insects, crustaceans, and most mollusks have an open circulatory system. In an open circulatory system, the blood is not enclosed in the blood vessels but is pumped into a cavity called a hemocoel and is called hemolymph because the blood mixes with the interstitial fluid.

8.3.1. Closed Circulatory Systems

In a closed circulatory system, blood is contained inside blood vessels and circulates unidirectionally from the heart around the systemic circulatory route, then returns to the heart again. All vertebrates having this type of circulatory system. This system contains two fluids, blood and lymph, and functions by means of two interacting modes of circulation, the cardiovascular system and the lymphatic system; both the fluid components and the vessels through which they flow reach their greatest elaboration and specialization in the mammalian systems and particularly in the human body.

Core Features of Circulatory Systems

All living organisms take in molecules from their environments, use them to support the metabolism of their own substance and release by-products back into the environment. The internal environment differs more or less greatly from the external environment, depending on the species. It is normally maintained at constant conditions by the organism so that it is subject to relatively minor fluctuations. In individual cells, either as independent organisms or as parts of the tissues of multicellular animals, molecules are taken in either by their direct diffusion through the cell wall or by the formation by the surface membrane of vacuoles that carry some of the environmental fluid containing dissolved molecules. Within the cell, cyclosis (streaming of the fluid cytoplasm) distributes the metabolic products (Michael Francis Oliver).

Molecules are normally conveyed between cells and throughout the body of multicellular organisms in a circulatory fluid called blood, through special channels called blood vessels, by some form of pump which, if restricted in position, is usually called a heart. In vertebrates blood and lymph (the circulating fluids) have an essential role in maintaining homeostasis (the constancy of the internal environment) by distributing substances to parts of the body when required and by removing others from areas in which their accumulation would be harmful.

An internal circulatory system transports essential gases and nutrients around the body of an organism, removes unwanted products of metabolism from the tissues and carries these products to specialized excretory organs.

8.3.2. Body Fluids

Lymph

Lymph essentially consists of blood plasma that has left the blood vessels and has passed through the tissues. It is generally considered to have a separate identity when it is returned to the bloodstream through a series of vessels independent of the blood vessels and the coelomic space. Coelomic fluid itself may circulate in the body cavity. In most cases this circulation has an apparently random nature, mainly because of movements of the body and organs.

Blood

Blood is circulated through vessels of the blood vascular system. Blood is moved through this system by some form of pump. The simplest pump called heart, may be no more than a vessel along which a wave of contraction passes to propel the blood. This simple, tubular heart is adequate where low blood pressure and relatively slow circulation rates are sufficient to supply the animal's metabolic requirements, but it is inadequate in larger, more active, and more demanding species. In the latter animals, the heart is usually a specialized, chambered, muscular pump that receives blood under low pressure and returns it under higher pressure to the circulation. Where the flow of blood is in one direction, as is normally the case, valves in the form of flaps of tissue prevent backflow.

A characteristic feature of hearts is that they pulsate throughout life and any prolonged cessation of heartbeat is fatal. Contractions of the heart muscle may be initiated in one of two ways. In the first, the heart muscle may have an intrinsic contractile property that is independent of the nervous system. This myogenic contraction is found in all vertebrates and some invertebrates. In the second, the heart is stimulated by nerve impulses from outside the heart muscle. The hearts of other invertebrates exhibit this neurogenic contraction.

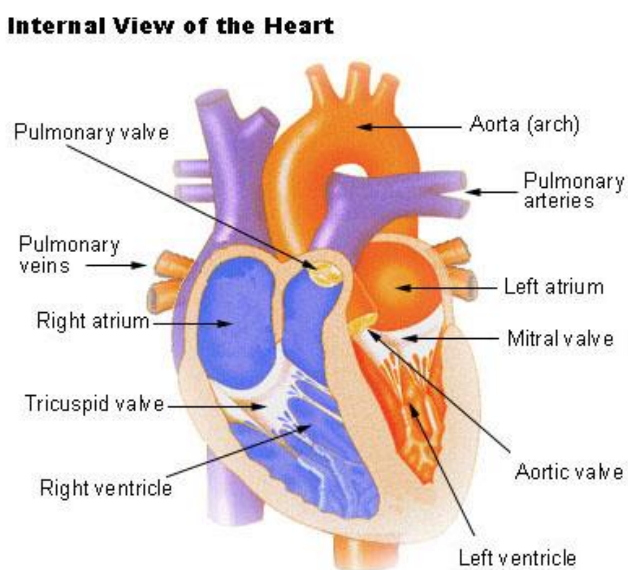

Fig. 8.1. Structure of Human Heart

8.3.3. Chambers of Hearts

There are 3 basic type of heart found in animals: a two chambered heart, a three chambered heart, and a four chambered heart. Fish have two chambers, one atrium and one ventricle. Amphibians and reptiles have three chambers: two atria and a ventricle. Reptiles have a three-chambered heart, but have little mixing of the blood; Crocodiles are the one reptilian exception, as they have four chambers (two atria and two ventricles). Birds and mammals have four chambers (two atria and two ventricles).

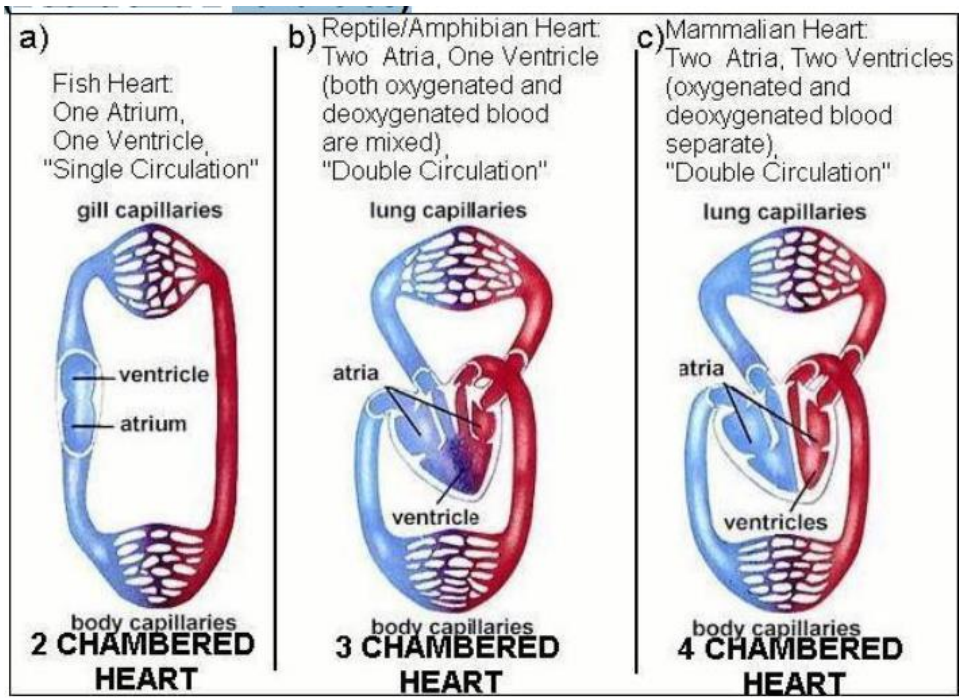

Fig. 8.2. Hearts of vertebrates with multiple chambers.

Chambered hearts, as found in vertebrates and some larger invertebrates, consist of a series of interconnected muscular compartments separated by valves. The first chamber, the auricle acts as a reservoir to receive the blood that then passes to the second and main pumping chamber, the ventricle. Expansion of a chamber is known as diastole and contraction as systole. As one chamber undergoes systole the other undergoes diastole, thus forcing the blood forward. The series of events during which blood is passed through the heart is known as the cardiac cycle.

Contraction of the ventricle forces the blood into the vessels under pressure, known as the blood pressure. As contraction continues in the ventricle, the rising pressure is sufficient to open the valves that had been closed because of attempted reverse blood flow during the previous cycle. At this point the ventricular pressure transmits a high-speed wave, the pulse, through the blood of the arterial system. The volume of blood pumped at each contraction of the ventricle is known as the stroke volume, and the output is usually dependent on the animal's activity.

After leaving the heart, the blood passes through a series of branching vessels of steadily decreasing diameter. The smallest branches, only a few micrometers (there are about 25,000 micrometers in one inch) in diameter, are the capillaries, which have thin walls through which the fluid part of the blood may pass to bathe the tissue cells. The capillaries also pick up metabolic end products and carry them into larger collecting vessels that eventually return the blood to the heart. In vertebrates there are structural differences between the muscularly walled arteries, which carry the blood under high pressure from the heart, and the thinner walled veins, which return it at much reduced pressure. Although such structural differences are less apparent in invertebrates, the terms artery and vein are used for vessels that carry blood from and to the heart, respectively.

Chambered hearts with valves and relatively thick muscular walls are less commonly found in invertebrates but do occur in some mollusks, especially cephalopods (octopus and squid). Blood from the gills enters one to four auricles (depending on the species) and is passed back to the tissues by contraction of the ventricle. The direction of flow is controlled by valves between the chambers. The filling and emptying of the heart are controlled by regular rhythmical contractions of the muscular wall.

The control of heart rhythm may be either myogenic (originating within the heart muscle itself) or neurogenic (originating in nerve ganglia). The hearts of the invertebrate mollusks, like those of vertebrates, are myogenic. They are sensitive to pressure and fail to give maximum beats unless distended; the beats become stronger and more frequent with increasing blood pressure.

Fig. 8.3. Development of Circulatory Organs

The rudiment of the heart in vertebrates develops from the ventral edges of the mesodermal mantle in the anterior part of the body, immediately.

8.4. Hemichordata

Among the phylum Hemichordata are the enteropneusts (acorn worms), which are worm-shaped inhabitants of shallow seas and have a short, conical proboscis, which gives them their common name. The vascular system of the Enteropneusta is open, with two main contractile vessels and a system of sinus channels. The colorless blood passes forward in the dorsal vessel, which widens at the posterior of the proboscis into a space, the contractile wall of which pumps the blood into the glomerulus, an organ formed from an in tucking of the hind wall of the proboscis cavity. From the glomerulus the blood is collected into two channels that lead backward to the ventral longitudinal vessel. This vessel supplies the body wall and gut with a network of sinuses that eventually drain back into the dorsal vessel.

8.5. Chordata

The phylum Chordata contains all animals that possess, at some time in their life cycles, a stiffening rod (the notochord), as well as other common features. The subphylum Vertebrata is a member of this phylum and will be discussed later (see below the vertebrate circulatory system). All other chordates are called protochordates and are classified into two groups: Tunicata and Cephalochordata.

The blood-vascular system of the tunicates or sea squirts is open the heart consisting of no more than a muscular fold in the pericardium. There is no true heart wall or lining and the whole structure is curved or U-shaped, with one end directed dorsally and the other ventrally. Each end opens into large vessels that lack true walls and are merely sinus channels. The ventral vessel runs along the ventral side of the pharynx and branches to form a lattice around the slits in the pharyngeal wall through which the respiratory water currents pass. Blood circulating through this pharyngeal grid is provided with a large surface area for gaseous exchange. The respiratory water currents are set up by the action of cilia lining the pharyngeal slits and, in some species, by regular muscular contractions of the body wall. Dorsally, the network of pharyngeal blood vessels drains into a longitudinal channel that runs into the abdomen and breaks up into smaller channels supplying the digestive loop of the intestine and the other visceral organs. The blood passes into a dorsal abdominal sinus that leads back to the dorsal side of the heart. The circulatory system of the sea squirt is marked by periodic reversals of blood flow caused by changes in the direction of peristaltic contraction of the heart.

Sea squirt blood has a slightly higher osmotic pressure than seawater and contains a number of different types of amoebocytes, some of which are phagocytic and actively migrate between the blood and the tissues. The blood of some sea squirts also contains green cells, which have a unique vanadium containing pigment of unknown function.

Amphioxus (*Branchiostoma lanceolatum*) is a cephalochordate that possesses many typical vertebrate features but lacks the cranial cavity and vertebral column of the true vertebrate. Its circulatory pattern differs from that of most invertebrates as the blood passes forward in the ventral and backward in the dorsal vessels. A large sac, the sinus venosus is situated below the posterior of the pharynx and collects blood from all parts of the body. The blood passes forward through the sub-pharyngeal ventral aorta, from which branches carry it to small accessory branchial hearts that pump it upward through the gill arches. The oxygenated blood is collected into two dorsal aortas that continue forward into the snout and backward to unite behind the pharynx. The single median vessel thus formed branches to vascular spaces and the intestinal capillaries. Blood from the gut collects in a median subintestinal vein and flows forward to the liver, where it passes through a second capillary bed before being collected in the hepatic vein and passing to the sinus venosus. Paired anterior and posterior cardinal veins collect blood from the muscles and body wall. These veins lead through a pair of common cardinal veins (duct of Cuvier), to the sinus venosus.

There is no single heart in the amphioxus and blood is transported by contractions that arise independently in the sinus venosus, branchial hearts, subintestinal vein and other vessels. The blood is non-pigmented and does not contain cells; oxygen transport is by simple solution in the blood (Bernard Edward Matthews).

All vertebrates have circulatory systems based on a common plan, and so vertebrate systems show much less variety than do those of invertebrates. Although it is impossible to trace the evolution of the circulatory system by using fossils (because blood vessels do not fossilize as do bones and teeth), it is possible to theorize on its evolution by studying different groups of vertebrates and their developing embryos. Many of the variations from the common plan are related to the different requirements of living in water and on land.

8.6. Circulatory System in Fishes

Fishes are cold-blooded aquatic vertebrates and can be found in both saline and fresh water. The circulatory system of fishes is responsible for transporting blood and nutrients throughout the body. It has a closed circulatory system, i.e. blood travels across the body through the network of blood vessels.

Fish heart carry only deoxygenated blood that is why it is called as venosus heart.

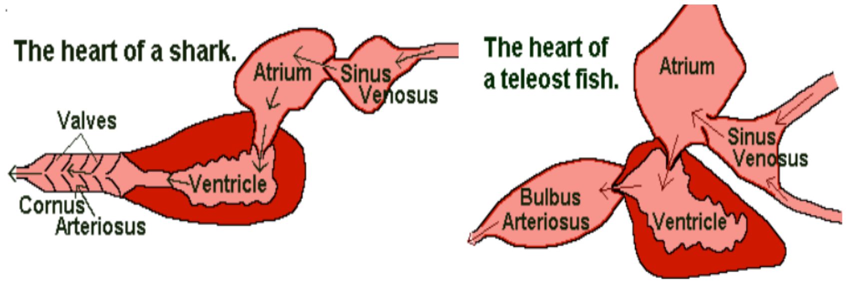

Fig. 8.4. Schematic Diagram of Heart OfFishes

Fish have a closed circulatory system with a heart that pumps blood around the body in a single loop from the heart to the gills, from the gills to the rest of the body, and then back to the heart. The fish's heart consists of four parts: the sinus venosus, atrium, ventricle, and the bulbus arteriosus.

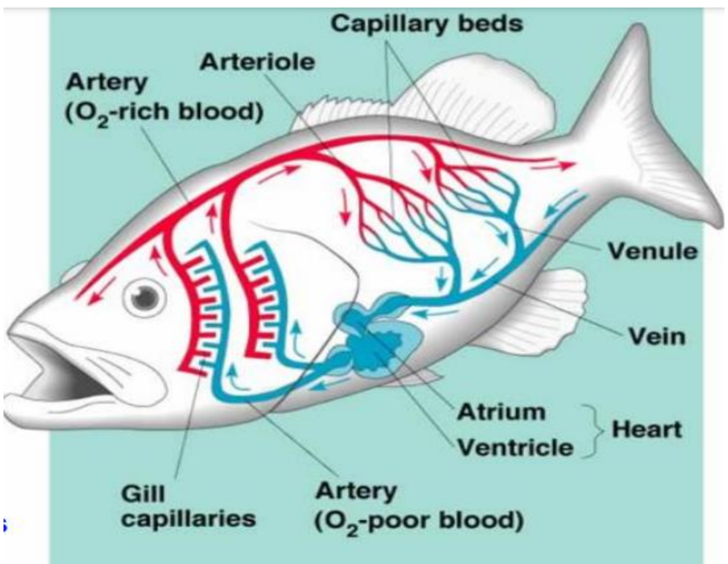

Fig. 8.5. Circulatory System of Fish

The circulatory system of fish is quite simple and consists of Heart, Blood and Blood Vessels.

8.7. Heart

Heart is a simple muscular structure that is located below the pharynx and immediately behind the gills. It is enclosed by the pericardial membrane or pericardium. In most of the fishes, the heart consists of an atrium, a ventricle, a sac-like thin walled structure known as sinus venosus and a tube, known as bulbus arteriosus. In spite of containing four parts, the heart of a fish is considered two-chambered.

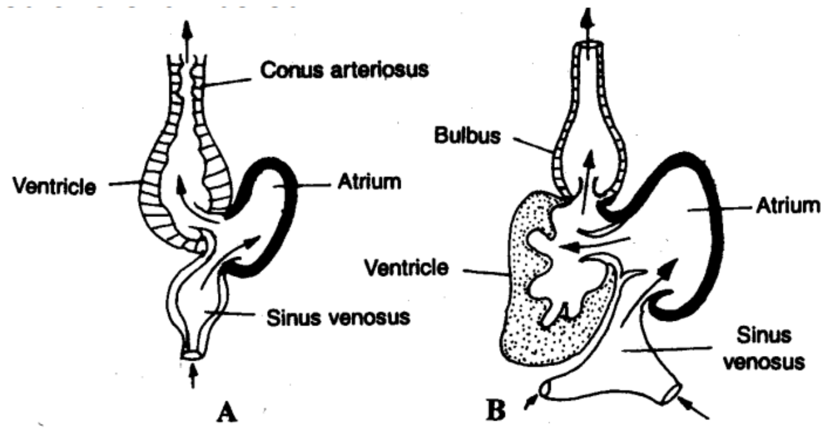

Fig. 8.6. Heart of a) Chodrichthyes and b) Teleost

Let us sum up

Under this unit, we studied about the circulatory system. Under this unit we focused on the different types of circulatory systems such as closed and open type of circulatory system, body fluid, chambers of heart, heart of hemichordates, chordates, circulatory system in fish and heart of fish.

Check your Progress

1) Molecules are conveyed between cells and throughout the body of multicellular organisms in a circulatory fluid called __________.
2) __________ essentially consists of blood plasma that has left the blood vessels and has passed through the tissues.
3) The fishes has __________ chambered heart, they are __________ and __________.
4) The series of events during which the blood is passed through the heart is known as __________.
5) The protochordates are classified into two grops namely, __________ and __________.

Glossaries

1. Hemocoel : The primary body cavity of most invertebrates, containing circulatory fluid

2. Myogenic : Originating in muscle tissue (rather than from nerve impulses).

Suggested readings

1) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.
2) **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.

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General plan of circulation in vertebrates https://www.britannica.com/science/circulatory-system/The-vertebrate-circulatory-system

Answers to check your progress

1) Blood
2) Lymph
3) 2, Atrium, ventricle
4) Cardiac cycle
5) Tunicate and cephalochordate

Unit 9

Blood and Components of Blood

OBJECTIVES

After completing this unit, the students will be able to

- Explain blood
- Explain the components and functions of blood
- List out the disorders caused by blood
- Explain blood grouping.

OVERVIEW

In this unit, we will study about the blood and components of blood. Under this unit, we will focus on the blood components like plasma, red blood cells, white blood cells, platelets and we will also study about the functions of blood, blood groups and disorders caused due to blood deficiency.

9.1. INTRODUCTION

Vertebrate blood is bright red when its hemoglobin is oxygenated. Some animals, such as crustaceans and mollusks (invertebrates), use hemocyanin to carry oxygen, instead of hemoglobin. The study of blood is known as Heamatology. Heamatologists work to identify and prevent blood and bone marrow diseases. They also study and treat the immune system, blood clotting, and blood vessels. A person who draws blood for diagnostic tests or to remove blood for treatment purposes is known as Phlebotomist.

9.2. BLOOD

Blood is a red color substance which has a combination of plasma and cells that circulate through the body. It supplies essential substances, such as sugars, oxygen and hormones, to cells and organs and removes waste from cells.

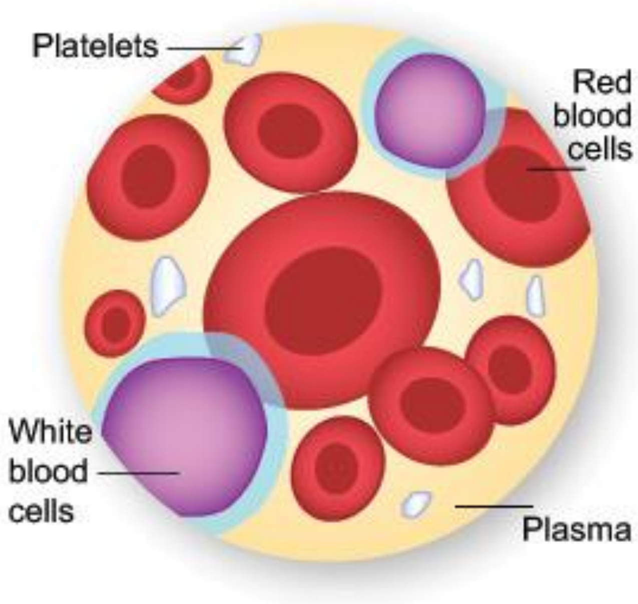


Fig. 9.1. Blood and its Components

Health conditions that affect the blood can be life threatening, but effective treatment is often available. Iron deficiency anemia (IDA) continues to be major public health problem in India. It is estimated that about 20% of maternal deaths are directly related to anemia and another 50% of maternal deaths are associated with it (*TanuAnand et al*).The main components of blood are:

- Plasma
- Red Blood Cells
- White Blood Cells
- Platelets

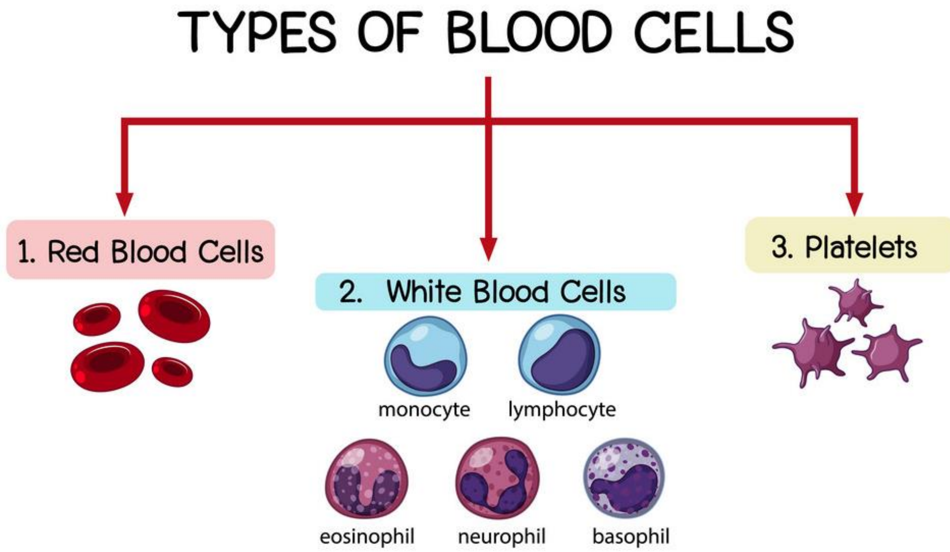


Fig. 9.2. Different Types of Blood Cells

9.2.1. Plasma

Plasma accounts for around 55% of blood fluid in humans. Plasma is 92% water, and the contents of the remaining 8% include:

- Glucose
- Hormones
- Proteins
- Mineral salts
- Fats
- Vitamins

The remaining 45% of blood mainly consists of red and white blood cells and platelets. Each of these has a vital role to play in keeping the blood functioning effectively.

9.2.2. Red Blood Cells (RBC) or Erythrocytes

Red blood cells have a slightly indented, flattened disk shape. They transport oxygen to and from the lungs. Hemoglobin is a protein that contains iron and carries oxygen to its destination. The life span of a red blood cell is 4 months, and the body replaces them regularly. The human body produces around 2 million trusted Source blood cells every second.

- The expected number of red blood cells in a single drop (microliter) of blood is 4.5–6.2 million in males and 4.0–5.2 million in females.

9.2.3. White Blood Cells (WBC) or Leukocytes

- White blood cells make up less than 1% of blood content, forming vital defenses against disease and infection. The number of white blood cells in a microliter of blood usually ranges from 3,700–10,500. Higher or lower levels of white blood cells can indicate disease. White blood cells have morphologically distinct shapes such as monocytes, lymphocytes, neutrophils, eosinophils, and basophils. The first two simply called as agranulocytes and the subsequent cells called granulocytes.

9.2.4. Platelets or Thrombocytes

- Platelets interact with clotting proteins to prevent or stop bleeding. There should be between 1,50,000 and 400,000 platelets per microliter of blood.
- Bone marrow produces red blood cells, white blood cells and platelets, and from there they enter the bloodstream. Plasma is mostly water that is absorbed from ingested food and fluid by the intestines. The heart pumps them around the body as blood by way of the blood vessels.

9.3. Functions of Blood

Blood has various functions that are central to survival. They include:

- Supplying oxygen to cells and tissues
- Providing essential nutrients to cells, such as amino acids, fatty acids, and glucose

- Removing waste materials, such as carbon dioxide, urea, and lactic acid
- Protecting the body from diseases, infections, and foreign bodies through the action of white blood cells
- Regulating body temperature

The platelets in blood enable the clotting, or coagulation, of blood. When bleeding occurs, the platelets group together to create a clot. The clot forms a scab, which stops the bleeding and helps protect the wound from infection.

9.4. Blood Groups

A person's blood type is determined by the antigens on the red blood cells. Antigens are protein molecules on the surface of these cells.

Antibodies are proteins in plasma that alert the immune system to the presence of potentially harmful foreign substances. The immune system protects the body from the threat of disease or infection.

Knowing a person's blood type is essential if they are receiving an organ donation or blood transfusion. Antibodies will attack new blood cells if the blood is the wrong type, leading to life threatening complications. For example, anti-A antibodies will attack cells that have A antigens.

Red blood cells sometimes contain another antigen called RhD. Doctors also note this as part of the blood group. A positive blood group means that RhD is present.

Humans can have one of four main blood groups. Each of these groups can be RhD-positive or -negative, forming eight main categories.

- **Group A Positive:** A antigens are present on the surfaces of blood cells. Anti-B antibodies are present in the plasma.
- **Group B Positive:** B antigens are present on the surfaces of blood cells. Anti-A antibodies are present in the plasma.
- **Group AB Positive:** A and B antigens are present on the surfaces of blood cells. There are no antibodies in the plasma.
- **Group O Positive:** There are no antigens on the surfaces of blood cells. Both anti-B and anti-A antibodies are present in the plasma.

People with group O blood can donate to any blood type, and people with group AB+ blood can usually receive blood from any group.

People can talk with their medical practioner to find out their blood type or find out by donating blood.

Blood groups are important during pregnancy. If a pregnant person has RhD-negative blood, for example, but the fetus inherits RhD-positive blood, treatment will be necessary to prevent a condition known as hemolytic disease of the newborn.

9.5. Disorders

Disorders and diseases of the blood can impair the many functions that blood performs.

Some common blood disorders are:

- **Anemia:** This happens when low red blood cell or hemoglobin levels trusted Source mean the cells do not transport oxygen effectively, leading to fatigue, pale skin and other symptoms.
- **Blood clotting:** Clotting helps wounds and injuries heal, but blood clots that form inside a blood vessel can create a blockage, which can be life threatening. If clots become dislodged and move through the heart to the lungs, a pulmonary embolism can form.
- **Blood cancers:** Cancers such as leukemia, myeloma, and lymphoma occur when blood cells start to divide uncontrollably without dying off at the end of their life cycle.
- **Hemophilia:** If a person has low levels of clotting factors in the blood, they can bruise or bleed trusted Source very easily. They may bleed for too long after a minor injury or surgery or during menstruation. It affects around 18,000 people in the U.S.
- **Sickle cell disease:** An inherited trait causes red blood cells to take on a crescent shape. It affects over 100,000 people in the U.S., mostly Black Americans. It can severely impact how blood functions and can be life threatening.
- **Thalassemia:** This is also a type of inherited anemia in which the body produces an unusual form of hemoglobin. It affected around 1,000 people in the U.S. in 2008 and is most common in people from around the Mediterranean and parts of Asia (*Tanu Anand, et al.* 2014).

Let us sum up

Under this unit, we studied about blood and components of blood. We also focused about the blood components like plasma, red blood cells, white blood cells, platelets and we will also study about the functions of blood, blood groups and disorders caused due to blood deficiency.

Check your Progress

1) The blood fluid in human consists of ___________ of plasma and ___________ of WBC, RBC and platelets.
2) ___________is caused due to low RBC that affects the transport of oxygen.
3) ___________ is a type of inherited anemia in which the body produces an unusual form of hemoglobin.
4) Plasma is mostly water that is absorbed from ingested food and fluid by the ___________.
5) ___________ provides essential nutrients to cells and remove waste and regulates body temperature.

Glossaries

1. Peritoneum : It is the tissue that lines your abdominal wall and covers most of the organs in your abdomen. A liquid, peritoneal fluid, lubricates the surface of this tissue.

2. Coelomic : The main body cavity in most animals and is positioned inside the body to surround and contain the digestive tract and other organs

Suggested readings

1) **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.
2) **ROMER, A.S** (1974), The Vertebrate Body, W.B. Saunders, London.

Weblink

Blood types in vertebrates https://en.wikipedia.org/wiki/Blood_type_(non-human)

Blood composition vertebrates
https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Map%3A_Raven_Biology_12th_Edition/48%3A_The_Circulatory_System/48.02%3A_Components_of_Vertebrate_Blood

Answers to check your progress

1) 55 % and 45%
2) Anemia
3) Thalassemia
4) Intestine
5) Blood

Unit 10

Evolution of Heart

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the circulation pattern
- Illustrate the basic structure of vertebrate heart
- Describe heart of fish, amphibia, birds and mammals.

OVERVIEW

In this unit, we will study about the evolution of heart. Under this unit, we will focus on the circulation pattern of heart, basic structure of vertebrate heart such as heart of fishes, heart of amphibians, heart of reptiles, heart of birds and mammals.

10.1. INTRODUCTION

In vertebrate animals, the heart is a hollow muscular organ that functions to pump the blood through the circulatory system. It can contain up to four chambers (as is the case in mammals and birds, including humans) and it works by rhythmically contracting and dilating. The heart typically lies ventrally, near the anterior end of the trunk; it is located ventral and medial to the gills in fish and at the base of the neck or in the chest region of tetrapods. In humans, it is located behind the breastbone and ribs between the third and fifth costal cartilages. Its anterior portion or base is directed to the right and dorsally and is the area where the great vessels enter and leave the heart. The lower muscular portion ends in a blunt apex that lies behind the fifth costal cartilage on the left.

10.2. Circulation Patterns

Blood travels in one of two general patterns:

(1) A single circulation and

(2) Double circulation.

Most fishes have a single circulation (Figure 10.1 a) pattern in which blood passes only once through the heart during each complete circuit. With this design, blood moves from the heart to the gills to the systemic tissues and back to the heart. The heart which pumps blood via ventral aorta directly to the gills (then to body) is called branchial heart.

Amniotes have a double circulation (Figure 10.1 b) pattern in which blood passes through the heart twice during each circuit, traveling from the heart to the lungs, back to the heart (pulmonary circuit), out to the systemic tissues, and back to the heart (systemic circuit) a second time.

Functional intermediates with characteristic so both conditions. The intermediates include lung fishes, amphibians and reptiles.

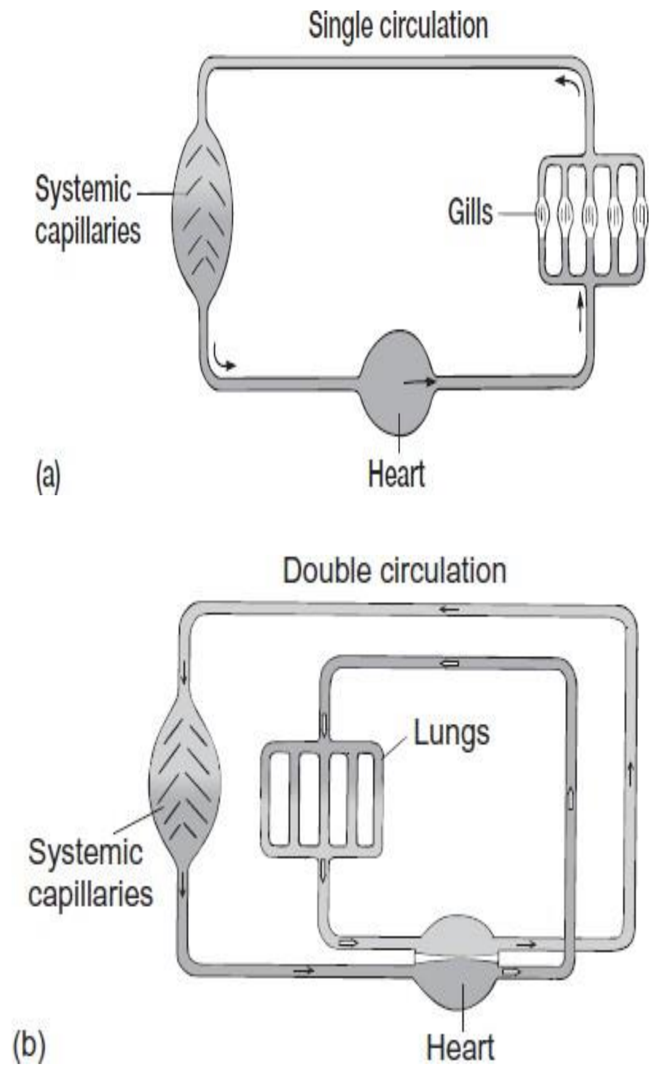


Fig. 10.1. Circulation Pattern

10.3. Basic Structure of Vertebrate Heart

Phylogenetically, the heart probably began as a contractile vessel, much like those of amphioxus. The embryonic fish heart consists of four chambers in series, so that blood flows in sequence from the sinus venosus, to the atrium, to the ventricle and finally to the fourth and most anterior heart chamber, the bulbus cordis, before entering the ventral aorta. The bulbus cordis is termed in the adult the conus arteriosus if its contractile walls possess cardiac muscle (and conal valves internally; E.g. chondrichthyans, holosteans, and dipnoans) or bulbus arteriosus if its elastic walls lack cardiac muscle (teleost). The adult bulbus arteriosus, in some fishes, mayalso incorporate part of the adjoining ventral aorta as well.

Besides conal valves, the endocardium develops the sinoatrial (SA) valves formed between the sinus venosus and the atrium, and the atrioventricular (AV) valves formed between the atrium and ventricle. Valves prevent retro grade blood flow.

The heart lies within the pericardial cavity lined by a thin epithelial membrane, the pericardium. In many fishes, the pericardial cavity lies within bone or cartilage.

In tetrapods, the bulbus cordis divides into the bases of the aortae. Term truncusarteriosus of the older literature, should apply only to the ventral aorta or its derivatives but not to any part of the heart proper. In birds and mammal both the atrium and the ventricle become divided into left and right compartments to produce four anatomically separate chambers.

In *Branchiostoma*, instead of a true heart, a part of ventral aorta below pharynx becomes muscular and contractile; considered as a single chambered heart by some.

In fish, internally each chamber may contain various numbers of conal valves. In some fishes, most notably in teleosts, the bulbus arteriosus is thin walled with smooth muscle and elastic fibers, but it lacks both cardiac muscle and conal valves.

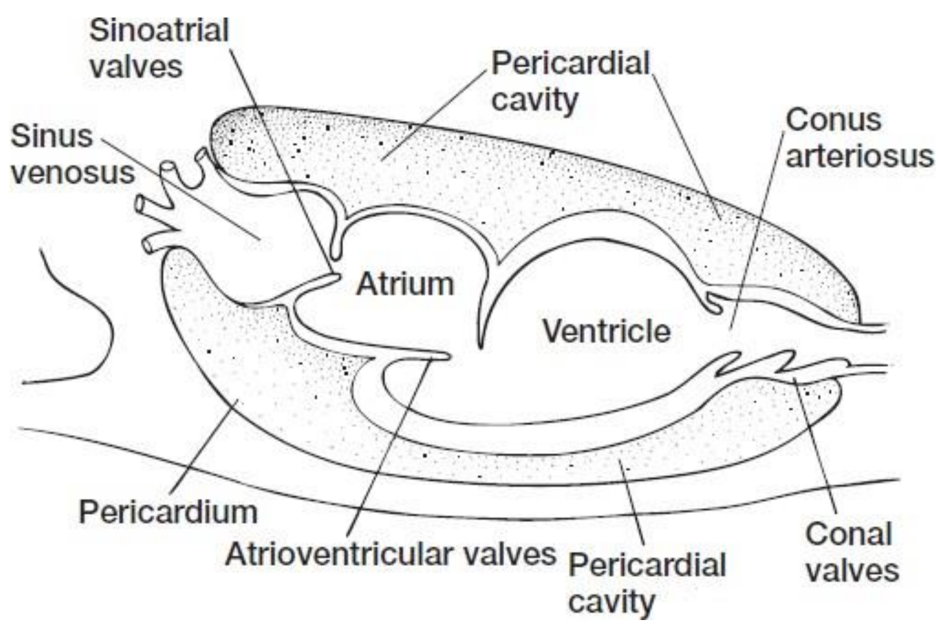


Fig. 10.2. Basic heart structure of fish

Basic Heart Structure: The four chambers of the fish heart are enclosed within the pericardial cavity. One-way valves between each chamber prevent reverse flow of blood as successive chambers contract.

In many fishes and primitive tetrapods, there is a direct respiratory gas exchange between the myocardium and blood passing through its lumen. In others, the coronary vessels perfuse the heart wall (usually only the outer part of the myocardium), especially in elasmobranchs, crocodiles, birds and mammals. In fishes, the coronary arteries are derived from the efferent arches or collecting loops of the gills, which carry oxygenated blood. The coronary veins enter the sinus venosus.

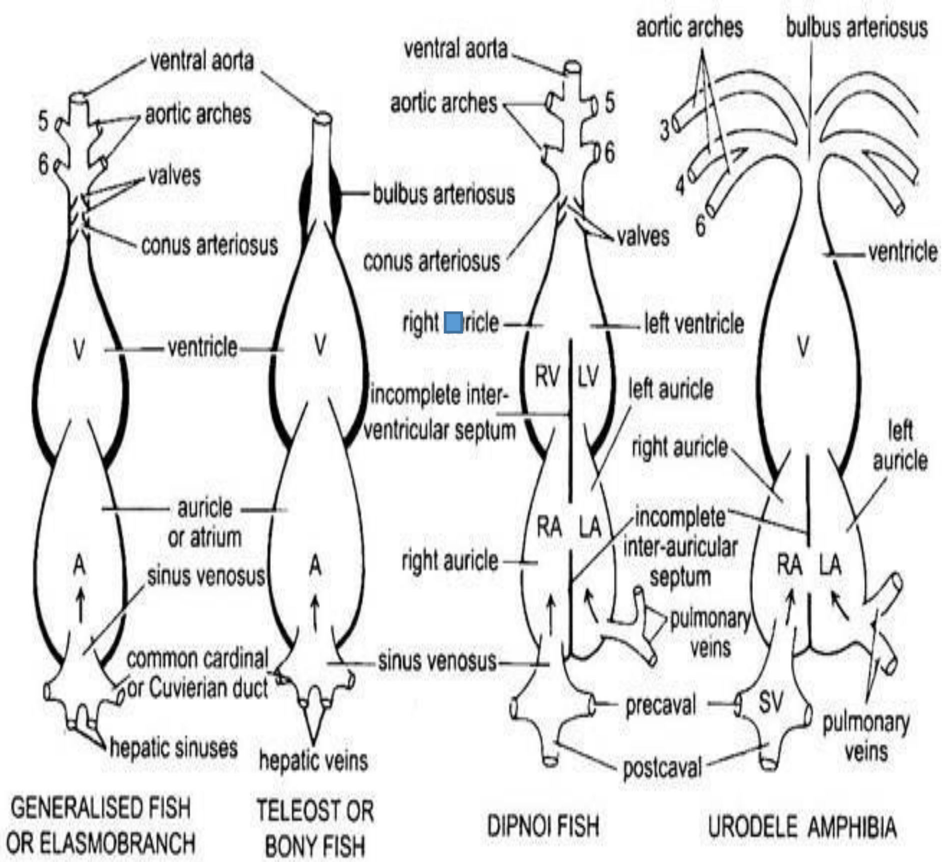


Fig. 10.3. Evolution of heart in vertebrates. A, atriumorauricle; LA, left auricle; RA, right atrium; V, ventricle; LV, left ventricle; RV, right ventricle; SV, sinus venosus; 3 to 6 are aortic arches. Shaded chambers contain mainly oxygenated blood. Note: In dipnoan, draw AV plug and IV septum separately.

Progressive modification of heart from primitive to higher chordates (vertebrates) occurs on the following lines:

Cardiac tube forms chambers due to constrictions.

Each chamber tends to divide into two separate chambers due to formation of partitions.

Subsequent folding of the tubular heart twists the heart into different configurations, but the internal sequence of blood flow remains the same.

Heart gradually shifts from just behind head (fishes, amphibians) near gills into thoracic cavity (amniotes) with elongation of neck and development of lungs.

- In Branchiostoma, a contractile muscular thickening of ventral aorta below pharynx is often treated as a single-chambered heart.
- Cyclostomes and fishes (except dipnoans) have 2-chambered, single circuit, venosus and branchial hearts.
- Hagfish has 3- “chambered” heart; lamprey heart also has the 4th chamber – bulbus arteriosus having semilunar valves.
- Fish heart has typical 4 chambers. Elasmobranch heart is S- shaped, auricles lying dorsal to ventricles. Teleost has bulbus arteriosus having a single pair of bulbular valves dipnoan, amphibians and reptiles (except crocodile) having 3 chambered transitional hearts. In crocodile 4 chambered heart, birds and mammals have 4 chambered, double circuit pulmonary heart.

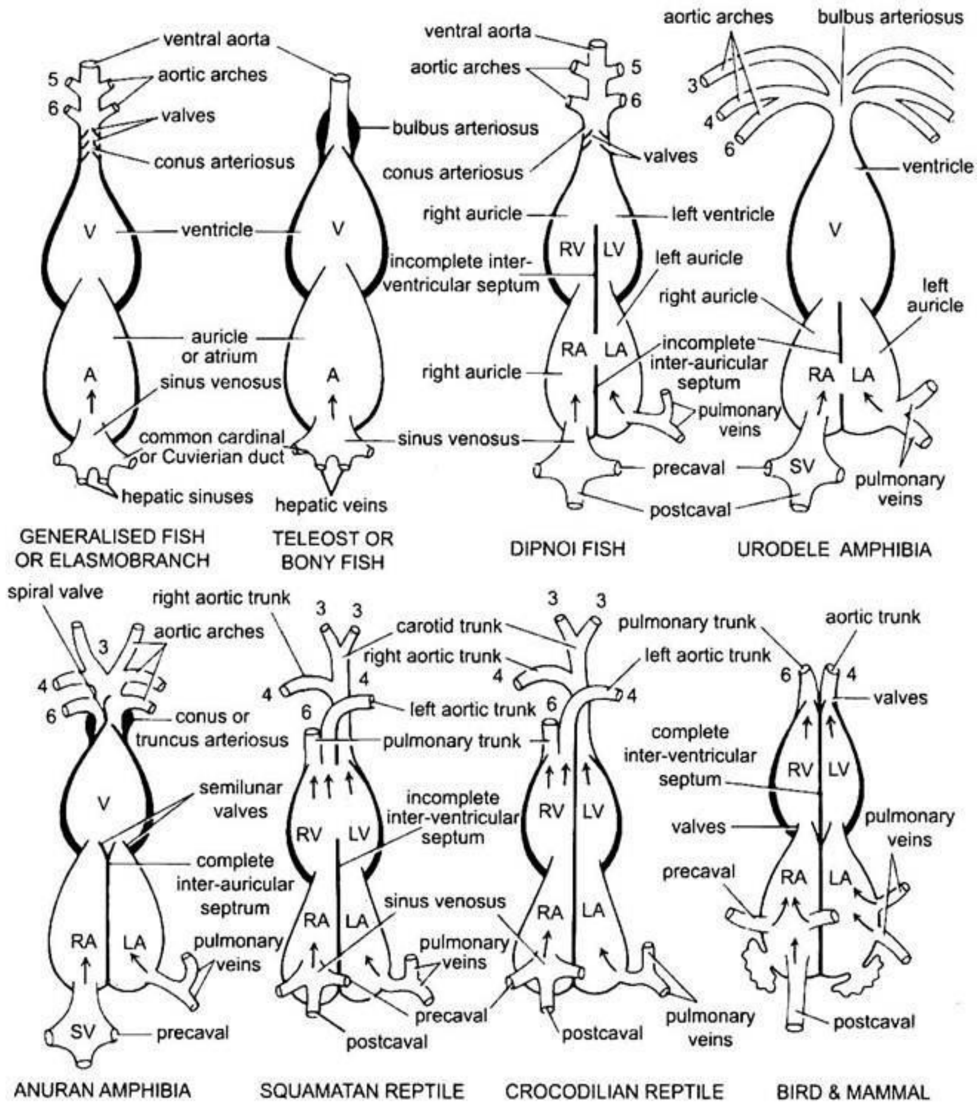


Fig. 10.4. Evolution of heart in different vertebrates. A, atriumorauricle; LA, left auricle; RA, right atrium; V, ventricle; LV, left ventricle; RV, right ventricle; SV, sinus venosus; 3 to 6 are aortic arches. Shaded chambers contain mainly oxygenated blood. Note: In dipnoan, draw AV plug and IV septum separately.

In Branchiostoma, a contractile muscular thickening of ventral aorta below pharynx is often treated as a single-chambered heart.

Cyclostomes (2-chambered, single circuit, venosus and branchial hearts**)**

Hagfishes

The hag fish heart has three chambers in series: the sinus venosus, the atrium and the ventricle. A slight microscopic thickening of the base of the ventral aorta is treated by some as a fourth compartment, the bulbus arteriosus. No major nerves innervate the hagfish heart to stimulate contraction. Instead, filling of the sinus venosus by returning blood elicits the Frank-Starling reflex. Accessory 'hearts' (contractile but lack cardiac muscle) like cardinal hearts, caudal hearts, portal heart (has cardiac muscles) are blood pumps in different parts of the circulation.

The lamprey heart (branchial heart) has four compartments - sinus venosus, atrium and ventricle and bulbus arteriosus. The luminal walls of the bulbus arteriosus are thrown into leaflets, collectively forming the semilunar valves. Unlike hag fishes, the heart is innervated and further, the ventricle empties into the bulbus arteriosus.

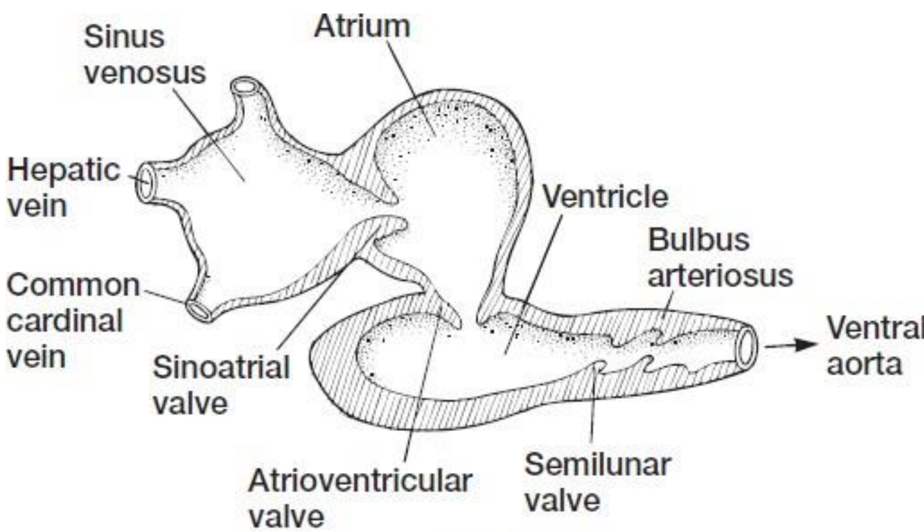


Fig. 10.6. The Lamprey Heart

10.3.1. Heart of Fishes

(*2*-chambered, single circuit, venosus and branchial hearts**)**

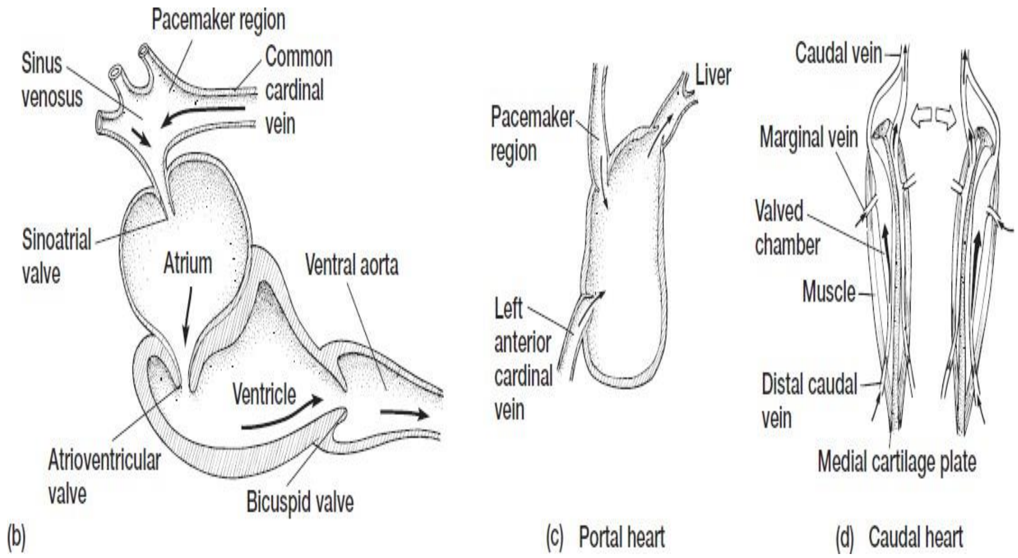


Fig.10.7. Structure of 2 chambered heart fish

The hearts of chondrichthys and bony fishes consist of four basic chambers- sinus venosus, atrium, ventricle (with thick muscular wall is the actual pumping portion of the heart), and conus arteriosus (can contract and act as an auxiliary pump) (or bulbus arteriosus in teleost). One-way valves are situated between compartments.

Fish hearts called as "two-chambered" (not a definitive term) recognizes only atria and ventricles as chambers. The S-shaped arrangement of chambers in the fish heart places the thin walled sinus venosus and atrium dorsal to the ventricle, so that atrial contraction assists ventricular filling.

In teleosts, the conus arteriosus may regress, leaving only remnants of a myocardial conus or be replaced entirely by an elastic, non-contractile bulbus arteriosus (as in *Necturus* and some other perenni branchiate amphibians). A single pair of **bulbar valves** at the juncture of the bulbus arteriosus and the ventricle prevents retro grade flow. When receiving blood following ventricular contraction, the bulbus arteriosus stretches and then gently undergoes elastic recoil to maintain blood flow into the ventral aorta. The result is a **depulsation,** ordampening of the large oscillations in blood flow and pressure introduced by ventricular contractions. This has been proposed as a means of protecting the delicate gill capillaries up next in the circulation from exposure to sudden spurts of blood a thigh pressure that would otherwise occur.

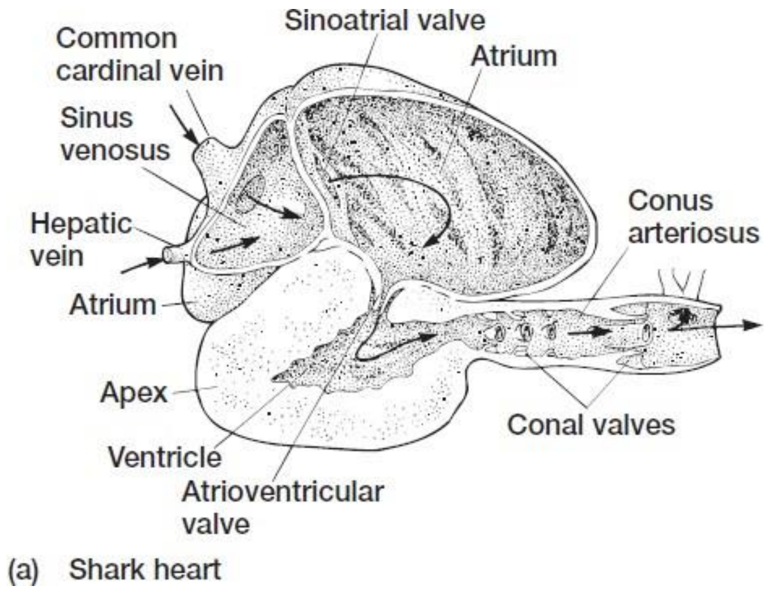


Fig. 10.8. a: Shark Heart

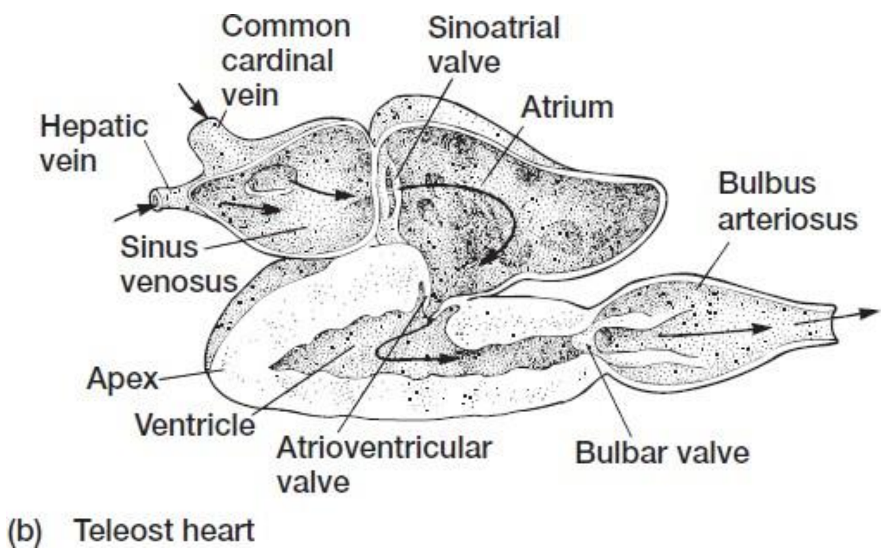


Fig.10.8. b: Teleost Heart

Dipnoans (Lungfishes): The single atrium is partially divided internally by an incomplete inter atrial septum (IA septum, pulmonalis fold; with foramen ovale) that defines a larger right (receiving deoxygenated blood from sinus venosus) and smaller left (receiving pulmonary vein) atrial chamber.

Pulmonary veins empty directly into the left atrial chamber (*Lepidosiren* and *Protopterus* and tetrapods) or into the sinus venosus (only *Neoceratodus*). In place of AV valves is the atrioventricular plug, a raised cushion in the wall of the ventricle, to prevent retrograde flow. The ventricle is also divided partially by an interventricular septum (also in *Siren*, a urodele). Alignment of the IV septum, AV plug and IA septum establishes a left channel (that tends to receive oxygenated blood returning from the lungs), and a right channel (that tends to carry deoxygenated systemic blood from the sinus venosus). The spiral valve (also inanurans) internally divide the conus into two spiraling channels. Thus, despite the anatomically incomplete internal septation, the deoxygenated blood entering from the sinus venosus does not tend to mix with the oxygenated blood returning from the lungs.

The left channel supplies the oxygenated blood, through aortic arches III and IV (which lack gills) to systemic tissues directly. The right channel supplies the deoxygenated blood through the V and VI arches to the gills and/or lungs. During aquatic respiration, gills oxygenate the blood and pass it on directly to the body, and only slightly to the lungs. When DO declines and lungfish rely on air, most of the deoxygenated blood is passed on to the lungs for oxygenation.

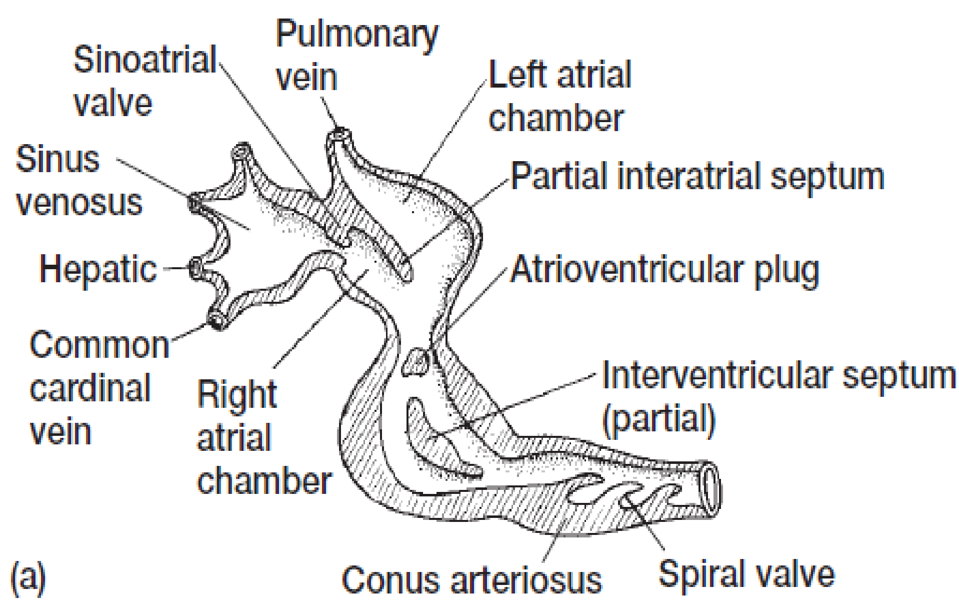


Fig. 10.9. Heart with Spiral Valve

Air-breathing teleosts differ in that oxygenated blood returns to the systemic veins, resulting in mixing prior to arrival at the heart. In these taxa the aerial respiration is an accessory (secondary to the gill respiration) mechanism. But the **extant dipnoans and tetrapods are obligate air breathers**.

In Dipnoi, III and IV aortic arches lack gills and pulmonary artery arises from the efferent side of the VI arch. The oxygenated blood returning from the lung, via left side of the heart is shunted through aortic arches III and IV, which lack gills and flows to systemic tissues directly. Venosus blood returning via sinus venosus and right side of the heart is shunted through the posterior arches V and VI, and then diverted to the gills and/or lungs. During aquatic respiration, gills oxygenate the blood [and pass it on directly (i.e. without returning it back to heart again) to the body] and only few bloods is passed on to the lungs. When DO declines and lungfish rely on air, most of the deoxygenated blood is passed on to the lungs for oxygenation, then it return to left auricle and then supplied to the body via III and IV arches.

The spiral valve (also in anurans) within the conus arteriosus aids in separating oxygenated and deoxygenated blood. Apparently derived from conal valves, the spiral valve consists of two (a pair; in anurans a single flap) endocardial, longitudinal, typhlosole like folds whose opposing free edges touch but do not fuse. The conus makes a couple of sharp bends and rotates about 270°, thus turning these folds into a spiral within its lumen. Although unfused, these twisting folds internally divide the conus into two spiraling channels. Because the conus is attached directly to the ventricle, oxygenated blood entering the left channel and deoxygenate blood entering the right channel tend to flow through different spiraling channels within the conus and remain separate. The cardiac oxygenated and deoxygenated streams of blood enter different sets of aortic arches. The oxygenated blood returning from the lung, via left side of the heart, is shunted through aortic arches III and IV, which lack gills, and flows to systemic tissues directly. Venosus blood returning via sinus venosus and right side of the heart is shunted through the posterior arches V and VI, and then diverted to the lung. Oxygenated blood traveling through the left side of the heart is channeled along the opposite spiral of the conus to enter the anterior set (III and IV) of aortic arches. When oxygen levels in the water decline, leaving little to diffuse across gills into the blood, the lungfish comes to the surface to gulp fresh air into its lungs. Under these deteriorating conditions, in Protopterus, deoxygenated blood returning from systemic tissues tends to be diverted to the lungs (not to the gills), and about 95% of the oxygenated blood from the lungs tends to be directed via anterior aortic arches to the systemic tissues (not through the gills). The fraction of blood that passes from the lungs to the anterior arches steadily declines to about 65% just before the next breath, following which the fraction returns again to 95%.

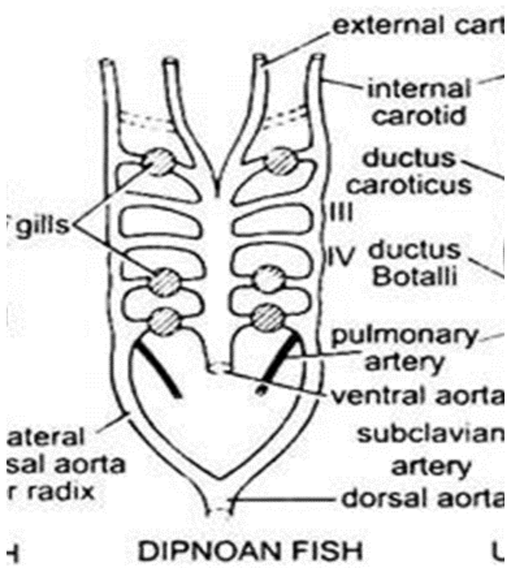


Fig. 10.10. Aortic arches of Dipnoi

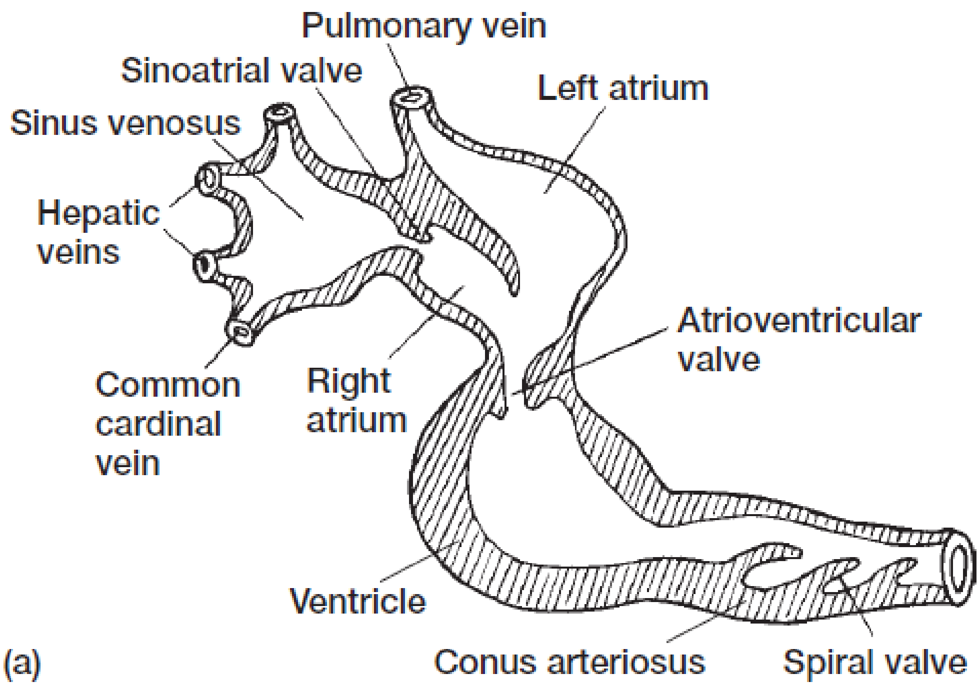
10.3.2. Heart of Amphibians (3-chambered transitional hearts)

Amphibians rely on cutaneous gas exchange (plethodontid salamanders lack lungs entirely), on gills (many larval forms), on lungs (most toads and frogs) or on all three modes (most amphibians). Because the sources of oxygenated and deoxygenated blood vary, heart structure varies as well.

Urodela: In lungless salamanders or those with reduced lung function, the interatrial septum and spiral valve may be much reduced or absent entirely (so atrium remains totally undivided). In the lungless plethodontids, left atrium is absent. Where gills predominate over lungs as respiratory organs (e.g., Necturus), the interatrial septum is reduced or perforated. Siren (a salamander) have a partial interventricular septum. The two different streams of blood returning from the systemic (deoxygenated) and pulmonary (oxygenated) circuits are kept mostly separate as they pass through the heart. When a frog dives, a sphincter at the base of the pulmonary artery constricts, resulting in reduced blood flow to the lung and increased flow to the skin. Thus, while a frog is submerged, loss of pulmonary respiration is somewhat offset by increased cutaneous respiration.

Anura: Generally, in amphibians with functional lungs, the heart includes a sinus venosus, right and left atria divided by an anatomically complete interatrial septum, a trabeculate ventricle lacking any internal subdivision (but trabeculae are thought to separate streams of blood that differ in oxygen tension), and a conusarteriosus with a spiral valve (establishing separate channels for systemic and pulmocutaneous arches). Except for Siren (a salamander), which have a partial interventricular septum, amphibians are unique among air breathing vertebrates in lacking any internal division within the ventricle.

The two different streams of blood returning from the systemic (deoxygenated) and pulmonary (oxygenated) circuits are kept mostly separate as they pass through the heart. When a frog dives, a sphincter at the base of the pulmonary artery constricts, resulting in reduced blood flow to the lung and increased flow to the skin. Thus, while a frog is submerged, loss of pulmonary respiration is somewhat offset by increased cutaneous respiration.



(a)

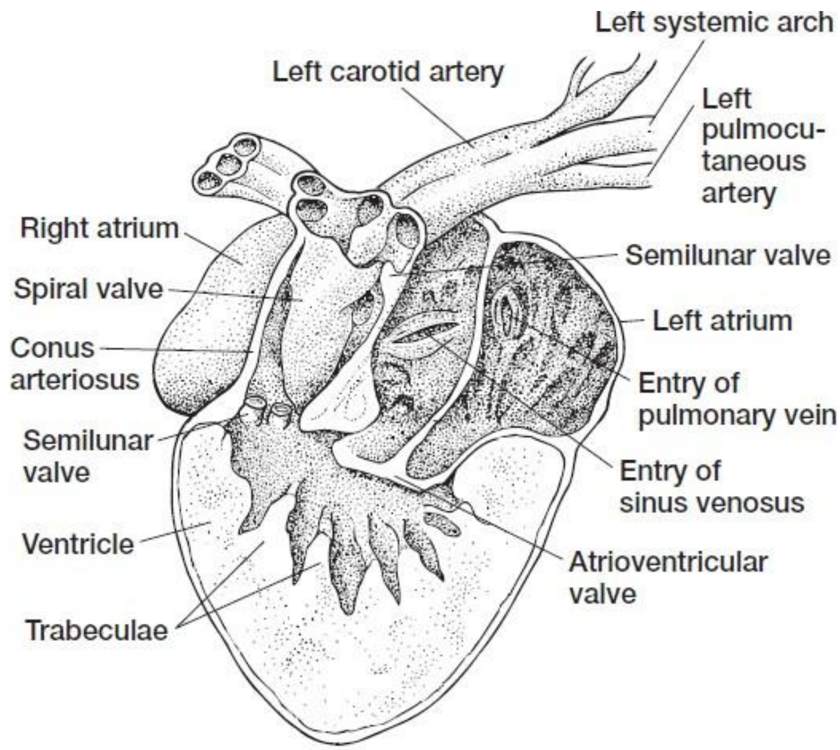


Fig. 10.11. Amphibian hearts. (a) Diagram of typical amphibian heart. The atrium is divided into left and right chambers but the ventricle lacks an internal septum. Conus with spiral valves. (b) Bullfrog (Ranacatesbeiana) heart. Although lacking internal septa, the wall of the ventricle folds into numerous trabeculae that aid in separating bloodstreams.

Amniota: In amniotes, the right and left atria are completely separated by a complete interatrial septum (also in anurans). However they are confluent during embryonic development via an interatrial foramen or foramen ovale, which closes near the time of hatching or at birth. In adult mammals, the site of the obliterated foramen is marked by a depression, the fossa ovalis, in the medial wall of the right atrium. Embryonic conus arteriosus (or bulbuscordis) becomes divided in the adult to form the bases (trunks) of three (or two) aorta - the pulmonary trunk and the right and left systemic trunks.

10.3.3. Reptiles

Two basic reptilian heart patterns are recognized. (1) 3-chambered transitional hearts: chelonians (turtles) and squamates (lizards and snakes), (2) 4-chambered hearts: crocodilians

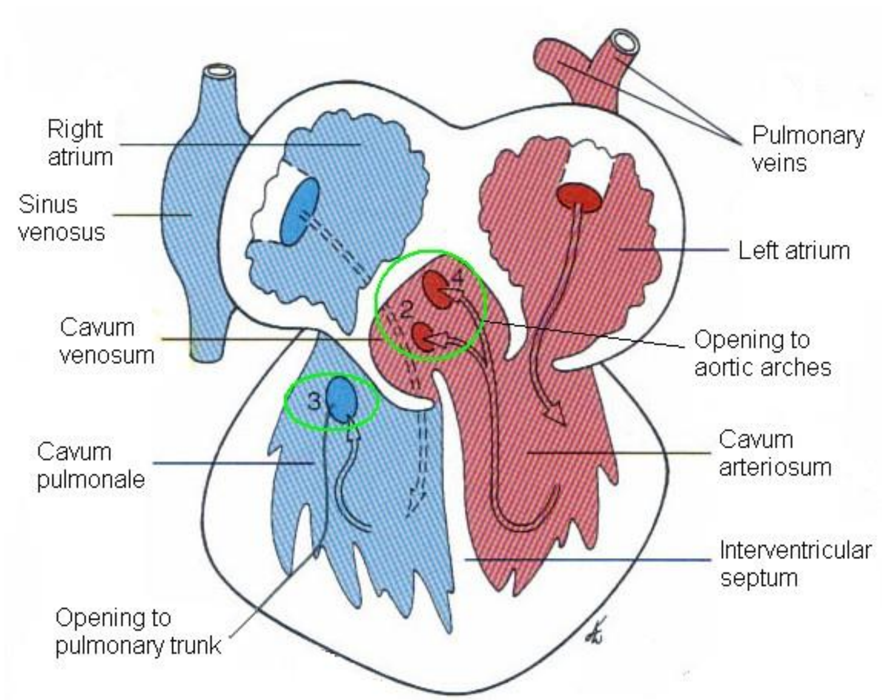


Fig. 10.12. Chelonian heart chambers and circulation path.

Chelonian/Squamate Hearts: Sinus venosus reduced; atrium completely divided into right and left atria by a complete interatricular septum. The embryonic conus arteriosus (or bulbuscordis) becomes divided in the adult to form the bases (trunks) of three aorta: the pulmonary trunk (from right side of ventricle), the right and left systemic trunks. In snakes, a valved inter aortic foramen connects the bases of adjacent aortae. But the shunting of blood made possible by this foramen has not been explored. Ventricle single (IV septum incomplete) but has internally three interconnected compartments: the **cavumvenosum** and the **cavumpulmonale** separated by a muscular ridge, and the cavumarteriosum connected to the cavumvenosum via an interventricular canal. Normally the cavumarteriosum receives oxygenated blood from the left atrium and passes it on (through the interventricular canal) to the aortic arches (then to the body). Much of the blood filling the cavumvenosum is deoxygenated blood from the right atrium. Blood from the cavumvenosum moving across the muscular ridge fills the cavumpulmonale (to be passed on to lungs). When the turtle dives beneath the water (lung is of little use), heart responds with a right-to-left or cardiac shunt. Here, returning blood to the right side of the heart (destined to go to lungs) goes directly (through the interventricular canal) to the left side and departs for systemic tissues, thereby bypassing the lungs.

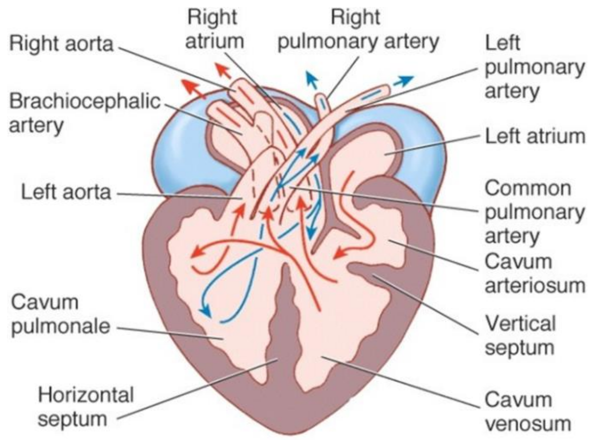


Fig. 10.13. Crocodilian Hearts (4-chambered)

The pulmonary vein enters the left atrium in adults. In embryo, the pulmonary veins one from each lung unite as a single stem, the pulmonary vein and that enters the sinus venosus. As embryonic development proceeds, this part of the sinus venosus together with the associated pulmonary vein become incorporated into the developing left atrium. The ventricle is divided by an anatomically complete interventricular septum into distinct left and right chambers. The pulmonary trunk and left aortic arch open off the thick-walled right ventricle. The right aortic arch opens off the left ventricle. A narrow channel called the foramen of Panizza connects the left and right aortic arches shortly after they depart from the ventricle. At the moment of systole, pressure is greatest in the left ventricle. The oxygenated blood it holds enters the right aorta, and also into the left aorta via the foramen of Panizza. High pressure in the left aorta keeps the lunar valves at its base closed, leaving only the pulmonary route of exit for blood in the right ventricle. As a result, both aortic arches carry oxygenated blood to systemic tissues, and the pulmonary artery carries deoxygenated blood to the lungs.

When a crocodile dives, this pattern of cardiac blood flow changes because of a cardiac shunt. Resistance to pulmonary flow increases due to vasoconstriction of the vascular supply to the lungs and partial constriction of a sphincter at the base of the pulmonary artery. Blood in the right ventricle now tends to exit through the left aortic arch rather than through the pulmonary circuit, which presents high resistance to blood flow. Diversion of blood in the right ventricle to the systemic circulation represents a right-to-left cardiac shunt. Blood in the right ventricle, which would flow to the lungs in an air breathing crocodile, instead travels through the left aortic arch, joining the systemic circulation and bypassing the lungs. This lung bypass confers the same physiological advantages we have seen in turtles, namely, an increase in efficiency of blood flow while fresh air is unavailable.

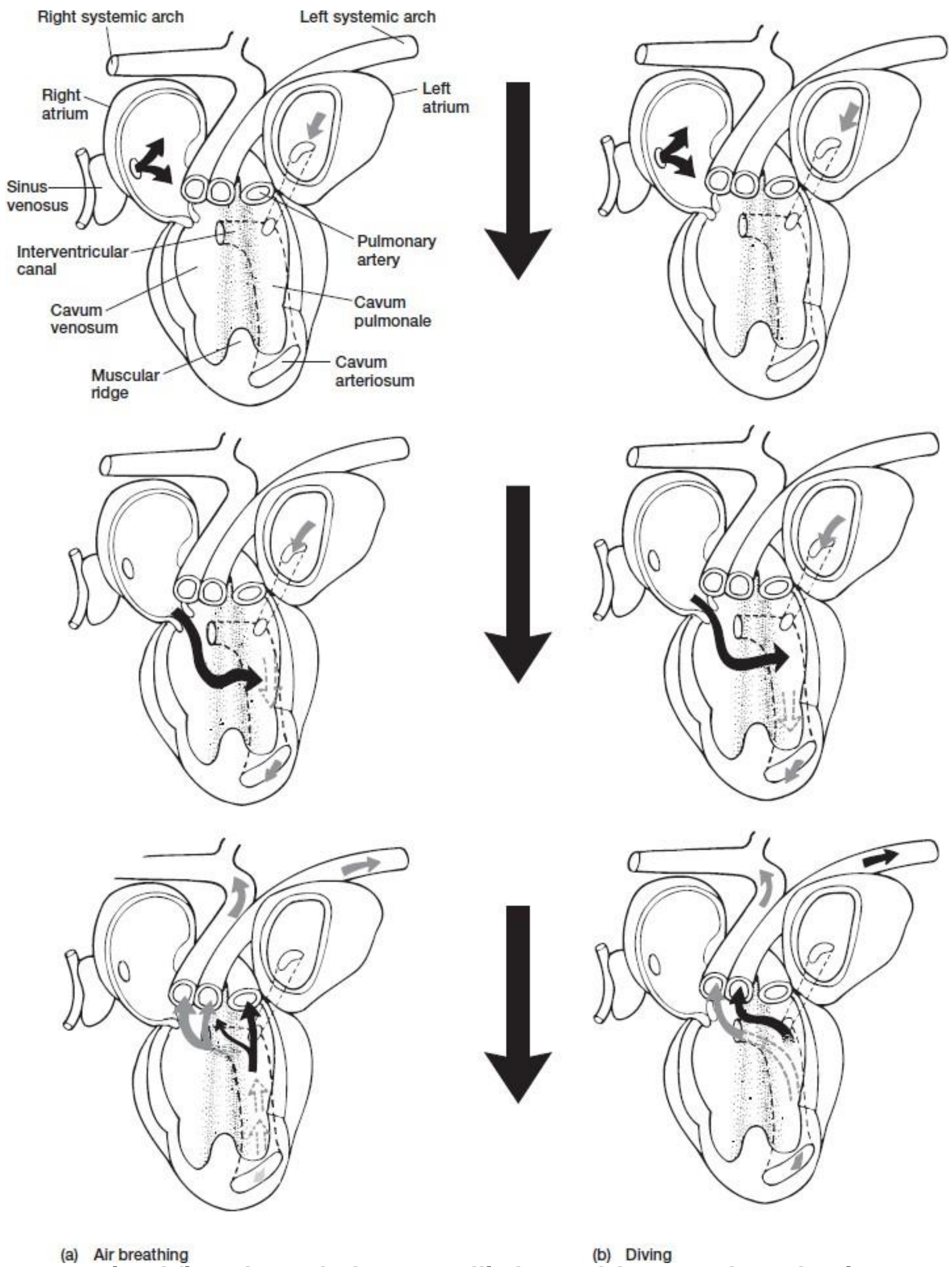


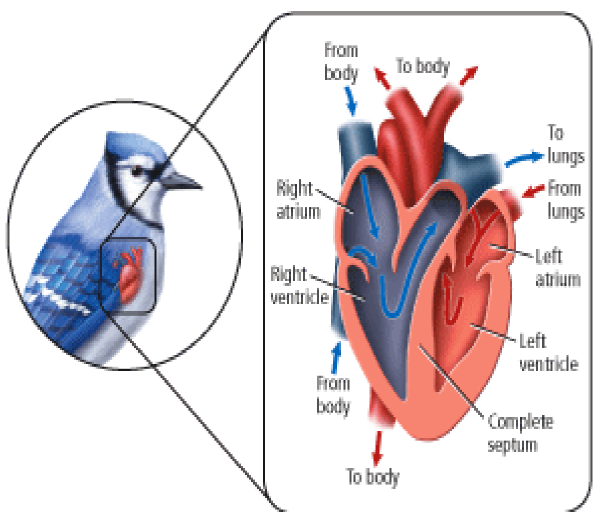
Fig. 10.13: Blood flow through the crocodile heart. (a) Systemic and pulmonary blood flow when the crocodile breathes air. (b) Internal changes that result in decreased pulmonary flow when the crocodile dives.

10.3.4. Birds and Mammals (4-chambered, double circuit pulmonary hearts)

The hearts of birds and mammals have four chambers. In birds, the sinus venosus is reduced to a small but still anatomically discrete area. In mammals, the sinus venosus is reduced to a patch of Purkinje fibers or sinoatrial node (pacemaker), in the wall of the right atrium. The embryonic conus arteriosus (bulbuscordis) gives rise to the pulmonary trunk and a single aortic trunk (left in mammals while right in birds; in both cases it arises from left ventricle) in the adult. Although structurally similar, bird and mammal hearts arose independently from different groups of tetrapod ancestors. This difference is reflected in their embryonic development.

Appearance of the interventricular and interatrial septa occurs quite differently in the two groups. In mammals only, each atrium has an ear like flap or auricle (with no known function), within which is a blind chamber (Kent). In mammals, the muscular walls lining the ventricular chambers exhibit sturdy inter-anastomosing muscular ridges and columns, the **trabeculaecarneae**. They strengthen the walls and increase the force exerted by them.

Due to anatomically divided left and right compartments, unlike in amphibians and reptiles, a cardiac shunt cannot be used to decouple perfusion of the lung and systemic tissues. Although the reasons are not well understood, some propose that endothermic animals (birds and mammals) may require complete anatomical separation of the cardiac chambers to prevent blood being sent to the lungs at the same high pressure as blood sent to systemic tissues.



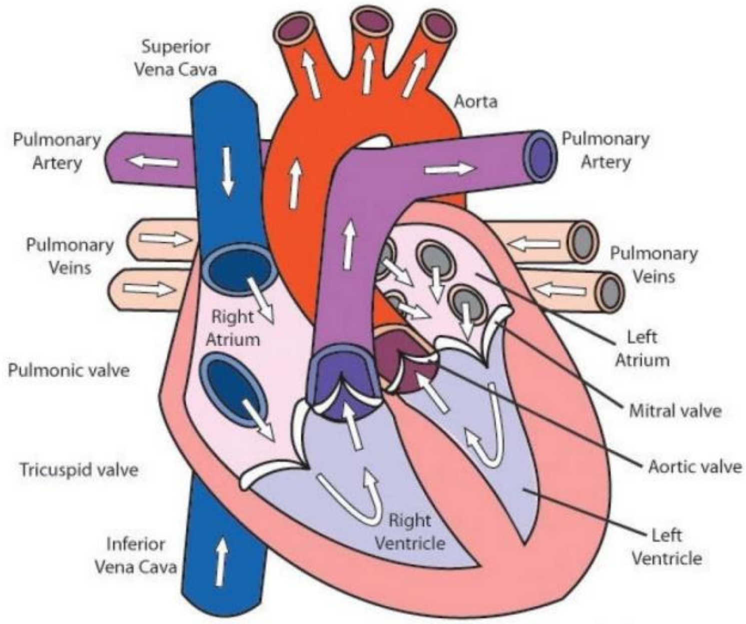


Fig. 10.14: Heart of bird (Top) and mammal (Beneath). The pulmonary trunk arises from right ventricle. The single aortic trunk (left in mammals while right in birds) arises from left ventricle.

Let us sum up

Under this unit, we studied about the evolution of heart. In this unit, we also focused on the circulation pattern of heart, basic structure of vertebrate heart such as heart of fishes, heart of amphibians, heart of reptiles, heart of birds and mammals.

Check your Progress

1) The heart which pumps blood via ventral aorta directly to the gills is called __________.
2) The heart of the Chondrichthyes and the bony fishes consists of four chambers, they are __________, __________, __________ and __________.
3) The amphibians consist of __________ chambers.
4) In amniote the right and the left atria are separated by __________ septum.
5) The cavumarteriosum receives __________ from the left atrium and passes it on to the aortic arches.

Glossaries

1. Myogenic : Originating in muscle tissue (rather than from nerve impulses).

2. Peritoneum : It is the tissue that lines your abdominal wall and covers most of the organs in your abdomen. A liquid, peritoneal fluid, lubricates the surface of this tissue.

3. Coelomic : The main body cavity in most animals and is positioned inside the body to surround and contain the digestive tract and other organs

Suggested readings

1) **ROMER, A.S** (1979), Hyman's Comparitive Vertebrate Anatomy, III Ed., The University of Chicogo Press, London.
2) **WEICHERT, C.K** (1965), Anatomy of the Chordates, McGraw Hill Book Co., New York.

Weblink

Evolution of hearts in vertebrates
https://www.slideshare.net/pranabjdas/evolution-of-heart

Answers to check your progress

1) Branchial heart
2) Sinus venosus, atrium, ventricle and conus arteriosus
3) 3
4) Interatrial
5) Oxygenated blood

Unit 11

Comparative Anatomy of Aortic Arches in Vertebrates

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the aortic arches
- Illustrate the basic plane of aortic arches
- Describe the evolutionary significance of aortic arches.

OVERVIEW

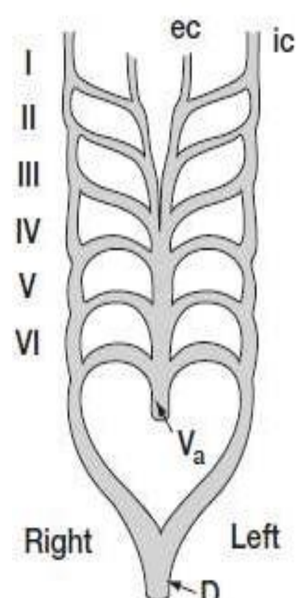
In this unit, we will focus on the comparative anatomy of aortic arches of vertebrates. Under this unit, we will also focus on the basic plane of aortic arches in cyclostome, elasmobranch, teleost, dipnoans, amphibians, reptiles, aves and mammals. We will also study about the evolutionary significance of aortic arches.

11.1. INTRODUCTION

The aortic arches or pharyngeal arch arteries are a series of six paired vascular structures which connect ventral aorta to the dorsal aorta and arise from the aortic sac.

11.2. Basic Plane

The basic fundamental plan of the aortic arches is similar in different vertebrates during embryonic stages. But in adult the condition of the arrangement is changed either being lost or modified considerably. The number of aortic arches is gradually reduced as the scale of evolution of vertebrates is ascended



Basic pattern

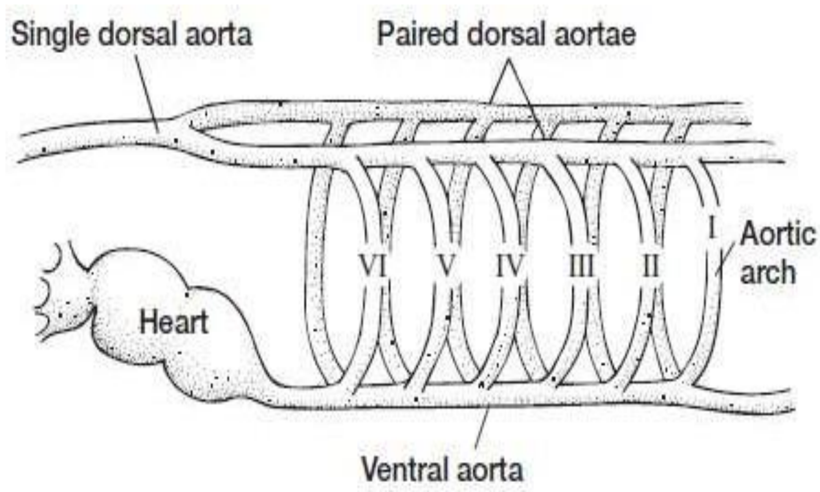


Fig. 11.1. Primitive pattern of aortic arches. Diagram of the basic six-arch pattern. (Da= Dorsal Aorta; Va= Ventral Aorta; ec= external Carotid; ic= internal carotid)

Development of the basic pattern and associated arteries

I. The first pair of aortic arches is formed by the curving of the ventral aorta into the primitive dorsal aorta. This arch is hidden in the mandibular arch and participates in formation of the maxillary artery, and contribute to the external carotid artery.
II. The second pair of aortic arches make their appearance in the middle of week 4. They cross the second branchial arches and give rise to the stapedial and hyoid arteries.
III. The third pair of aortic arches make their appearance at the end of week 4. They give rise to the common carotids and proximal portions of the internal carotid arteries. The latter are the short cephalic prolongations of the primitive dorsal aortas and are associated with development and supply of the brain

A. The internal carotid arteries are secondarily attached to the cranial portions of the dorsal aortas, which form the remainder of the carotid artery

B. The origin of the external carotid arteries is controversial, but in later stages of development, they are found to sprout from aortic arch II (Arch I, however, has been implicated in its developmental contribution)

IV. The fourth pair of aortic arches make their appearance shortly after the third arches, at the end of week 4. Their development is different for the right and left sides.

A. On the right side arch IV forms the proximal portion of the right subclavian artery and is continuous with the seventh segmental artery 1. The caudal portion of the right primitive dorsal aorta disappears 2. The distal portion of the subclavian artery forms from the right dorsal aorta and the right seventh inter segmental artery
B. On the left side arch IV persists as the arch of the aorta, which grows significantly and is continuous with the primitive left dorsal aorta. 1. The left subclavian artery (or seventh segmental) arises directly from the aorta
C. The short portion of the right primitive ventral aorta, which persists between arches IV and VI, forms the brachiocephalic arterial trunk and the first portion of the aortic arch

V. The fifth pair of aortic arches: in 50% of embryos, these arches are rudimentary vessels that degenerate with no derivatives. In fact, they may never even develop.
VI. The sixth pair of aortic arches make their appearance in the middle of week 5 and give rise to the right and left pulmonary arteries. After pulmonary vascularization is established, the communication with the corresponding primitive dorsal aorta regresses. Modifications in different vertebrate groups.

11.2.1. Cyclostomes

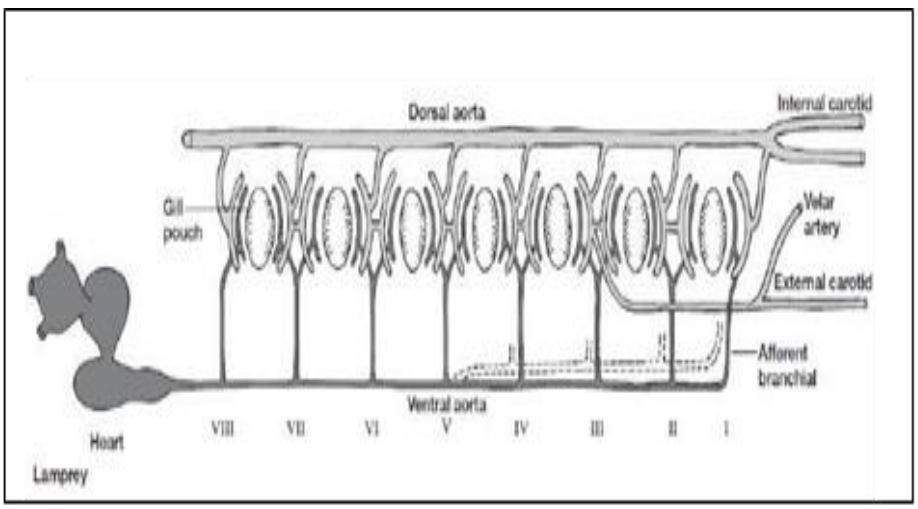


Fig. 11.2. Aortic arches of cyclostome

1. In lampreys (Petromyzon) there are eight pairs of aortic arches and in hag fishes (Bdellostoma) there are fifteen pairs. The aortic arch is divided into afferent branchial artery and efferent branchial artery.

2. In lampreys each aortic arch divides and sends branches to the posterior hemibranch and anterior hemibranch of the adjacent gill pouch. In hagfishes each arch supplies to the hemibranch of a single gill pouch.

11.2.2. Elasmobranchs

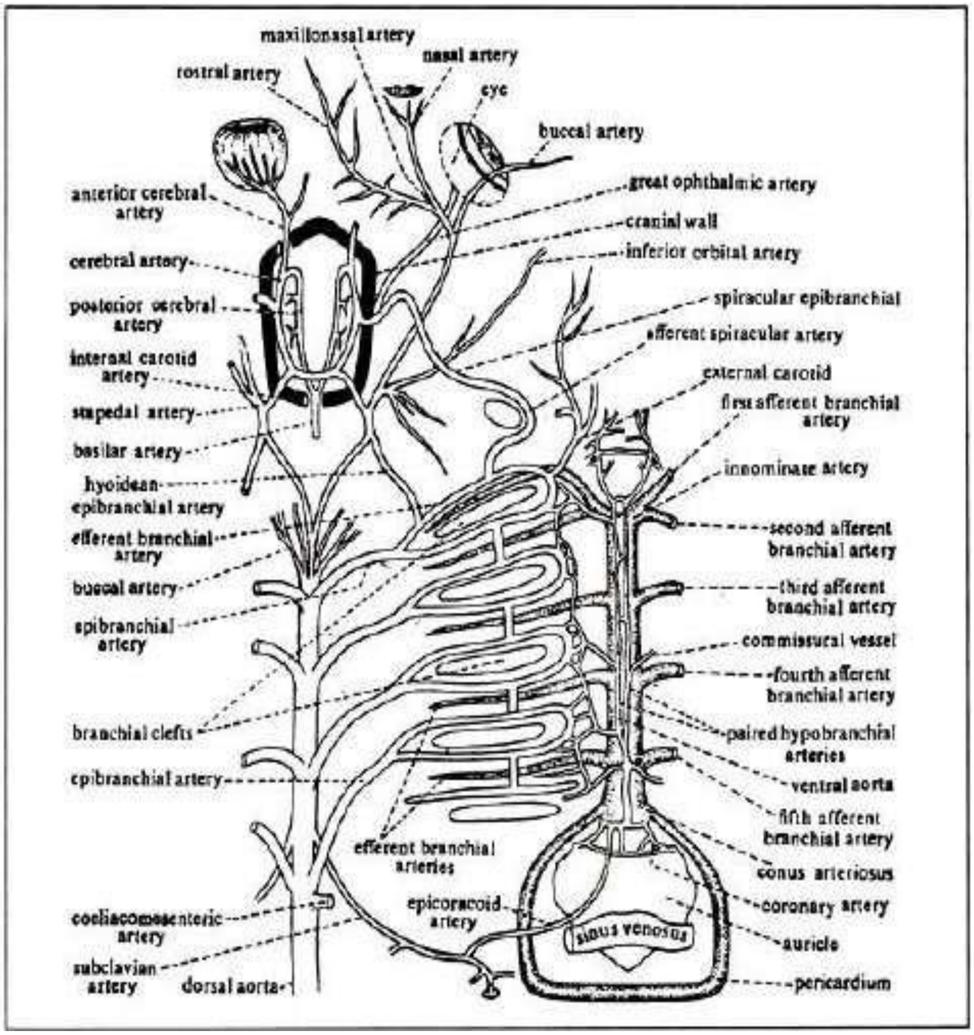


Fig. 11.3. Aortic arches of elasmobranch

1. Generally, there are five pairs of aortic arches in elasmobranchs but in some cases there is a variation. In Hexanchus there are six pairs of aortic arches. In Heptranchias there are seven pairs.
2. In elasmobranchs the first pair of aortic arches (mandibular) disappear. Second to sixth pair of aortic arches (II-VI) persist as

branchial arteries. Each aortic arch is divided into afferent and efferent branchial arteries.

3. Five pairs afferent arteries arise from ventral aorta and supply deoxygenated blood to the respective gills. The ventral aorta divides into two branches, called innominate arteries which again bifurcate into the first and second afferent branchial arteries. From the gills the oxygenated blood is collected by efferent branchial arteries.
4. In elasmobranchs there are nine pair's efferent branchial arteries of which the first eight arteries form a series of four complete loops but ninth efferent branchial artery collects blood from the demi- branch of the fifth gill pouch.

11.2.3. Teleosts

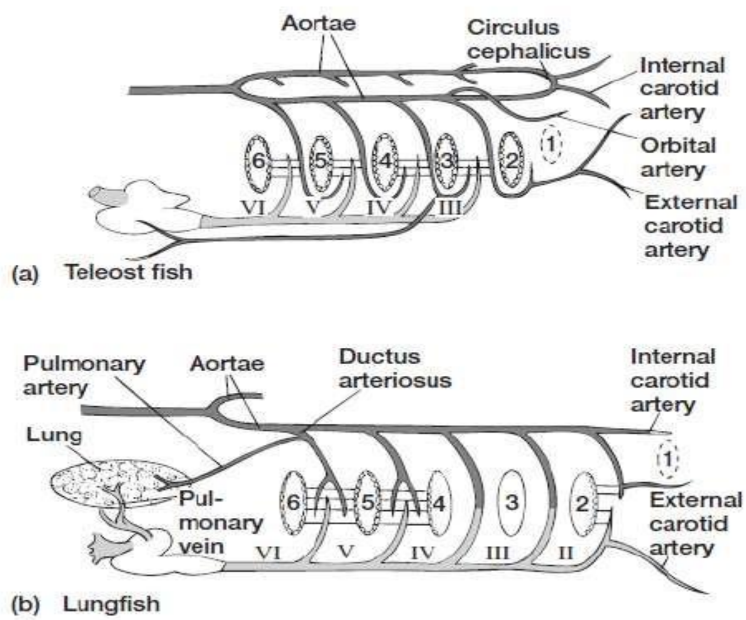


Fig. 11.4. Aortic arches of teleost

1. In teleosts there are four pairs of aortic arches. First pair (mandibular) and second pair (hyoidean) are lost, only four pairs (third to sixth) persist as branchial arteries. Four pairs afferent branchial arteries arise from the ventral aorta.
2. They supply deoxygenated blood to the gills for aeration. The ventral aorta bifurcates anteriorly to form the first pair of afferent branchial arteries. In sturgeon (Acipenser) and Amia each afferent branchial arch bifurcates as in elasmobranchs.

11.2.4. Dipnoans

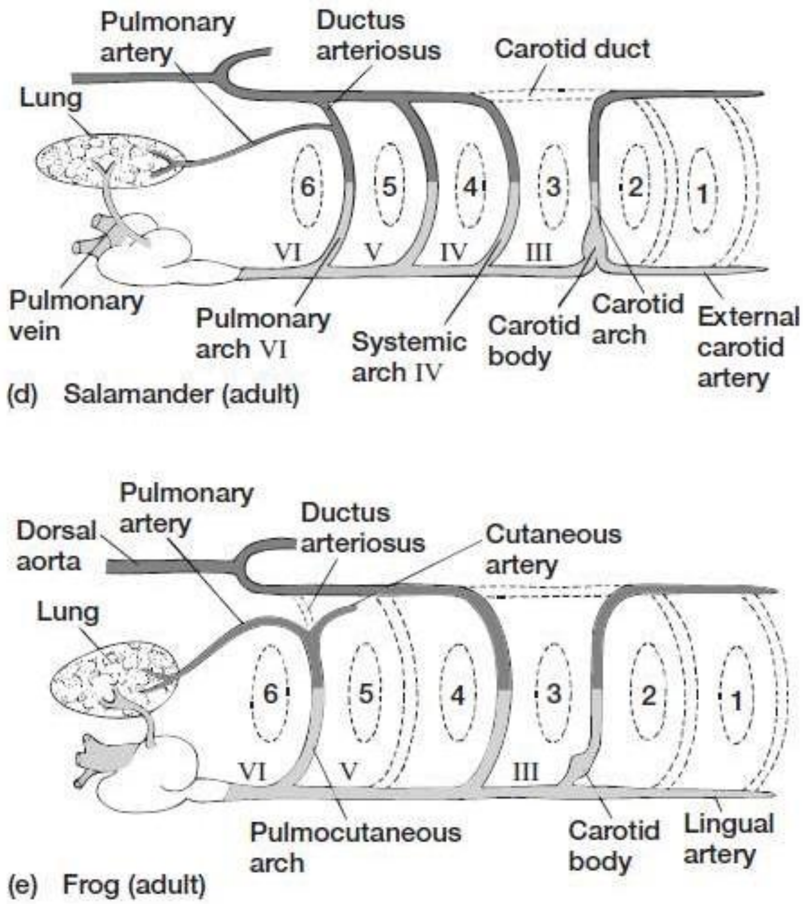


Fig. 11.5. Aortic arches of dipnoans

1. In lungfishes, as in other bony fishes, the first pharyngeal slit is reduced to a spiracle that has no respiratory function.
2. Its associated aortic arch (I) is reduced as well as the IInd arch.
3. In the Australian lungfish, Neoceratodus, the remaining five pharyngeal slits open to fully functional gills supplied by four aortic arches (III–VI).
4. In the African lungfish, Protopterus, the functional gills are reduced further. The third and fourth gills are absent entirely, but their aortic arches (III–IV) persist.
5. In all lungfishes, the efferent vessel of the most posterior aortic arch (VI) gives rise to the pulmonary artery but maintains its connection to the dorsal aorta via the short ductus arteriosus.

11.2.5. Amphibians

In amphibians, the first two aortic arches (I, II) disappear early in development. The pattern of the remaining arches differs between larvae and metamorphosed adults.

11.2.5.1. Urodales

1. In most larval salamanders, the next three aortic arches (III–V) carry external gills, and the last aortic arch (VI) sprouts the pulmonary artery to the developing lung.
2. A notable exception is the neotenic salamander Necturus, in which part of the sixth arch disappears and only its dorsal section persists, forming the base of the pulmonary artery. In most species of salamanders, the external gills are lost following the larva's transformation into the adult, but the aortic arches are retained as major systemic vessels.
3. The short section of dorsal aorta between aortic arches III and IV, termed the carotid duct, usually closes at metamorphosis. This forces the carotids to fill with blood from a derivative of the ventral aorta. The section of ventral aorta between arches III and IV becomes the common carotid artery, which feeds the external carotid (from the anterior ventral aorta) and the internal carotid (the anterior section of the dorsal aorta together with the third aortic arch).
4. The carotid body is a small cluster of sensory cells associated with capillaries, usually located near the point at which the common carotids branch. Its functions are not completely known. Certainly the carotid body plays a role in sensing the gas content or pressure of the blood as well as having some endocrine functions.
5. The next two arches (IV, V) constitute major systemic vessels that join the dorsal aorta.
6. The final aortic arch (VI) also joins the dorsal aorta, its last short section forming the ductus arteriosus. Shortly before joining the dorsal aorta, the sixth aortic arch gives off the pulmonary artery, which itself divides into small branches to the floor of the mouth, pharynx, and esophagus before actually entering the lungs.
7. In lungless salamanders, the pulmonary artery, if it persists, supplies the skin of the neck and back.

11.2.5.2. Anurans

1. In frogs, the larva usually has internal gills that reside on the last four aortic arches (III–VI), and the embryonic pulmonary artery buds from arch VI. At metamorphosis, these gills are lost together with the carotid duct and all of arch V.
2. The aortic arches that persist (III, IV and VI) expand to supply blood to the head, body and pulmonary circuits, respectively.
3. The third arch and associated section of anterior dorsal aorta become the internal carotid. The anterior extension of the ventral aorta is the external carotid. Internal and external carotids both branch from the common carotid, the section of ventral aorta between arches III and IV.
4. A carotid body can usually be found at the root of the internal carotid. The next enlarged aortic arch (IV) joins with the dorsal aorta, the major systemic artery supplying the body.
5. The last arch (VI) loses its connection to the dorsal aorta because the ductus arteriosus closes and becomes the pulmocutaneous artery. One branch of the pulmocutaneous artery is the now well-developed pulmonary artery that enters the lung. The other branch is the cutaneous artery, which delivers blood to the skin along the dorsal and lateral body wall.

11.2.6. Reptiles

1. Beginning in reptiles, but carried into birds and mammals, the symmetrical aortic arches of the embryo tend to become asymmetrical in the adult. Aortic arches III, IV and VI persist in reptiles, but most of the changes center on enhancements and modification of the fourth arch.
2. Perhaps the most significant anatomical modification of the arterial system in reptiles is the subdivision of the ventral aorta. During embryonic development, the ventral aorta splits to form the bases of three separate arteries leaving the heart: the left aortic arch, the right aortic arch and the pulmonary trunk.
3. The base of the left aortic arch, the left aortic arch (IV) itself, and the curved section of the left dorsal aorta into which it continues constitute the left systemic arch. The right systemic arch includes the same components on the right side of the body: the base of the right aortic arch, the right aortic arch itself, and the arched section of the right

dorsal aorta. The two systemic arches unite behind the heart to form the common dorsal aorta.

4. The right systemic arch tends to be the more prominent of the two, primarily because of the additional vessels that it supplies. For example, the carotid arteries, originating from the ventral aorta in more primitive vertebrates, arise in reptiles from the right systemic arch. Blood passing through the right systemic arch might flow to the body or enter the carotid arteries to supply the head. In most reptiles, the sub-clavian arteries branch from the dorsal aorta, but in some reptiles, they branch from the systemic arches. These modifications of the aortic arches in reptiles produce one pulmonary circuit and two systemic circuits, each of which arises independently from the heart.
5. The pulmonary trunk incorporates the bases of the paired sixth arch and their branches as part of the pulmonary arch to the lungs.

11.2.7. Birds

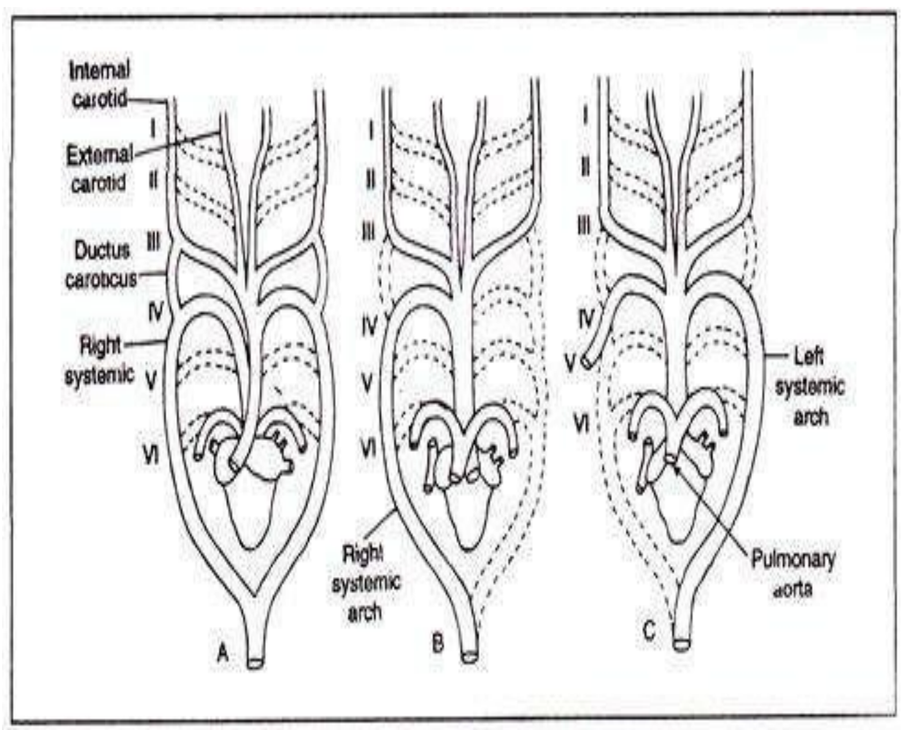


Fig. 11.6. Aaortic arches A. Reptiles (Lizards), B. Birds, C. Mammals

1. In birds, the right systemic arch becomes predominant. The bases of the aortic arch, the right aortic arch (IV), and the adjoining section of the right dorsal aorta form the right systemic arch during embryonic development.

2. Its opposite member, the left systemic arch, never fully develops.
3. The carotids arise generally from the same components of the aortic arches as in reptiles (aortic arch III and parts of the ventral and dorsal aortae), and they branch from the right systemic arch. However, the paired subclavians to the wings arise from the internal carotids and not from the dorsal aorta.
4. The common carotids and subclavians supply the head and forelimbs, respectively. The common carotids can branch from the right systemic arch separately or both can join to form a single carotid.
5. A short but major vessel, the brachiocephalic artery, is present in a few reptiles, especially turtles, but serves as the major anterior vessel in many birds. It too branches from the right systemic arch. Beyond this junction of the brachiocephalic artery, the systemic arch curves posteriorly to supply the rest of the body. In birds as in reptiles, the pulmonary arch forms from the bases of the paired sixth arch and their branches to supply both lungs

11.2.8. Mammals

1. Up to six aortic arches arise in the mammalian embryo, but only three persist in the adult as the major anterior arteries: the carotid arteries, the pulmonary arch and the systemic arch.
2. The carotid arteries and pulmonary arch are assembled from the same arch components as those of reptiles. The mammalian carotids arise from the paired aortic arches (III) and parts of the ventral and dorsal aortae.
3. The pulmonary arch forms from the bases of the paired sixth arch and its branches.
4. The systemic arch arises embryonically from the left aortic arch (IV) and left member of the paired dorsal aorta, and therefore is a left systemic arch in mammals. The common carotids may share a brachiocephalic origin or branch independently from different points on the aortic arch.
5. The other notable difference in mammals is in the formation of the subclavian arteries. The left subclavian departs from the left systemic arch in mammals. The right subclavian, however, includes the right aortic arch (IV), part of the adjoining right dorsal aorta, and the arteries that grow from these into the right limb.

11.3. Evolutionary Significance of Aortic Arches

a) In most fishes, the aortic arches deliver deoxygenated blood to the respiratory surfaces of the gills and then distribute oxygenated blood to tissues of the head (via the carotids) and remainder of the body (via the dorsal aortae).

b) In lungfishes and tetrapods, the aortic arches contribute to the pulmonary arch, the arterial circuit to the lungs, and the systemic arches, the arterial circuits to the rest of the body. The carotid arteries still bear the primary responsibility for supplying blood to the head in tetrapods, but now they usually branch from one of the major systemic arches.

c) The double systemic arches (left and right) present in amphibians and reptiles become reduced to a single systemic arch, the right in birds, the left in mammals.

d) Although birds and mammals share many similarities, including endothermy, active lives and diverse radiation, they arose out of different reptilian ancestries. Any similarities in their cardiovascular anatomies represent independent evolutionary innovations.

e) The basic six-arch pattern of aortic arches is a useful concept that allows us to track aortic arch derivatives and organize the diversity of anatomical modifications we encounter. Furthermore, the appearance of six aortic arches during the embryonic development of living gnathostomes suggests that this is the ancestral pattern.

f) However, as we have seen, the actual adult anatomy can be quite varied among different species.

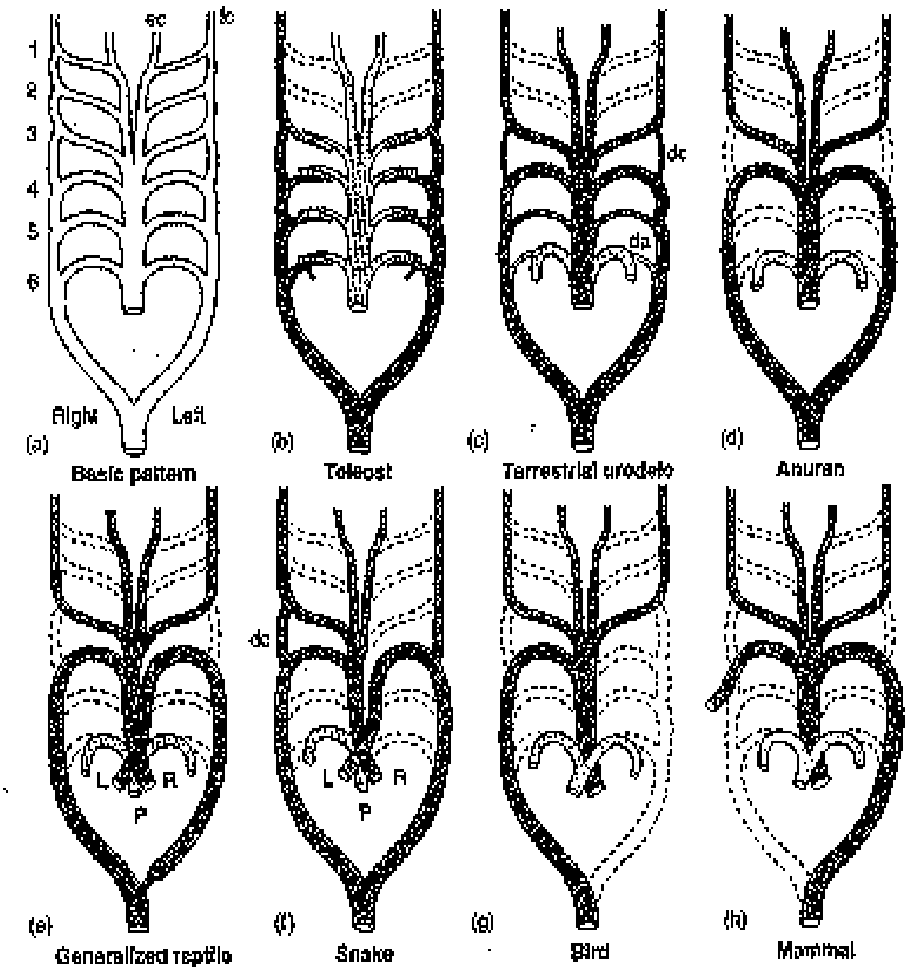


Fig. 11.7. Evolution of aortic arches

Table.11.1. The modifications of embryonic aortic arches in adult vertebrates

Embryonic aortic arches	Elasmo-branchs	Teleosts	Lower Amphibians	Higher Amphibians	Reptiles	Birds	Mammals
First pair	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear
Second pair	Persist as first branchial arteries	Disappear	Disappear	Disappear	Disapper	Disapper	Disappear
Third pair	Persist as second branchial arteries	Persist as first branchial arteries	Persist as carotid arteries	Persist as carotid arteries	Persist as carotid arteries	Same as reptiles	Same as birds
Fourth pair	Persist as third branchial arteries	Persists as second branchial arteries	Persist as left and right sys-temic arteries	Persist as left and right sys-temic arteries	Persist as right and left sys-temic arteries	Persist only as right systemic artery	Persist only as left systemic artery
Fifth pair	Persist as fourth branchial arteries	Persist as third branchial arteries	Persist as branchial arteries	Disappear	Disappear	Disappear	Disappear
Sixth pair	Persist as fifth branchial arteries	Persist as fourth branchial arteries	Persist as right and left pulmo-nary arteries	Persist as right and left pulmo-nary arteries	Persist as right and left pul-monary arteries	Persist as right and left pul-monary arteries	Same as birds

Let us sum up

Under this unit, we studied about the comparative anatomy of aortic arches in vertebrates. In this unit, we also studied about the basic plane of aortic arches in cyclostome, elasmobranch, teleost, dipnoans, amphibians, reptiles, aves and mammals. We will also study about the evolutionary significance of aortic arches.

Check your Progress

1) The ventral aorta divides into two branches called __________.
2) The double systemic arches are present in __________.
3) In the embryonic stages of reptiles the ventral aorta splits to form three separate arteries, they are __________, __________ and __________.

Glossaries

1. Peritoneum : It is the tissue that lines your abdominal wall and covers most of the organs in your abdomen. A liquid, peritoneal fluid, lubricates the surface of this tissue.

2. Coelomic : The main body cavity in most animals and is positioned inside the body to surround and contain the digestive tract and other organs

3. Amoebocytes: They basically store, digest and transport food, excrete wastes, secrete skeleton and also may give rise to buds in asexual reproduction

Suggested readings

1) **NEWMAN, N.H** (1961), Phylum Chordate, The University of Chicago Press, Chicago.
2) **WATERMAN, A.J** (1971), Chordate Structure and Function, The Macmillan Company.

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Evolution of aortic arches https://youtu.be/OxuZRv7HqKg

Evolution of portal system https://youtu.be/wqY68oqSVwI

Answers to check your progress

1) Innominateries
2) Amphibians
3) Left aortic arche, right aortic arch and pulmonary trunk.

Unit 12

Respiratory System

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the anatomy of respiratory system
- List out the functions of respiratory system.

OVERVIEW

In this unit, we will study about the respiratory system. Under this unit, we will also study about the anatomy and functions of respiratory system.

12.1. INTRODUCTION

The respiratory system is constantly filtering through the external environment as humans breathe air. The airways must maintain the ability to clear inhaled pathogens, allergens and debris to maintain homeostasis and prevent inflammation.

The respiratory system subdivides into a conducting portion and a respiratory portion. The majority of the respiratory tree, from the nasal cavity to the bronchi, is lined by pseudostratified columnar ciliated epithelium. The bronchioles are lined by simple columnar to the cuboidal epithelium, and the alveoli possess a lining of thin squamous epithelium that allows for gas exchange.

The respiratory system is the network of organs and tissues that help you breathe. It includes your airways, lungs and blood vessels. The muscles that power your lungs are also part of the respiratory system.

12.2. Functions of respiratory system

The respiratory system has many functions. Besides helping you inhale (breathe in) and exhale (breathe out) it:

- Allows you to talk and to smell.
- Warms air to match your body temperature and moisturizes it to the humidity level your body needs.
- Delivers oxygen to the cells in your body.
- Removes waste gases, including carbon dioxide, from the body when you exhale.
- Protects your airways from harmful substances and irritants.

12.3. Anatomy of respiratory system

Parts of the respiratory system

The respiratory system has many different parts that work together to help you breathe. Each group of parts has many separate components.

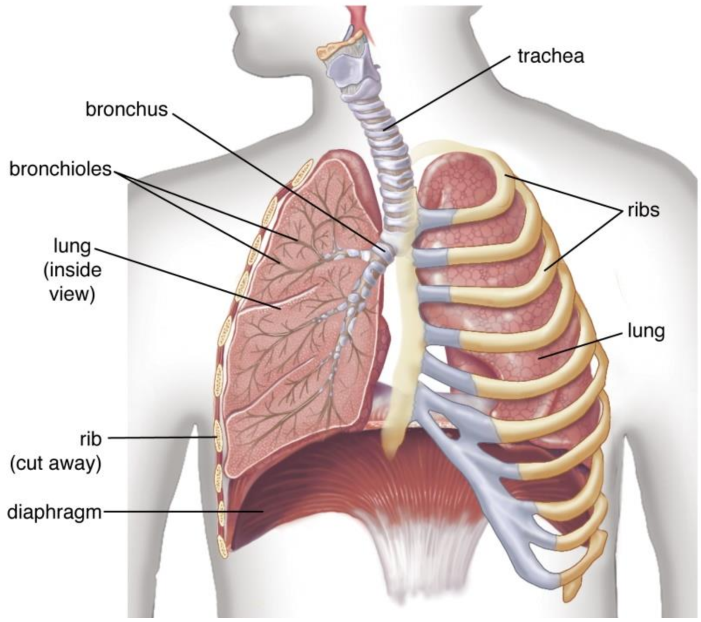

Fig. 12.1: Position of Lungs in Human

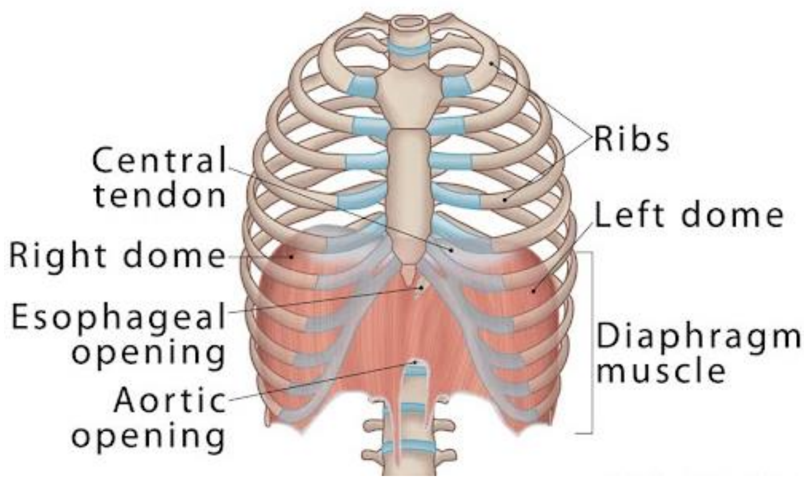

Fig. 12.2: Location of Diaphragm

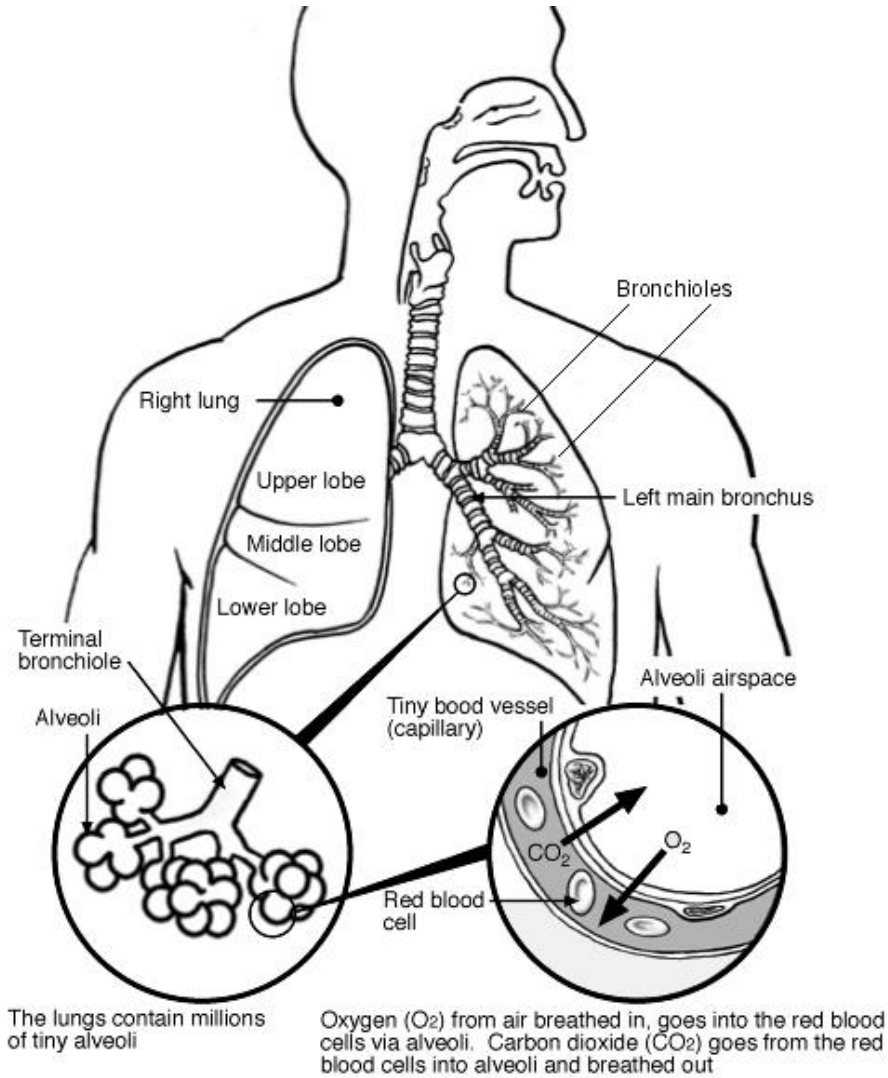

Fig. 12.3: Lung Showing Alveoli

Your airways deliver air to your lungs. Your airways are a complicated system that includes:

- **Mouth and nose:** Openings that pull air from outside your body into your respiratory system.
- **Sinuses:** Hollow areas between the bones in your head that help regulate the temperature and humidity of the air you inhale.
- **Pharynx (throat):** Tube that delivers air from your mouth and nose to the trachea (windpipe).
- **Trachea:** Passage connecting your throat and lungs.

- **Bronchial tubes:** Tubes at the bottom of your windpipe that connect into each lung.
- **Lungs:** Two organs that remove oxygen from the air and pass it into your blood.

From your lungs, your bloodstream delivers oxygen to all your organs and other tissues.

Muscles and bones help move the air you inhale into and out of your lungs. Some of the bones and muscles in the respiratory system include:

- **Diaphragm:** Muscle that helps your lungs pull in air and push it out.
- **Ribs:** Bones that surround and protect your lungs and heart.

When you breathe out, your blood carries carbon dioxide and other waste out of the body. Other components that work with the lungs and blood vessels include:

- **Alveoli:** Tiny air sacs in the lungs where the exchange of oxygen and carbon dioxide takes place.
- **Bronchioles:** Small branches of the bronchial tubes that lead to the alveoli.
- **Capillaries:** Blood vessels in the alveoli walls that move oxygen and carbon dioxide.
- **Lung lobes:** Sections of the lungs — three lobes in the right lung and two in the left lung.
- **Pleura:** Thin sacs that surround each lung lobe and separate your lungs from the chest wall.

Some of the other components of your respiratory system include:

- **Cilia:** Tiny hairs that move in a wave-like motion to filter dust and other irritants out of your airways.
- **Epiglottis:** Tissue flap at the entrance to the trachea that closes when you swallow to keep food and liquids out of your airway.
- **Larynx (voice box):** Hollow organ that allows you to talk and make sounds when air moves in and out.

Let us sum up

Under this unit, we studied about the respiratory system. In this unit, we also focused on the anatomy and various functions of respiratory system.

Check your Progress

1) ___________ is a tiny air sac in the lungs where the exchange of oxygen and carbon dioxide takes place.
2) ___________ is a tissue at the entrance to the trachea that closes when the food is swallowed to keep the food and liquid away from the airway.
3) ___________ is a hollow area between the bones of head that helps in regulating temperature and humidity of air that is inhaled.

Glossaries

1. Amoebocytes: They basically store, digest and transport food, excrete wastes, secrete skeleton and also may give rise to buds in asexual reproduction

2. Phlebotomist: Health care worker who performs phlebotomy in healthcare settings.

Suggested readings

1) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.
2) **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.

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Respiratory system in vertebrates https://youtu.be/5QRC_Hcxm34

Answers to check your progress

3) Alveoli
4) Epiglottis
5) Sinuses

Unit 13

Characters of Respiratory Tissues

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the process of gas exchange during respiration
- Explain the humidification and warming
- Explain the filtration mechanism
- Explain the oxidant defense and response to injury.

OVERVIEW

In this unit, we will study about the characters of respiratory tissues. We will also focus on the conducting portions, gas exchange portion, humidification and warming, filtration, oxidant defense and response to injury and gaseous exchange.

13.1. INTRODUCTION

The respiratory system is constantly maintaining homeostasis and prevents inflammation from pathogens.

In the respiratory system, the nasal cavity to the bronchi is lined by pseudostratified columnar ciliated epithelium. The bronchioles are lined by simple columnar to the cuboidal epithelium, and the alveoli possess a lining of thin squamous epithelium that allows for gaseous exchanges.

There are four main histological layers within the respiratory system: respiratory mucosa which includes epithelium and supporting lamina propria, submucosa, cartilage and/or muscular layer and adventitia. Respiratory epithelium is ciliated pseudostratified columnar epithelium found lining most of the respiratory tract; it is not present in the larynx or pharynx. The epithelium classifies as pseudostratified; though it is a single layer of cells along the basement membrane, the alignment of the nuclei is not in the same plane and appears as multiple layers. The role of this unique type of epithelium is to function as a barrier to pathogens and foreign particles; however, it also operates by preventing infection and tissue injury via the use of the mucociliary elevator.

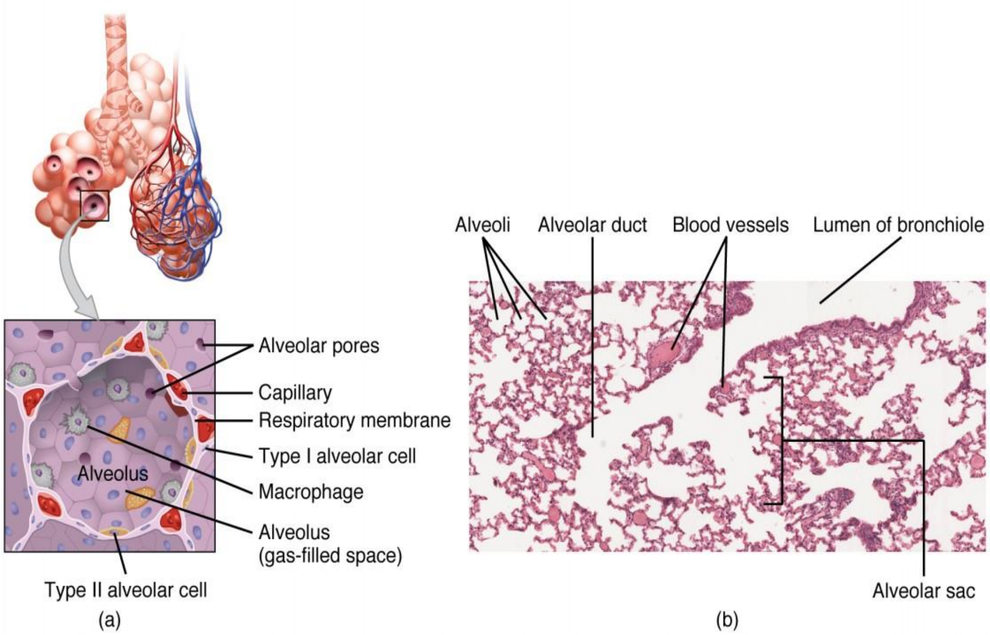

Fig. 13.1: Organs and Structures of the Respiratory Zone

13.2. Conducting Portion

The conducting piece of the respiratory system consists of the nasal cavity, trachea, bronchi, and bronchioles. The luminal surfaces of this entire portion have a lining of ciliated pseudostratified columnar epithelium and contain goblet cells. Their role is to secrete mucus that serves as the first line of defense against incoming environmental pathogens. Cilia move the mucus-bound particulate up and away for expulsion from the body. The various types and abundance of cells are dependent on this region of the airway.

In the most proximal airway, hyaline cartilage rings support the larger respiratory passages, namely, the trachea and bronchi, to facilitate the passage of air. Three major cell types are found in this region: ciliated, non-ciliated secretory cells and basal cells.

Ciliated cells, each lined with 200 to 300 cilia, account for more than half of all epithelial cells in the conducting airway. As the degree of branching within the airway tree continues, the epithelium gradually changes from pseudostratified to simple cuboidal; and the predominant cells become non-ciliated cells, Clara cells.

13.3. Gas-Exchange Portion

The respiratory or gas-exchange region of the lung is composed of millions of alveoli, which are lined by an extremely thin, simple squamous epithelium that allows for the easy diffusion of oxygen and carbon dioxide. Additionally, cuboidal, surfactant-secreting cells, Type II pneumocytes, are also found lining the walls of alveoli. Surfactant, which is primarily composed of dipalmitoylphosphatidylcholine, has a vital role in lowering the surface tension of water to allow for effective gas exchange (*Rokicki et al*. 2015).

Type I pneumocytes are flattened cells that create a very thin diffusion barrier for gases. Tight junctions are found connecting one cell to another (Frank, J. A, 2012). The principal functions of Type I pneumocytes are gas exchange and fluid transport. Type II Pneumocytes secrete surfactant, which decreases the surface area between thin alveolar walls, and stops alveoli from collapsing during exhalation. These cells connect to the epithelium and other constituent cells by tight junctions. Type II pneumocytes also play a vital role in acting as progenitor cells to replace injured or damaged Type I pneumocytes (*Reid L et al*. 2005).

Functions

Just as the skin protects humans from external pathogens and irritants, the respiratory epithelium acts to protect and effectively clear the airways and lungs of inhaled pathogens and irritants.

The division of the respiratory system into conducting and respiratory airways delineates their function and roles. The conducting portion, consisting of the nose, pharynx, larynx, trachea, bronchi and bronchioles, which all serve to humidify, warm, filter air. The respiratory portion is involved in gas exchange. There are three major types of cells found in respiratory epithelium, and each holds a vital role in regulating how humans breathe. If any of these components of the barrier are not properly functioning, the body becomes susceptible to acquiring infections, pathogens or inducing inflammation and disturbing hemostasis.

13.4. Humidification & Warming

Humidification requires serous and mucous secretions, and warming relies on the extensive capillary network that lays within the alveoli. The alveoli are also extensively enveloped by capillaries that allow for air to be conditioned and heated by the vascular plexus that surrounds them and provides for heat-exchange. The branching of the arteries and veins of the pulmonary system follow a similar branching pattern to that of the airway tree. The walls of the pulmonary arteries and veins are more delicate than the vasculature in other regions of the body, as the pulmonary circulation functions at a lower pressure than the systemic circulation.

13.5. Filtration

Filtration occurs by the trapping mechanism of mucus secretions and ciliary beating. This process allows trapped particulate to move towards the throat where mucus is swallowed or expelled by the body.

Goblet cells are columnar epithelial cells that secrete high molecular weight mucin glycoproteins into the lumen of the airway and provide moisture to the epithelium while trapping incoming particulate and pathogens. In a healthy airway, ciliated cells are columnar epithelial cells that are modified with hundreds of hair-like projections, beating at a rapid frequency of approximately 8 to 20 Hz, mobilizing the mucus that is found resting on it.

13.6. Oxidant Defense & Response to Injury

Cells found in the respiratory epithelium are continually fighting off inhaled particulate and pathogens and regenerating themselves after injury. Basal cells, which are small, nearly cuboidal cells, attached to the basement membrane by hemidesmosomes, can differentiate into other cell types found within the epithelium. Basal cells provide an attachment site for ciliated and goblet cells to the basal lamina. They also respond to injury and act in oxidant defense of the airway epithelium and transepithelial water movement.

13.7. Gaseous Exchange

Within the millions of microscopic alveolar sacs, the exchange of oxygen for carbon dioxide occurs. Inhaled air diffuses through the alveoli into the pulmonary capillaries, and at the same time, carbon dioxide from deoxygenated blood diffuses into the capillaries then into the alveoli and is expelled through the airways as exhalation occurs.

Let us sum up

Under this unit, we studied about the characteristics of respiratory tissue. We also focused on the conducting portions, gas exchange portion, humidification and warming, filtration, oxidant defense and response to injury and gaseous exchange.

Check your Progress

1) The role of respiratory epithelium is to function as a barrier to ___________.
2) The three major cell types that is found in the conducting portion of respiratory system are ___________, ___________ and ___________.
3) The gas exchange portion of respiratory system is composed of millions of ___________.

Glossaries

1. Phlebotomist: Health care worker who performs phlebotomy in healthcare settings.

2. Hemophilia: A medical condition in which the ability of the blood to clot is severely reduced, causing the sufferer to bleed severely from even a slight injury.

3. Thalassemia: Group of hereditary haemolytic diseases caused by faulty haemoglobin synthesis

Suggested readings

1) **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.
2) **ROMER, A.S** (1974), The Vertebrate Body, W.B. Saunders, London.

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Characters of respiratory tissue https://youtu.be/0fVoz4V75_E

Answers to check your progress

1) Pathogens
2) Ciliated, non-ciliated secretory cells and basal cells
3) Alveoli

Unit 14

Internal and External Respiration

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the external and internal respiration
- Explain the respiratory pattern in mammals
- Illustrate the mechanism of respiration.

OVERVIEW

In this unit, we will study in detail about the internal and external respiration.

14.1. INTRODUCTION

During the gaseous exchange in animals, oxygen and carbon dioxide diffuse in and out of the blood in lungs and metabolizing tissues. Oxygen is used in the cellular respiration, produces metabolic energy in order to carry out cellular functions. During cellular respiration, carbon dioxide is produced as a waste. The gas exchange occurs at the respiratory membrane in 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.

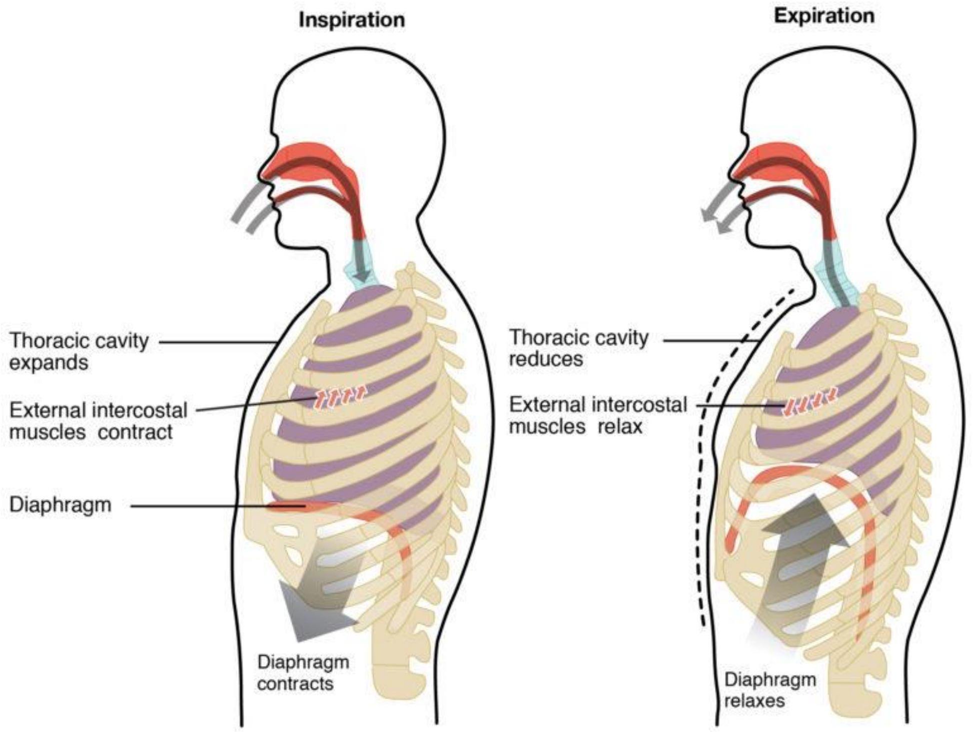


Fig. 14.1. Expiration and Inspiration

14.2. External Respiration

External respiration describes respiration that occurs between the external environment and the cells of the body.

External respiration consists of two stages:

- Breathing
- Gas exchange

The first stage involves ventilation or breathing, which is the intake of oxygen into the body and expulsion of carbon dioxide out of the body.

The second stage involves the exchange of gases between the blood capillaries and the alveoli of the lungs. The alveoli are thin walled round shaped cells (or air sacs) that occur in groups within the lungs. There are several of these air sacs packed together to increase surface area for gas exchange.

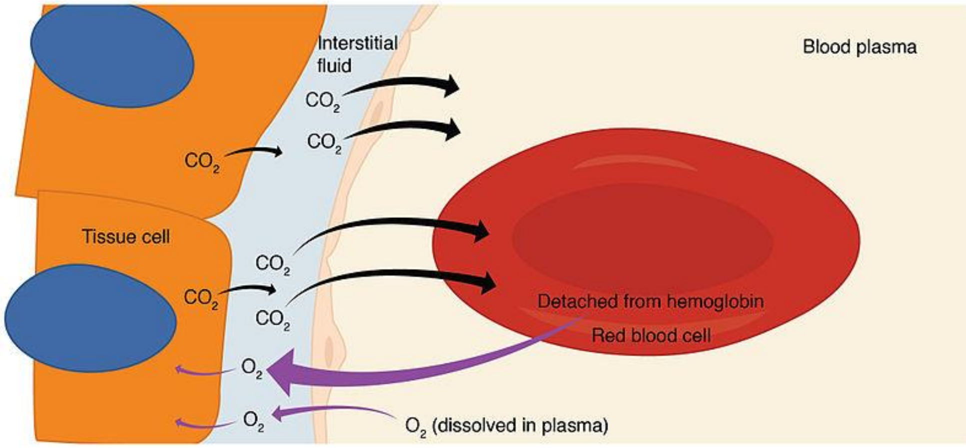


Fig. 14.2. External respiration

Gases move between cells in external respiration. Oxygen that is inhaled diffuses from the alveoli into the blood of capillaries. There the oxygen attaches reversibly to the heme (iron) of the hemoglobin of the red blood cell.

Carbon dioxide which attaches to an amino acid in the blood offloads from the red blood cell in order to be exhaled from the body. The blood cells transport the gases around the body. This is how oxygenation of body cells is achieved and waste products removed.

Many animals do not have lungs for gas exchange. Animals such as fish that live in water have gills instead of lungs for instance, and some animals in water can also use the skin as a gas exchange surface.

What is important is that the gas exchange surface needs to be kept moist in order for gases to be exchanged. In terrestrial animals these surfaces are kept moist, for instance by production of mucus in the lungs.

Oxygen is needed for internal respiration to occur thus external respiration is critical in keeping our cells alive. Very few organisms can continue to undergo cellular respiration in the absence of oxygen.

14.3. Internal Respiration

Internal respiration occurs within cells of the body and involves all body cells, not just cells of the lungs. It uses oxygen to break down molecules in order to release energy in the form of adenosine triphosphate (ATP). Internal respiration is often also called cellular respiration since it occurs within the cell.

Internal cellular respiration can occur in two forms:

- Aerobic respiration which requires oxygen
- Anaerobic respiration (also known as fermentation) which does not require oxygen

The cells of most living organisms cannot survive long periods of anaerobic respiration, and thus oxygen is needed. Aerobic respiration generates large amounts of energy as ATP while anaerobic respiration cannot produce very much energy (ATP).

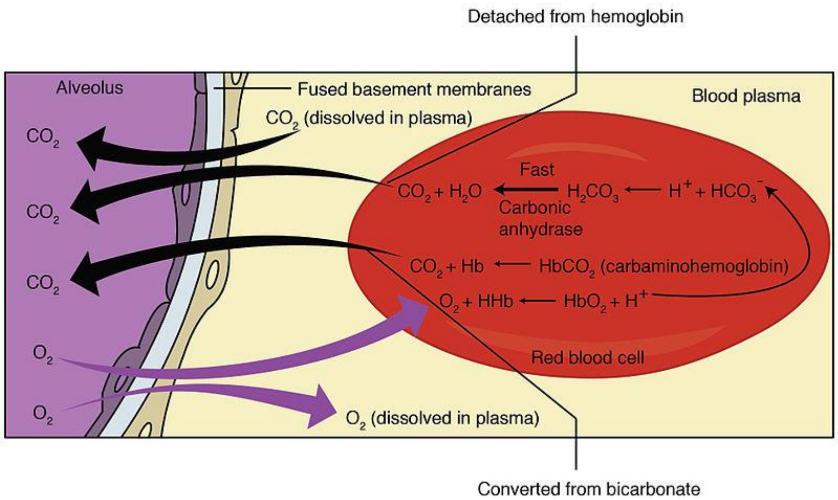


Fig.14.3. Internal respiration

Aerobic respiration involves three stages:

- Glycolysis (splitting of sugar) which occurs in the cytoplasm
- Kreb's cycle which occurs in the matrix of the mitochondrion

Oxidative phosphorylation which occurs across the membrane of the mitochondrion.

The oxygen is the final electron acceptor of what is known as the electron transport chain found in the last stage, oxidative phosphorylation, of aerobic cellular respiration. Oxygen provides a force to drive the transport of electrons down the chain. As electrons move across the membrane, ATP is formed from ADP.

Water and carbon dioxide are produced as waste products of internal cellular respiration. Water is formed when protons combine with oxygen at the end of the electron transport chain.

Difference between External Respiration and Internal Respiration

External respiration occurs between cells of the body and the external environment while internal respiration occurs within cells.

Breathing:

External respiration involves breathing, while internal respiration does not.

Role of Hemoglobin:

External respiration involves oxygen attaching to or offloading from the heme of hemoglobin. This is not an internal respiration process.

Oxidation:

Internal respiration involves three stages: glycolysis, Krebs cycle and oxidative phosphorylation; this is not the case for external respiration.

Role of Oxygen:

Internal respiration can sometimes occur without oxygen, this is not the case with external respiration.

Entrance:

External respiration involves oxygen first entering the ventilatory structures such as lungs or gills; this is not the case with internal respiration.

Chemical Reaction:

External respiration is the mechanism of how oxygen physically enters the body and is moved around, while internal respiration is only a process of chemical reactions which involves oxygen as a driving force.

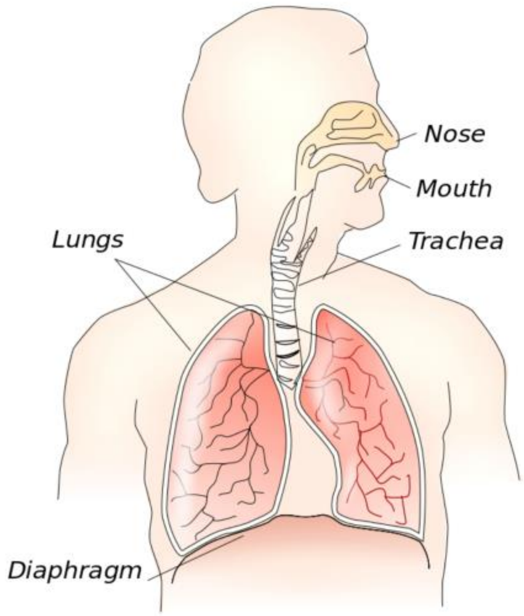


Fig. 14.4. Simple anatomy of respiratory system

Gas Exchange:

External respiration involves gas exchange, internal respiration does not.

Involvement of Water vs. Oxyhemoglobin:

Internal respiration involves protons eventually combining with oxygen to form water while in external respiration oxygen combines with hemoglobin to form oxyhemoglobin.

Let us sum up

Under this unit, we studied in detail about the internal and external respiration.

Check your Progress

1) The internal respiration is often called as __________ since it occurs within the cells.
2) The external respiration consists of two stages, they are __________ and __________.
3) The aerobic respiration generates a large amount of __________.

Glossaries

1. Amoebocytes: They basically store, digest and transport food, excrete wastes, secrete skeleton and also may give rise to buds in asexual reproduction

2. Phlebotomist: Health care worker who performs phlebotomy in healthcare settings.

3. Hemophilia : A medical condition in which the ability of the blood to clot is severely reduced, causing the sufferer to bleed severely from even a slight injury.

4. Thalassemia: Group of hereditary haemolytic diseases caused by faulty haemoglobin synthesis.

Suggested readings

1) **ROMER, A.S** (1979), Hyman's Comparitive Vertebrate Anatomy, III Ed., The University of Chicogo Press, London.
2) **WEICHERT, C.K** (1965), Anatomy of the Chordates, McGraw Hill Book Co., New York.

Weblink

Internal respiration https://youtu.be/6rVMNMZKBo0

External respiration https://youtu.be/YGGG_gKi0m8

Answers to check your progress

1) Cellular respiration
2) Breathing and gas-exchange
3) ATP

Unit 15

Comparative account of Respiratory Organs in Vertebrates

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able

- Explain the structure of gills
- Differentiate different kinds of gills
- Describe the mechanism of respiration
- List out the different types of accessory respiratory organs.

OVERVIEW

In this unit, we will study about the comparative account of respiratory organs in vertebrates. We will also focus on the various topics such as internal and external gills, spiracles, lungs, larynx, trachea, mechanism of respiration, accessory respiratory organs such as skin, swim-bladder, epithelial lining, pharyngeal diverticula, swim or air bladders.

15.1. INTRODUCTION

In vertebrates, the skin may be respiratory organ (e.g., anurans), while in some fishes and aquatic turtles, the vascular rectum or cloaca is respiratory organ. But there are two main types of respiratory organs, gills for aquatic respiration and lungs for aerial respiration. Both gills and lungs may occur in the same animal.

Accessory respiratory organs are also present in some vertebrates. In both kinds of respiration two conditions are essential; firstly the respiratory organs must have a rich blood supply with very thin moist epithelium covering the blood vessels so that these blood vessels are through into close contact with the environment (water or air).

Secondly in the organs of respiration the blood vessels should be reduced to thin capillaries which expose a large surface area to the environment, so that blood is brought into close contact with the water or air in the respiratory organs.

Exchange of oxygen and carbon dioxide occurs at two places, i.e., in the respiratory organs and in tissues. During internal respiration or tissue respiration exchange of O_2 and CO_2 occurs between blood and tissues (cells) of the body. During external respiration, gaseous exchange takes place between blood and external environment (e.g., in aerial respiration within lungs and in aquatic respiration within water and gills surface).

In lower aquatic vertebrates the respiratory organs are not connected to the olfactory organs, but in air-breathing vertebrates there is a close association between the two. In Choanichthyes there is a direct connection between the olfactory and respiratory organs in which the internal nares or choanae open from the nasal cavities into the buccal cavity, but it is only in tetrapoda that air enters through the nasal cavities into the buccal cavity and then into the lungs.

15.2. Gills

Gills are used for aquatic respiration found in fishes and amphibians. Gills are lacking in anamniotes. Besides exchange of gases at the surface of gills, salts are also eliminated from the gills surface in marine teleosts. Gills are of two types on the basis of their position- external gills and internal gills.

15.2.1. External Gills

In larvae of most amphibians the integument covering the outer surface of visceral arches gives off branching outgrowths which are tufts of filaments and are respiratory. Thus, these are of ectodermal origin. In some tailed amphibians, external gills and gill-slits are retained throughout life, but in some tailed and all tailless amphibians they are lost during metamorphosis and, hence, called larval gills.

In the embryo usually five pairs of pharyngeal pouches arise, of which only second, third and fourth perforate and open to the exterior. In most amphibians these gill-clefts are closed during metamorphosis. The third, fourth, and fifth visceral arches bear external gills. External gills are in direct contact with water and an exchange of gases occurs through their surface epithelium.

Later an operculum arises and covers these gill- clefts and gills externally in tadpoles so that the gills become enclosed in an opercular chamber lined with ectoderm. These external gills soon degenerate and a new set of gills called internal gills develop from the same visceral arches. However, these internal gills and operculum are not homologous with those of fishes.

External gills, though rare in fishes, are found in some larval forms of lampreys, Polypterus (bichir) has one pair of external gills. Dipnoi (Lepidosireri) have four pairs of filamentous external gills attached to the outer edges of the branchial arches.

The external gills of fishes disappear in the adult. Gills may be pectinate, bipinnate, dendritic or leaf-like. A gill has a narrow central axis bearing double row of filaments. These are richly vascularised by aortic arches. Gill-slits are not found.

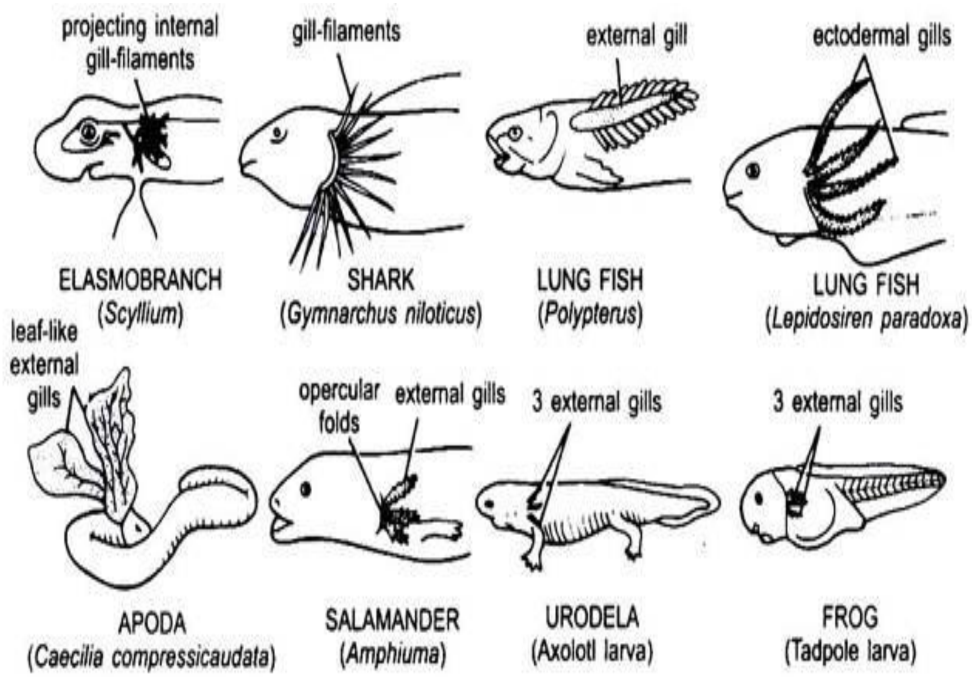


Fig. 15.1. Larval external gills of fishes and amphibians

15.2.2. Internal or True Gills

Internal gills are characteristic of fishes. These are placed in the gill-slits and attached to the visceral arches. In amniotes embryonic pharyngeal pouches do not communicate to the outside through gill-slits in the adults. Gills are not found in them.

Gill-Slits:

Embryologically gill-cleft develops as a result of a series of evaginations from the pharynx which grow outward and meet corresponding ectodermal invaginations from the outside. At each point of junction a cleft or pouch is formed so that water coming into the pharynx from the mouth may pass to outside.

The partitions between these passage ways contain cartilaginous or bony supports for the gill-filaments which are located on each side. These gill-slits persist in the adults of cyclostomes, fishes and certain amphibians, but become abolished in higher vertebrates. The number of gill-slits is 6-14 pairs in cyclostomes, 5 to 7 pairs in sharks and rays, 4 pairs in most bony fishes.

Structure of a True Gill:

These gills develop on the walls of gill-pouches or gill-arches. A gill is formed of two rows of a series of gill-filaments or gill-lamellae develop from the epithelium covering the interbranchial septum on both sides. Interbranchial septum extends outward from the cartilaginous arch.

A single row of gill-filaments on one side of interbranchial septum forms a half gill called a hemibranch or demibranch. An interbranchial septum with two hemibranchs (anterior and posterior) forms a complete gill or holobranch. These are richly supplied with blood vessels associated with aortic arches so that carbon dioxide in the blood may be exchanged for dissolved oxygen in the water.

Sharks and rays have generalized structure of gills. In higher bony fishes the interbranchial septum is lacking so that the hemibranchs on the anterior and posterior part of each branchial arch are no longer separated from one another.

Furthermore, the gill-apertures also no longer open separately to the outside. Instead, the gills are enclosed in a single chamber and covered externally by a large bony operculum which opens and closes posteriorly to permit water to pass to the outside. In most bony fishes there are four pairs of functional gills.

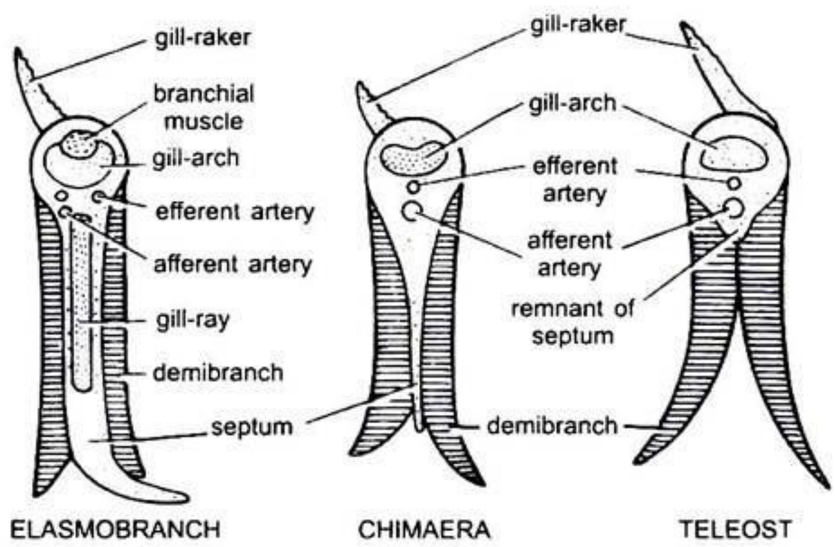


Fig. 15.2. Types of gills in fishes (L.S)

15.3. Spiracles

In sharks and rays an anterior pair of non-respiratory openings, one on either side between mandibular and hyoid arches are called spiracles or pseudobranchs. These are internally closed. These become closed or lost in lung fishes and bony fishes.

15.4. Lungs

Most adult amphibians and all amniotes breathe by means of lungs, though lungs are also present in lung fishes. In an embryo a hollow outpushing, called lung primordium arises from the ventral wall of the pharynx. It grows backwards and divides into two, right and left lung buds. The undivided proximal portion develops into trachea and larynx, and opens into pharynx by glottis.

Later lung buds grow posteriorly into coelom and branch repeatedly and get covered by mesoderm. Thus, each lung has an endodermal lining and an outer visceral peritoneum and in between the two mesodermal mesenchyme having blood and lymph vessels, nerves, and smooth muscle fibers and connective tissue. Inner endodermal epithelium of lungs is raised into a network of ridges to increase the vascularized surface exposed to the action of air.

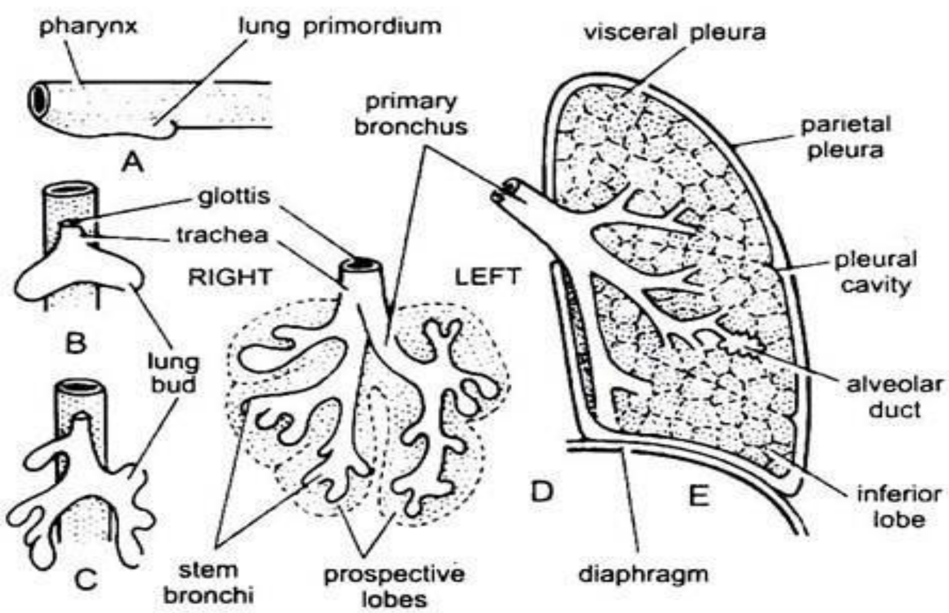


Fig.15.3. Development of a vertebrate lung in embryo

A. Lung Primordium; B & C. Lung buds; D. Embryonic lung; E. Lung at birth

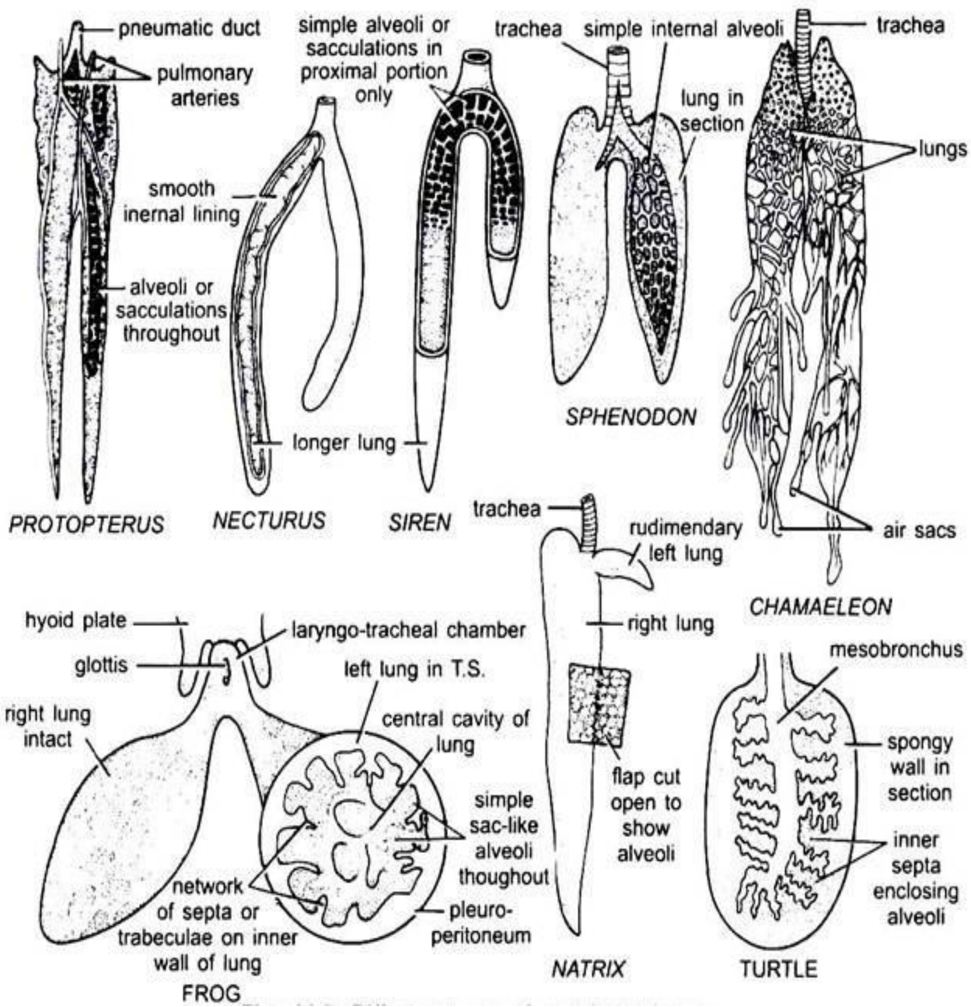


Fig. 15.4. Different types of a vertebrate lung

In lower forms, the lungs are hollow bags, but in higher forms the ridges increase in number and unite with one another across the lumen of the lung to convert it into a solid but spongy structure with innumerable air spaces. In mammals, the internal surface area of lungs may be thirty times that of the external surface area of the body.

The original duct of the lung sac connecting the pharynx to the lungs becomes a trachea in most. Trachea is absent in anurans. In many tetrapoda the anterior end of the trachea becomes modified into a larynx or sound box which opens into the pharynx by a glottis. At its lower end, the trachea divides into two bronchi, each of which enters a lung.

The bronchi divide to form an immense system of bronchioles carrying air into minute bags or alveoli. The alveoli have very thin walls invested with blood capillaries, an exchange of gases occur in the alveoli.

15.5. Larynx

The upper end of trachea is enlarged, especially in frogs and toads, to form the larynx or sound box in which the vocal cords are located. In Necturus, it is supported by a pair of lateral cartilages bounding the glottis. In other amphibians, each lateral cartilage is divided into a dorsal arytenoid and a ventral cricoid cartilage.

In frog, both the cricoid fuse to form a cartilaginous ring. Larynx is not more developed in reptiles. Larynx is not sound producing organ in birds, but serves to modulate tones that originate in the syrinx. Syrinx lies at the lower end of trachea where it divides into two bronchi.

It is the sound producing organ. Larynx is greatly developed in mammals. Its wall is supported by a pair of arytenoid, single cricoid and a single thyroid cartilage on the ventral surface. Glottis may be closed at the time of swallowing of food by a flap of muscular epiglottis.

15.6. Trachea

Trachea is extremely short or absent in Anura. It is merged with the larynx to form laryngotracheal chamber. Many caudate amphibians possess a short trachea, supported by cartilages. Trachea is simple in reptiles as in amphibians or may be long in long-necked reptiles such as turtles, trachea is long and convoluted.

Tracheal cartilages are sometimes in the form of complete rings. In birds, the trachea is long. In swans and cranes, trachea is longer than the neck and tracheal rings are complete and ossified. Trachea in mammals is variable and tracheal rings are usually incomplete on the upper side.

Lungs

In Polypterus (African bichir) paired ventral lungs are present which enable these to survive during periods of draught. Dipnoans belonging to subclass Sarcopterygii which branched off from Actinopterygii also have a lung-like structure. In all the living lung fishes, the lung is dorsal to the gut connected by a tube to the ventral side of the oesophagus.

In Protopterus (African) and South American Lepidosiren it is bilobed and unpaired in Australian lung fish. Their lungs unlike Polypterus contain internal chambers or pockets to increase the respiratory surface and highly vascularized by branches of pulmonary arteries and veins. In most bony fishes and presumably the crossopterygians also, the primitive lung has modified into a gas or swim bladder or hydrostatic organ.

It may or may not be connected with the oesophagus by a dorsal connection. In amphibians the lungs are simple, sac-like structures with a central large cavity. In aquatic amphibians the inner surface of lungs is smooth. In frogs and toads the inner walls contain numerous folds lined with alveoli so as to increase the respiratory surface. They are richly vascular and lined with mucous epithelium whose cells are columnar and ciliated.

In reptiles, lungs are more complex than those of amphibians with an increase in the number of internal chambers and alveoli. In some lizards one lung is considerably larger than the other, and in snakes the left lung is reduced or even absent in some species. Crocodilians possess lungs that are quite similar to those of mammals. A few lizards possess diverticula, extending posteriorly from the lungs, resembling air sacs of birds. In some lizards, the bronchi are subdivided into primary, secondary and tertiary bronchi.

In birds, the lungs are small and incapable of the great amount of expansion. The lungs, however, are connected with nine air sacs that are situated in various parts of the body. The air sacs have no respiratory epithelium, serve essentially as reservoirs. Air passes through the bronchial circuit into the air sacs and then returns, generally by a separate set of bronchi, to the air capillaries in the lungs.

The respiratory system of the mammal is much less complicated than that of the bird. The primary bronchi after entering the lung into secondary bronchi which divide into smaller and smaller bronchioles, finally terminating in tiny alveoli or blind pockets in which there is an exchange of gases.

In most mammals, lungs are subdivided externally into lobes, i.e., left lung has two lobes and right lung has three lobes in man and four lobes in rabbit. Lungs are simple and without lobes in whales, sirenians, elephants, hyrax and several perissodactyles. Right lung is lobulated in monotremes and rats. In sirenians, the lungs are elongated.

15.7. Mechanism of Respiration

In fishes and amphibians the mechanism of respiration is the same, the floor of the buccal cavity is lowered and water (fishes) or air (amphibians) is taken in, then the mouth is closed and the floor of the buccal cavity is raised which forces the water into gill-clefts in fishes or the air into the lungs in amphibians.

In amniotes air is taken in by increasing the volume of the lungs by an expansion of the thorax, this is done by movement of the ribs (and by movements of the diaphragm in mammals). In turtles where ribs are fixed to the carapace, the volume of lungs is increased by movements of the neck and limbs.

15.8. Accessory Respiratory Organs

Gills are the chief respiratory organs in aquatic vertebrates, like fishes and some aquatic urodeles, etc. The land vertebrates have the lungs for respiration. There are also other accessory structures for respiration, i.e., for taking oxygen directly from water or air.

15.8.1. Skin

Some fishes are able to survive outside water. The common eel, Anguilla can travel by wriggling on damp grass though it has no special respiratory organs, but it has vascular areas in the skin by which it can breathe both in water and on land. Secondly the opening of the operculum is small and rounded so that the eel can retain water in the branchial chamber and journey on land.

In amphibians also, the moist skin is highly vascular. Lungless salamanders (plethodonts) respire only through skin. Their larvae loses gills at metamorphosis and lungs do not develop in adults. African male hairy frog, Astylosternus have vascular hairy cutaneous outgrowths which act as respiratory surface.

Vascular caudal fin of Periophthalmus (mud-skipper) acts as respiratory organ during submergence. In the mud-skipper Periophthalmus of the Indian and Pacific Oceans the caudal fin is highly vascular, the head and trunk of the fish project above water when it perches on a rock, only the caudal fin remains submerged and acts as a respiratory organ.

15.8.2. Swim-Bladders

(i) The Indian climbing perch Anabas scandens has special air chambers above the gills, where three concentrically folded bony laminae, called labyrinth form organs are developed from the first epibranchial bone on each side. Their covering vascular mucous membrane brings about respiration. Anbas is so dependent on air that even in water it comes to the surface to gulp air and it is asphyxiated if prevented from doing so. It can survive for long periods on land and makes excursions by means of its many long spines on the operculum and ventral fins.

(ii) In Ophiocephalus there is an accessory branchial cavity on each side above the gills.

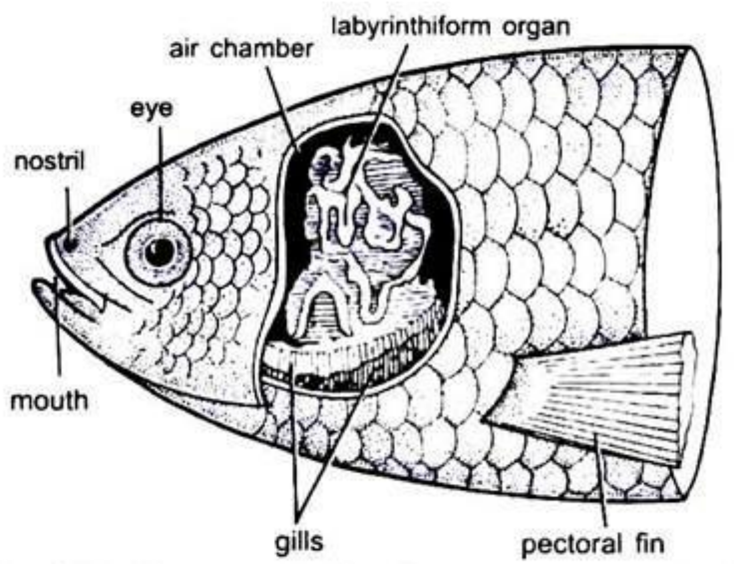


Fig. 15.5. Accessory respiratory organs of Anabas

15.8.3. Epithelial Lining

The loach Misgurnus swallows air which passes through the intestine and is voided by the anus, the highly vascular mucous membrane absorbs oxygen from the air, and carbon dioxide is also passed through the anus.

There may be other special organs for gaseous interchange. In Calichthys rectal respiration takes place, the rectum is highly vascular into which water is alternately taken in and pumped out.

15.8.4. Pharyngeal Diverticula

The Indian 'Cuchia eel' Amphipnous has poorly developed gills, but on each side of the body there is a vascular sac as an outgrowth of the pharynx which opens anteriorly into the first gill-cleft. These sacs are respiratory.

15.8.5. Branchial Diverticula

In the Indian catfish Saccobranchus (Fig. 15.6) there is a pair of large air sacs, each arising from the branchial chamber and extending laterally backwards into the trunk muscles. They can be filled with air for respiration.

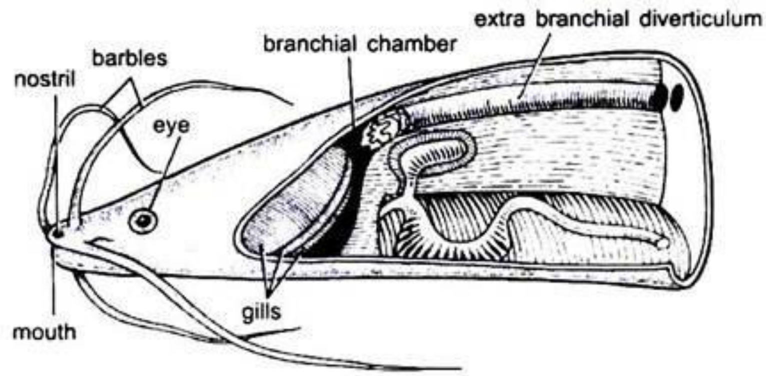


Fig.15.6. Accessory respiratory organs of Saccobranchus

The catfish Clarias (Fig. 15.7), found in Indian and African rivers, has a pair of supra-branchial organs, each lying on one side and divided into two parts, a highly branched arborescent organ formed from second and fourth branchial arches, and a vascular sac of the branchial chamber which encloses the arborescent organ.

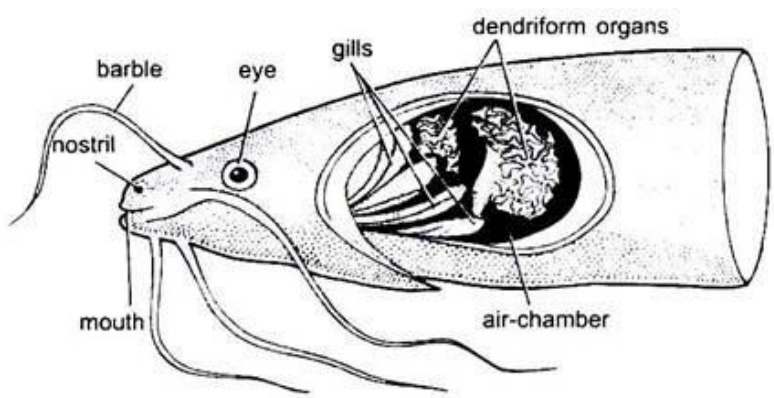


Fig.15.7. Accessory respiratory organs of Clarias

Several gill-fans formed by coalescing of gill-filaments close the entrance of the suprabranchial organ. Air is taken into the organ through the mouth continuously and Clarias cannot only live outside water for several hours but it can move along on damp grass. Accessory respiratory organs are found generally in tropical fishes of amphibious habit, they are devices for sustaining life out of water.

15.8.6. Swim or Air-Bladders

Swim or air-bladder arises as a diverticulum from the pharynx or oesophagus in bony fishes. It is originally lateral in position but becomes dorsal. It usually lies below or lateral to the vertebral column outside the coelom.

Let us sum up

Under this unit, we studied about the comparative account on respiratory system in vertebrates. We also focused on various topics such as internal and external gills, spiracles, lungs, larynx, trachea, mechanism of respiration, accessory respiratory organs such as skin, swim-bladder, epithelial lining, pharyngeal diverticula, swim or air bladders.

Check your Progress

1) The gills that are lost during metamorphosis is known as __________.
2) A single row of gill filaments on one side of interbranchial septum forms a half gill called __________.
3) In some fishes the anterior pair of non-respiratory opening which is present one on each side between the mandibular and hyoid arches are called __________.
4) __________ is a bone-laminae found in air chambers of climbing preach anabas.

Glossaries

1. Peritoneum :	It is the tissue that lines your abdominal wall and covers most of the organs in your abdomen. A liquid, peritoneal fluid, lubricates the surface of this tissue.
2. Coelomic :	The main body cavity in most animals and is positioned inside the body to surround and contain the digestive tract and other organs

Suggested readings

1) **WATERMAN, A.J** (1971), Chordate Structure and Function, The Macmillan Company.
2) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.

Weblink

Comparative account of respiratory organs https://youtu.be/iHIZOzBvafc

Answers to check your progress

1) Larval gills
2) Hemibranch
3) Spiracles
4) Labyrinth

Unit 16

Skeletal System

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able

- Explain the supporting tissues in animals
- Describe the human skeleton system
- Illustrate the development of skeletal system
- Explain the evolution of neurocranium and dermatocranium
- Explain appendicular skeleton and locomotion.

OVERVIEW

In this unit, we will study about the skeletal system. Under this, we will broadly focus on the support tissues of animals, human skeleton, development of skeleton, vertebrate skeletal anatomy, evolution of neurocranium, dermatocranium and visceral cranium, vertebral column, ribs, sternum, appendicular skeleton, locomotion and skeletal adaptation.

16.1. INTRODUCTION

The supportive framework of an animal body is called Skeleton. The skeleton of invertebrates, which may be either external or internal, is composed of a variety of hard non-bony substances. The more complex skeletal system of vertebrates is internal and is composed of several different types of tissues that are known collectively as connective tissues. This designation includes bone and the various fibrous substances that form the joints, connect bone to bone and bone to muscle, enclose muscle bundles and attach the internal organs to the supporting structure.

16.2. The supporting tissues of animals

Skeletons can be divided into two main types based on the relative position of the skeletal tissues. When these tissues are located external to the soft parts, the animal is said to have an exoskeleton. If they occur deep within the body, they form an endoskeleton. All vertebrate animals possess an endoskeleton, but most also have components that are exoskeletal in origin.

16.2.1. Exoskeletons

Many of the invertebrate phyla contain species that have a hard exoskeleton, for example, corals (Cnidaria); limpets, snails and Nautilus (Mollusca); and scorpions, crabs, insects and millipedes (Arthropoda). However, these exoskeletons have different physical properties and morphologies. The form that each skeletal system takes presumably represents the optimal configuration for survival.

Calcium carbonate is the commonly found inorganic material in invertebrate hard exoskeletons. The stony corals have exoskeletons made entirely of calcium carbonate, which protect the polyps from the effects of the physical environment and the attention of most predators. Calcium carbonate also provides a substrate for attachment, allowing the coral colony to grow. However, it is unusual to find calcium carbonate as the sole component of the skeleton. It normally occurs in conjunction with organic material, in the form of tanned proteins, as in the hard shell material characteristic of many mollusks. Cuticular exoskeletons are widely distributed among the invertebrates. They are formed by proteins that have been stiffened by the chemical action of phenols (the process is called tanning). Mineral salts may be incorporated within the cuticle for additional strength and stiffness.

The major advantage of a hard exoskeleton is the high degree of protection afforded to the body organs against mechanical damage and desiccation. Some disadvantages are the relatively large mass of the skeletal structure in proportion to the size of the soft tissues; the inability of some animals to remodel the skeleton and repair damage; and problems for a growing animal bounded by rigid skeletal tissues. Arthropods have solved this last problem by periodically shedding the old skeleton (molting) and replacing it with a new, larger one. Immediately after molting, the new skeleton is soft and compliant, allowing it to stretch to accommodate the increased size of the animal. During this period, the animal is more vulnerable to predation.

Endoskeletons Internal hard skeletons are less common among the invertebrates but are a feature of some mollusks and echinoderms. There are various degrees of skeletal reduction seen in these groups, as evidenced by the urchins which have a complete rigid skeletal test formed of calcareous ossicles sutured together, and by sea cucumbers in which the skeleton is reduced to microscopic ossicles. The vertebrate endoskeleton is usually constructed of bone and cartilage; only certain fishes have skeletons that lack bone. In addition to an endoskeleton, many species possess distinct exoskeletal structures made of bone or horny materials. This dermal skeleton provides support and protection at the body surface.

16.3. Human Skeleton

Various structural components make up the human skeleton, including collagen, three different types of cartilage, and a variety of bone types.

16.3.1. Collagen

Collagen is the most abundant protein in the body. It is of fundamental importance in all organ systems and is found in all parts of the musculoskeletal system. Tropocollagen, a structure composed of three polypeptide chains, forms the basic building unit of collagen. The rod like tropocollagen molecules polymerize into large collagen fibrils. Cross-links between adjacent molecules and also between fibrils give collagen its tensile strength. In tendons and ligaments, these fibrils are bundled together to form larger fibers. Tendons are formed from parallel bundles of fibers, an arrangement which allows tendons to support high uniaxial tensile loads to which they are subjected during activity. Although most ligament fibers are parallel, some have an oblique orientation. This reflects the more complex loading patterns applied to ligaments during movement, where small loads may be applied in a variety of directions. Collagen is stiff and strong only in tension.

16.3.2. Cartilage

The formation of cartilage (chondrogenesis) from mesenchyme occurs in many areas of the embryo, such as the skull, limbs and vertebral column. Most embryonic cartilage is replaced by true bone in endochondral bone formation, but in many regions the cartilage remains throughout life. The tissue consists of cartilage cells (chondrocytes) which manufacture, secrete, and maintain the extracellular organic matrix that surrounds them. This matrix contains a dense network of collagen fibrils within a concentrated solution of protein-polysaccharide molecules called proteoglycans.

The three main types of cartilage are fibrocartilage, elastic cartilage and hyaline cartilage.

Hyaline cartilage, the most abundant form of cartilage in the body, ossifies during development to become bone. In the adult it covers the articular surfaces of bones, supports the trachea and bronchi, forms the costal cartilages linking the first ten ribs to the sternum, and reinforces the nose. This type of cartilage contains extremely fine collagen fibrils that can be seen only with the electron microscope. Hyaline articular cartilage is a special form found within synovial joints. Its material characteristics are perfectly adapted to this mechanically demanding environment. Fibrocartilage is found predominantly in the pubic symphysis, the menisci of the knee, and the intervertebral discs. This type of cartilage is very durable and can withstand large tensile and compressive forces. It also represents a transitional material found at tendon and ligament insertions into bone and at the margins of some joint cavities. Histologically, it can be characterized by large collagen fibers running through the matrix. Elastic cartilage is similar to hyaline cartilage but contains abundant elastin fibers which give it a yellowish appearance and make it very flexible, while still maintaining its strength. It is found in the outer ear, the auditory tube, and the larynx.

16.3.3. Bone

This specialized rigid connective tissue comprises cells which produce an organic extracellular matrix of collagen fibers and ground substance, and inorganic materials in the form of mineral salts. In vertebrates, the mineral portion of bone consists primarily of calcium and phosphate in the form of hydroxyapatite crystals. The organic phase gives bone its resilience and flexibility, while the inorganic phase makes the bone hard and rigid. The functions of bone are numerous, relating to the maintenance of mineral (mainly calcium) homeostasis, formation of blood cells and mechanical requirements.

16.3.3.1. Mineral (mainly calcium) homeostasis

Plasma calcium ion (Ca,2+) concentrations are maintained at about 5 mEq/L. This concentration is effectively regulated by calcitonin and parathyroid hormone and is required for normal blood clotting and nerve and muscle function. Low concentrations of calcium in the extracellular fluid that bathes the parathyroid glands elicits parathyroid hormone release. This stimulates osteoclastic breakdown of bone, releasing calcium and phosphorus into the extracellular fluid. Simultaneously, calcium absorption from the gut is increased, calcium loss via the kidneys is decreased, and urinary phosphate excretion is elevated. Calcitonin, released from the thyroid gland in response to elevated calcium concentrations, inhibits calcium removal from bone and increases urinary calcium excretion.

16.3.3.2. Formation of blood cells

During embryonic development, cellular elements of the blood (red and white blood cells and platelets) are produced by a process known as hematopoiesis. Early production occurs in the vessels of the yolk sac, but following the development of other organ systems, major blood cell production occurs in the liver, spleen, thymus and bone marrow. At about the sixth developmental month, red bone marrow becomes the major site for the production of red and white blood cells and platelets. In adults, bone is the primary site for white cell production and the only site for red cell production, with portions of the sternum, ribs, vertebrae, skull, pelvis, scapulae and proximal femoral and humeral heads of particular importance.

16.3.3.3. Mechanical requirements (support, protection and leverage).

Bone has a protective function, particularly with regard to the central nervous system. The skeleton is the supporting framework for the body and provides stiff levers on which muscles act to generate movement.

There are a number of easily recognized bone types whose microstructure can be related to the mechanical functions required of the bone. The only type of bone that does not require a preexisting surface or structure for its formation is woven bone. Woven bone is formed during early stages of development, and in adults it is encountered only in pathological conditions, including bone fracture repair. It consists of randomly oriented, small-diameter, highly mineralized collagen fibers. It is not a strong form of bone because of its unordered structure and, particularly, because much of its volume is unmineralized. Its value lies in its ability to rapidly bridge the gap between broken ends of bone to act as temporary scaffolding during the process of repair. It is later removed by bone remodeling events

Lamellar bone is the dense hard material that constitutes most of the skeleton. In a typical bone, such as the femur, lamellar bone has two distinct types of organization. In the shaft (diaphysis) the material is deposited in layers to form compact or cortical bone. A transverse section through the diaphysis would show a tree-ring-like arrangement of bone. Bone cells (osteocytes) occupy spaces between adjacent lamellae. They interconnect with vascular spaces and one another by fine cellular extensions running in narrow channels (canaliculi). These cells maintain the integrity and normal functioning of bone. Two other main cell types important in normal bone are the bone-forming cells (osteoblasts), and the bone-destroying or bone-resorbing cells (osteoclasts).

Trabecular (spongy) bone is another form of lamellar bone found particularly in the expanded ends (epiphyses) of long bones and in the vertebrae. Although it is made of the same material as cortical bone, the mechanical characteristics of trabecular bone differ as a result of the honeycomb arrangement of bone into interlacing struts (trabeculae). This spongy bone is less dense and stiff than cortical bone, and has a large surface area which makes this tissue important for the exchange of calcium between the skeleton and the bloodstream.

Plexiform or fibrolamellar bone is a medium-density, relatively strong bone. It is found at sites of rapid growth where strength is also needed, such as in the limbs of large, fast-growing animals, which include humans during the growth phase in puberty.

Haversian systems or secondary osteons are structural units of bone that are formed secondarily within preexisting bone. This intracortical remodeling involves the formation of a tunnel through bone, achieved by the action of osteoclasts generating a resorption cavity. Following a reversal phase, in which a cement lining is deposited around the perimeter of the cavity, the tunnel is refilled with concentric rings of new bone by osteoblastic activity. A small-diameter central canal containing blood vessels is left unfilled. A completed secondary osteon is a branched structure. Secondary osteons form throughout life and are implicated in skeletal adaptation, repair processes, and mineral exchange between blood and bone (Fig. 16.1).

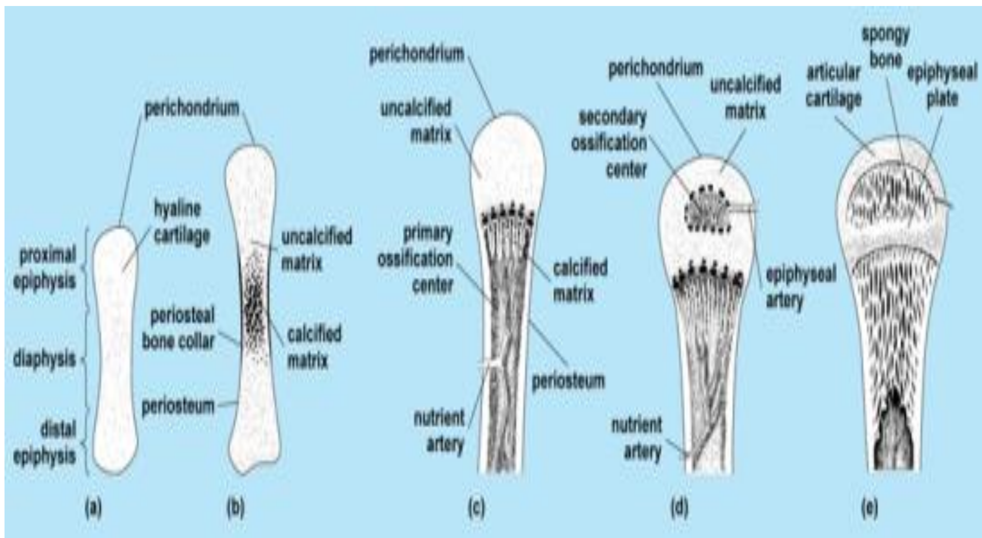


Fig.16.1: Development of endochondral ossification in a long bone. (a) Mesenchymal cells differentiate into chondroblasts which form the hyaline cartilage model. (b) The cartilage model grows, and chondrocytes in the midregion calcify the matrix. (c) The primary ossification center and the medullary cavity form. (d) Postnatal development of the secondary ossification center occurs. (e) Remnants of hyaline cartilage as articular cartilage and epiphyseal plate persist.

16.4. Development of the skeleton

All the components of the skeleton are derived from mesenchyme of either mesodermal or neural crest ectodermal origin. The majority of bones in the human body develop by the process of endochondral ossification; that is, the mesenchyme first forms a cartilaginous model which is subsequently replaced by true bone. The facial bones and certain bones of the cranium are formed by intramembranous ossification, in which mesenchyme is converted into skeletal elements by forming bone directly, without need of a cartilage stage. Sesamoid bones are specialized intramembranous bones that form within tendons

16.4.1. Ossification

The development of bone from the embryo to the adult depends on the orderly processes of mitotic division, growth and remodeling. These are determined largely by genetics, but are strongly influenced by hormonal action and nutrition. In endochondral ossification, the cartilaginous model is gradually calcified, resulting in cartilage cell (chondrocyte) death. Osteoblasts, together with a blood supply, invade the model and begin to secrete osteoid, which subsequently mineralizes and forms a primary ossification site. This process is repeated in the epiphyses of long bones to form secondary ossification sites. It is normal for the primary ossification site to form earlier, grow more rapidly, and cease ossification later than the secondary sites.

The locations and ages at which ossification sites are active in the developing human skeleton are well documented. Hand and wrist x-radiographs are used to determine the skeletal age of individuals because of the orderly progression of ossification in these regions. Such information is important for checking whether an individual's growth rate is abnormal and whether hormone treatment is indicated. Applications also exist in the forensic field, where age at death can be accurately predicted from skeletal remains.

Two parts of developing bones remain as cartilage: epiphyseal plates and articular cartilage. Epiphyseal plates are situated between the diaphysis and the epiphysis. Longitudinal bone growth occurs by chondrocyte proliferation on the diaphyseal sides. The plates are finally obliterated by an extension of diaphyseal ossification into these regions, thus preventing further growth in the length of the bone. Articular cartilage never ossifies except in pathological situations such as osteoarthritis.

Changes in the radial dimensions of long bones occur by new material being deposited beneath the periosteum, a connective tissue membrane surrounding the bone. The endosteal membrane is the equivalent structure lining the internal surfaces of tubular bones. Bone tissue can be added or removed at either site by the action of osteoblasts or osteoclasts, respectively. During growth and aging, there is a tendency for net bone deposition periosteally, with net resorption endosteally.

Bone growth and fracture repair can be increased by mechanical and electrical stimulation. Mechanical deformation of bone causes fluid flow through microscopic channels in bone, resulting in fluid shear stresses on cell membranes and/or production of strain-generated electrical potentials. Both effects have been shown to have osteogenic effects, with osteocytes responding to fluid flow changes, and osteoblast-mediated bone deposition occurring subsequent to mechanical loading in which strain-generated electrical potentials are recorded. In addition, electrical stimulation alone can promote osteogenesis under a wide range of conditions, including nonunion bone fractures and the maintenance of bone mass even in the absence of mechanical function. The mechanisms appear to involve insulin like growth factors and / or transforming growth factor-β. Elevated levels of both accompany electrical stimulation, and insulin like growth factors are capable of stimulating proliferation and differentiation of osteoprogenitor cells. Transforming growth factor-β is known to have important effects on bone formation, osteoblast proliferation and differentiation, and matrix synthesis. Furthermore, in vertebrates, there are transforming growth factor-β related signaling proteins (bone morphogenetic proteins and activin) that effectively regulate animal development, can induce cartilage and bone formation, and play critical roles in modulating mesenchymal differentiation.

16.4.2. Joints

In the human body there are fibrous, cartilaginous, and synovial joints. Functionally, these joints can be considered as immovable (synarthrosis), partly movable (amphiarthrosis), and freely movable (diarthrosis) joints, respectively.

Immovable joints are represented by cranial sutures and epiphyseal plates prior to their ossification. Little or no movement is available at these joints. Instead, their primary function is to allow bone growth at their margin (Fig. 16.2).

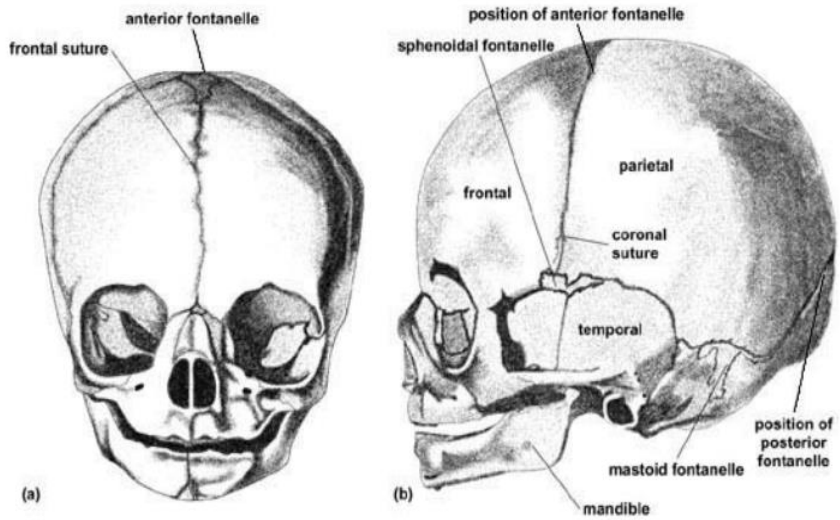


Fig. 16.2: Skull in a human newborn infant. Cranial sutures and areas of temporary cartilage (fontanelles) form articulations between bones. (a) Frontal view. (b) Lateral view.

Partly movable joints include the pubic symphysis that joins the two halves of the pelvis anteriorly and the fibrocartilaginous intervertebral discs. While the amount of movement between adjacent vertebrae is quite limited by disc stiffness, the vertebral column as a whole is quite flexible. Flexibility is achieved by combining each of the small movements permitted by individual discs.

Freely movable joints are the most complex and varied of the three types of joint, with their sizes and shapes matched to the functional requirements of the skeletal system at each location. At each joint, the surfaces of opposing bones are covered with a layer of articular cartilage that is a few millimeters thick. The joint is enclosed within a flexible joint capsule, the internal surface of which is lined by the synovial membrane that secretes the lubricating synovial fluid into the joint space. The main functions of articular cartilage are to distribute compressive loads over a wide area in order to reduce contact stresses, and to allow relative movement of opposing joint surfaces with minimum wear and friction. The combination of articular cartilage and synovial fluid gives these joints these remarkable properties.

16.4.3. Articular cartilage

Collagen fibrils, enmeshed within a proteoglycan solution, form the superficial part of articular cartilage. Beneath the relatively soft articular cartilage lies an interface (the tidemark) that indicates the start of the calcified cartilage layer. Beneath the cartilage lies a layer of subchondral bone which itself lies over the trabecular bone of the epiphysis. A gradient of increasing stiffness exists from the articular surface to the trabecular bone that helps protect the cartilage from splitting under loading conditions.

Synovial joints are subjected to an enormous range of forces. For example, the joints in the lower limb of humans have to support transient forces between two to five times body weight during running and jumping, and moderate but prolonged loading during standing. The nearly frictionless operation of joints is thought to be a function of lubricating films of synovial fluid between, and an adsorbed boundary lubricant on, the articular cartilage surfaces. The ability of cartilage to resist deformation when subjected to high stresses resides in complicated interactions between collagen fibrils, water and proteoglycans, particularly keratin sulfate, chondroitin sulfate, and hyaluronic acid.

Damage to cartilage is thought to be a function of both the magnitude of applied forces and the speed at which forces are applied (with impact loading causing more damage). Due to its avascular nature, articular cartilage has a limited capacity for repair of such damage

16.5. Vertebrate Skeletal Anatomy

The vertebrate skeleton consists of the axial skeleton (skull, vertebral column and associated structures) and the appendicular skeleton (limbs or appendages). The basic plan for vertebrates is similar, although large variations occur in relation to functional demands placed on the skeleton.

16.5.1. Axial skeleton

The axial skeleton supports and protects the organs of the head, neck and torso, and in humans it comprises the skull, ear ossicles, hyoid bone, vertebral column and rib cage.

16.5.2. Skull.

The adult human skull consists of eight bones which form the cranium or braincase, and 13 facial bones that support the eyes, nose and jaws. There are also three small, paired ear ossicles: the malleus, incus, and stapes, within a cavity in the temporal bone. The total of 27 bones represents a large reduction in skull elements during the course of vertebrate evolution. The three components of the skull are the neurocranium, dermatocranium and visceral cranium.

The brain and certain sense organs are protected by the neurocranium. All vertebrate neurocrania develop similarly, starting as ethmoid and basal cartilages beneath the brain, and as capsules partially enclosing the tissues that eventually form the olfactory, otic and optic sense organs. The basal and ethmoid plates expand to meet the olfactory and otic capsules to form a floor on which the brain rests. The optic capsule becomes the fibrous sclerotic coat of the eyeball and remains free to move independently of the skull. Further development produces cartilaginous walls around the brain. Passages (foramina) through the cartilages are left open for cranial nerves and blood vessels. The largest opening is the foramen magnum, through which the spinal cord passes. Endochondral ossification from four major centers follows in all vertebrates, except the cartilaginous fishes.

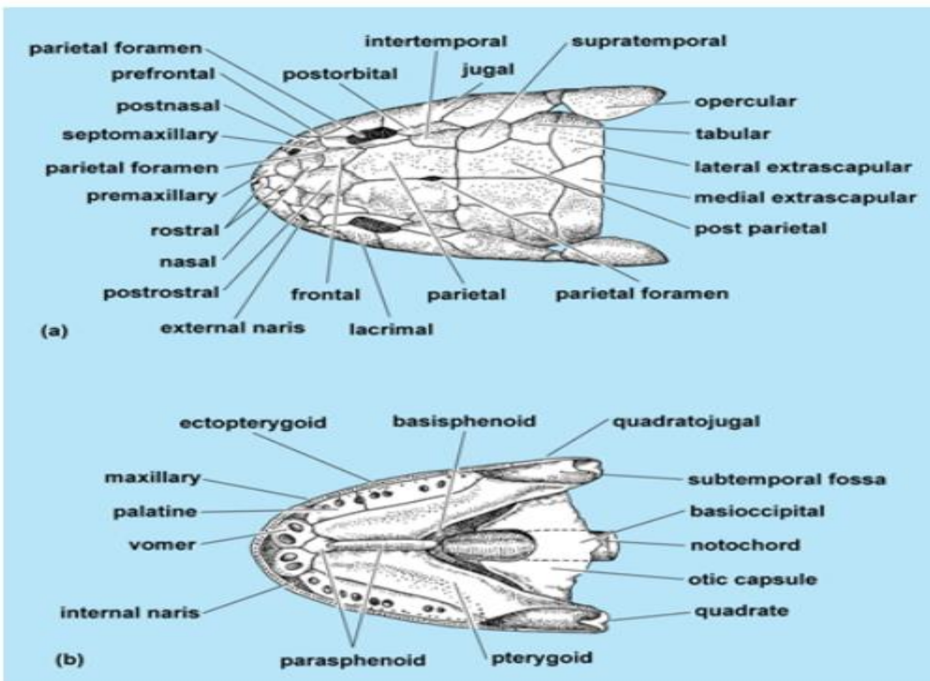


Fig. 16.3: Skull of Eusthenopteron, a generalized fossil crossopterygian fish from Devonian time. (a) Dorsal aspect. (b) Ventral aspect.

It is likely that the bones of the dermatocranium derive from the dermal armor (bony scales) of early fishes. In modern vertebrates, these bones form via intramembranous ossification from subdermal mesenchyme.

The basic structure from which the tetrapod dermatocranium probably evolved is seen in the primitive crossopterygian fishes and early amphibians. Four kinds of bones are involved.

(1) Roofing bones form above and on each side of the brain and neurocranium. These comprise paired nasal, frontal, parietal and postparietal bones that cover the dorsal parasagittal area, while prefrontal, postfrontal, post- orbital, infraorbital and lacrimal bones form a ring around the orbit. The posterolateral part of the skull is formed from the paired intertemporal, tabular, supratemporal, squamosal and quadratojugal bones.

(2) Dermal, tooth-bearing bones (premaxillae and maxillae) form the margins of the upper jaw.

(3) Bones of the primary palate form the roof of the mouth in lower tetrapods and the oropharynx of fishes, and are the paired vomers, palatines, pterygoids and ectopterygoids and the unpaired para-sphenoid.

(4) Opercular bones extend posteriorly from the hyoid arch to cover the gill slits. These are paired bones, represented by large opercular bones and smaller subopercular, preopercular and interopercular bones.

16.5.3. Visceral skeleton.

This skeleton of the pharyngeal arches is demonstrated in a general form by the elasmobranch fishes, where all the elements are cartilaginous and support the jaws and the gills. Each pharyngeal arch is typically composed of a number of cartilage elements, most of which support gills, but the first and second arches are modified to function in feeding. The mandibular (first) arch consists of two elements on each side of the body: the palatoquadrates dorsally, which form the upper jaw and Meckel’s cartilages, which join ventrally to form the lower jaw. The hyoid (second) arch has paired dorsal hyomandibular cartilages and lateral, gill-bearing ceratohyals. This jaw mechanism attaches to the neurocranium for support. Variations in this articulation occur between species and effectively determine jaw movement, and hence, the feeding abilities of fishes.

16.6. Evolution of neurocranium and dermatocranium.

Modern amphibian skulls differ considerably from the primitive forms. Most changes involve the loss of roofing bones, particularly those from around the orbit, and massive reduction of the primary palate. These changes allows the eyes, which normally protrude from the head for good vision, to retract until they bulge into the oral cavity.

Early reptiles maintained the primitive pattern of the skull roof, with loss of only the intertemporal bone. Later reptiles exhibited large losses of bony elements, mostly from the temporal region and the back margin of the skull. Major changes in the roof of the skull are associated with the development of temporal fenestrae, resulting in four recognized design types: anaspids exhibit a primitive condition with a solid skull roof (turtles and stem reptiles); diaspids have two openings on each side of the skull (archosaurs and the ancestors of lizards and snakes); euryapsids have a single, dorsal opening on each side (ichthyosaurs and plesiosaurs); and synapsids have a single, lateral opening (pelycosaurs and therapsids). Birds derive from archosaurian reptiles and have, essentially, a diaspid skull design. The pelycosaur stock with a synapsid skull, gave rise to the mammals.

A secondary palate appears for the first time in the reptiles as a horizontal shelf of bone dividing the oral cavity into separate nasal and oral passages. The remaining bones of the more primitive primary palate are located in the nasal passageway. Only the crocodilians, among the reptiles, have a complete secondary palate formed from medial extensions of the maxillae, premaxillae, pterygoid and palatine bones.

The avian skull has been modified from the diaspid reptilian type in line with increased brain size and changes in lifestyle, particularly feeding and flight behavior. Premaxillae and dentary bones form the majority of the upper and lower beak, respectively. Some birds can raise the upper portion of the beak relative to the rest of the skull by a hinge mechanism between the frontal bone and the premaxillae, maxillae and nasal bones. This is one of the many forms of cranial kinesis, where motion (usually of the upper jaw) is possible, partially independent of other parts of the skull. Most vertebrates other than mammals are capable of cranial kinesis, which is a feeding adaptation.

The therapsids are mammal like reptiles that evolved large temporal fenestrae in the dermal bones of the cheek region. Other notable changes involved the loss, fusion, or reduction of roofing bones and a large variation in bone proportions and sizes. A secondary palate formed from the premaxillae, maxillae, and palatines separates the nasal and oral cavities in a manner that was similar to the crocodilians. This palate continues posteriorly as a fold of skin, the soft palate. The value of a divided airway is that it gives the animal the ability to breathe while the mouth is full.

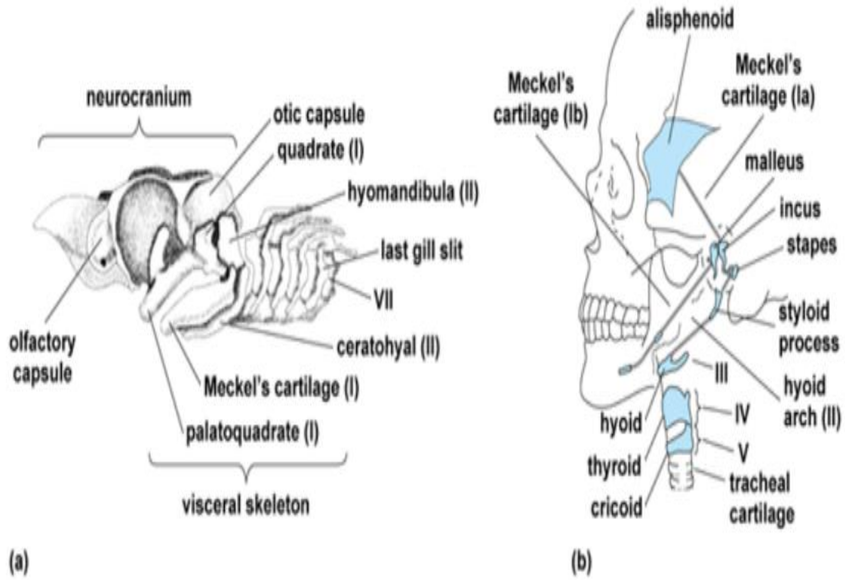


Fig. 16.4: Skull and visceral skeleton. (a) Shark. The skeleton of the first, second and seventh pharyngeal arches is indicated. (b) Human. Shaded regions show the components of the human skull and neck that are derived from the visceral skeleton.

Notable increases in the size of the brain during mammalian evolution have resulted in considerable changes to the neurocranium. The zygomatic arches are the true remnants of the original lateral walls of the skull. The temporal bone, as seen in humans, is a single unit, but is really a composite of a large number of fused skeletal elements of endochondral and membranous origin. The occipital bones are usually fused, and the single occipital condyle, present in reptiles and birds, divides to become a paired structure as in modern amphibians. Large changes occur in the organization of the otic capsule, with the inclusion of a new skull bone (the entotympanic) and dermal bone (derived from the angular bone of the reptilian jaw) in a protective role for the middle ear.

16.7. Evolution of visceral cranium.

In all jawed vertebrates except mammals, an articulation between the posterior ends of the palatoquadrate and Meckel's cartilages (which may be ossified or ensheathed in bone) occurs between the upper and lower jaws (Fig. 16.4). The bony fishes have elaborated on the primitive condition, where the upper jaw was fused to the skull and the lower jaw or mandible could move only in the manner of a simple hinge. Teleosts are able to protrude the upper and lower jaws. This motion, coupled with expansion of the buccal cavity, enables these fishes to generate the large suction forces used to draw food into the mouth. In the course of mammalian evolution, the dentary of the lower jaw enlarged and a ramus expanded upward in the temporal fossa. This eventually formed an articulation with the squamosal of the skull. With the freeing of the articular bone (seen as an ossified posterior end of Meckel's cartilage in teleosts) and the quadrate from their function in jaw articulation, they became ear ossicles in conjunction with the columella, that is, a skeletal rod that formed the first ear ossicle, arising in the amphibia to conduct sound waves from the eardrum to the otic capsule.

The remaining visceral skeleton has evolved from jaw and gill structures in the fishes to become an attachment site for tongue muscles and to support the vocal cords in tetrapods.

16.8. Vertebral column, ribs, and sternum.

The vertebral column is an endoskeletal segmented rod of mesodermal origin. It provides protection to the spinal cord, sites for muscle attachment, flexibility and support, particularly in land-based tetrapods where it has to support the weight of the body (Fig. 16.5).

16.8.1. Vertebrae

Hard, spool-shaped bony vertebrae alternate with tough but pliable intervertebral discs. Each typical vertebral body (centrum) has a bony neural arch extending dorsally. The spinal cord runs through these arches, and spinal nerves emerge through spaces. Bony processes and spines project from the vertebrae for the attachment of muscles and ligaments. Synovial articulations between adjacent vertebrae (zygapophyseal joints) effectively limit and define the range of vertebral motion.

Vertebral morphology differs along the length of the column. There are two recognized regions in fishes (trunk and caudal) and five in mammals (cervical, thoracic, lumbar, sacral and caudal), reflecting regional specializations linked to function. Humans have seven cervical, twelve thoracic, five lumbar, five (fused) sacral and four coccygeal vertebrae. Most amphibians, reptiles and mammals have seven cervical vertebrae regardless of neck length (giraffes have only seven), whereas the number is variable in birds. Specific modification to the first two cervical vertebrae in most reptiles, birds and mammals gives the head extra mobility. In humans, the occipital condyles articulate with the atlas, which in turn articulates with the axis, all via synovial joints. The atlas is a ringlike vertebra whose centrum is represented as a peg of bone fused to the axis. This odontoid process provides a pivot about which the atlas, and hence the head, swivels. The nodding movement is provided by rotational motion at the atlanto-occipital joint.

The presence of large ribs in the thoracic region often limits spinal flexibility. Birds utilize fusion of thoracic vertebrae to provide a rigid structure, adapted for the demands of powered flight. Additionally, fusion of the lumbar, sacral, and proximal caudal vertebrae produces a rigid back, the synsacrum In typical tetrapods, the sacral region is usually modified for support of the pelvic girdle, while the number of caudal vertebrae varies greatly (from 0 to 50) between and within animal groups. Birds have a specialized end cap to the caudal vertebrae (pygostyle) for the attachment of feathers.

16.8.2. Sternum and ribs

Jawed fishes have ribs that help maintain the rigidity and support of the coelomic cavity. These ribs typically follow the connective tissue septa that divide successive muscle groups. In the caudal region, they are often small paired ventral ribs, fused on the midline to form the haemal arches. Ancestral tetrapods had ribs on all vertebrae, and their lengths varied between the vertebral regions. Modern amphibia (frogs and toads) have few thoracic ribs, and these are much reduced and never meet ventrally. Reptiles have varied rib arrangements, ranging from snakes with ribs on each vertebra (important for locomotor requirements) to turtles with only eight ribs which are fused to the inside of the carapace. Flying birds and penguins have a greatly enlarged sternum that links the ribs ventrally. This provides a large surface area for the origin of the powerful pectoralis muscles that are used to power the down stroke of the wing. In humans, there are twelve pairs of ribs which form a strong but movable cage encompassing the heart and lungs.

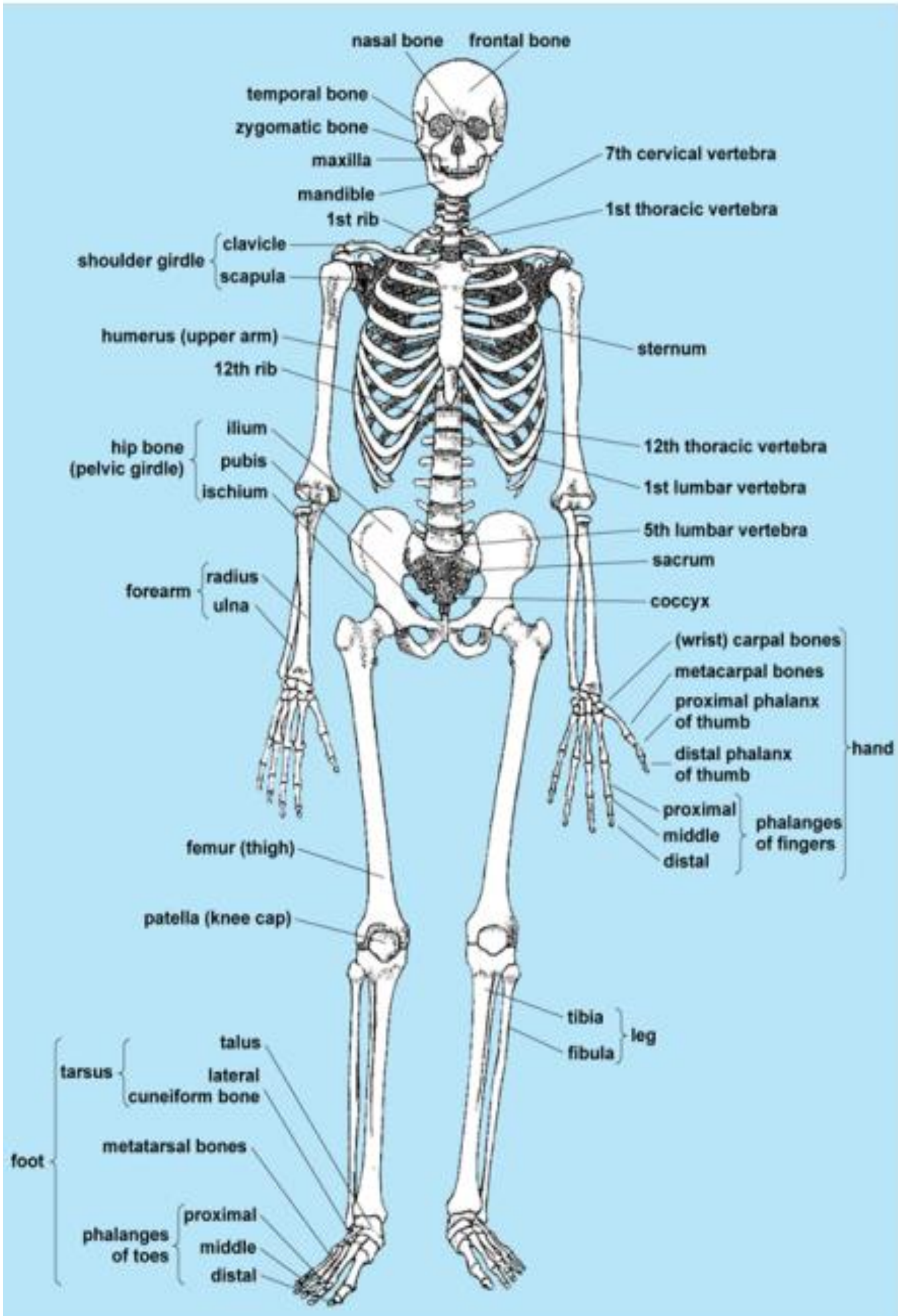


Fig. 16.5: Human skeleton (anterior view).

16.9. Appendicular skeleton

This section of the skeletal system comprises the pectoral and pelvic limb girdles and bones of the free appendages. The girdles provide a supporting base onto which the usually mobile limbs attach.

16.9.1. Pectoral girdle

The pectoral girdle has both endoskeletal and dermal components. The dermal components are derived from postopercular dermal armor of primitive fishes, and are represented by the clavicles and interclavicles in modern vertebrates, except where they are secondarily lost. Endochondral bone forms the scapula. In fishes, the main component of the girdle (the cleithrum) is anchored to the skull by other bony elements. Increased mobility of the girdle is seen in amphibia as it becomes independent of the skull. Further development and skeletal reduction have resulted in a wide range of morphologies, culminating in the paired clavicles and scapulae of mammals.

Birds have fused their paired clavicles and single interclavicle to form the wishbone or furcula. This provides an increased site for the origin of the pectoral muscles, both directly and from the fascial sheet spanning the two arms. Bending of the furcula during flight is thought to assist breathing by compressing or expanding underlying air sacs. It also has a role in storing, and subsequently returning, elastic strain energy at functionally useful parts of the wing beat cycle. Clavicles have disappeared in certain groups of bounding mammals to allow greater movement of the scapula. Although humans, and most other mammals, have a coracoid process on the scapula, other tetrapods typically have a separate coracoid bracing the scapula against the sternum and forming part of the glenoid fossa.

16.9.2. Pelvic girdle

The pelvic girdle forms by endochondral ossification, that is, the conversion of cartilage into bone. In the fishes, it is a small structure embedded in the body wall musculature just anterior to the cloaca. Each half of the girdle provides an anchor and articulation point for the pelvic fins. In tetrapods, the girdle attaches to the vertebral column to increase its stability and assist in the support of body weight and locomotor forces.

Humans, like all other tetrapods, have a bilaterally symmetrical pelvic girdle, each half of which is formed from three fused bones: the ischium, ilium and pubis. A part of each of these elements forms the acetabulum, the socket-shaped component of the hip joint, and that articulates with the femoral head.

The human pelvis is bowl-shaped, helping to support the viscera in upright stance. The large ilium (a feature shared with certain heavy-bodied animals such as cattle and horses) is the site of origin of hip extensor muscles, the gluteals. They prevent the body from bending sharply at the hip and also assist powerful thigh muscle extension during the propulsive stage of running.

All urogenital and digestive products have to pass through the pelvic outlet. This accounts for the pelvic sexual dimorphism seen in most mammals, where the pelvic opening is broader in females, because of the physical demands of pregnancy and parturition. In birds (with the exception of the ostrich and the rhea), both sexes have an open pelvic girdle, a condition also found in female megachiropteran bats (flying foxes), gophers and mole-rats.

16.9.3. Paired fins and tetrapod limbs

Paired fins in fishes come in different forms, but all are involved in locomotion. In the simplest form they are fairly rigid and extend from the body, functioning as stabilizers, but they are also capable of acting like a wing to produce lift as in sharks. In many fishes, the pectoral fins have narrow bases and are highly maneuverable as steering fins for low-speed locomotion. In addition, some fishes (such as the Australian lungfish) use their pectoral and pelvic fins to walk on the river bed, while others have greatly enlarged pectoral fins that take over as the main propulsive structures (for example, rays, flatfish).

The basic mammalian pectoral limb consists of the humerus, radius, ulna, carpals, five metacarpals and fourteen phalanges (arranged as 2-3-3-3-3, starting at the thumb; reptiles tend to have a 2-3-4-5-3 arrangement); and the pelvic limb consists of the femur, tibia, fibula, tarsal, five metatarsals and fourteen phalanges (mammals have various digital arrangements; most reptiles have a 2-3-4-5-4 arrangement). Variation in the shape and number of elements occurs primarily in the hand (manus) and foot (pes). A typical bird pelvic limb consists of a femur, tibiotarsus (formed by fusion of the tibia with the proximal row of tarsal bones), fibula and tarsometatarsus (formed by fusion of metatarsals II–IV), metatarsal I, and four digits (each consisting of two to five phalanges).

16.10. Locomotion and skeletal adaptations

Throughout evolution, the skeletal system has adapted to the needs of many different types of organisms. Such adaptations have been made for walking and running, speed, power, digging and burrowing, locomotion without limbs, and aerial and aquatic locomotion. Walking and running. The undulatory side-to-side flexion of the vertebral column seen in most fishes continued to play a role in early tetrapod locomotion. It still exists in the urodeles (for example, newts) and many reptiles where limbs project laterally, with the proximal element swinging in the horizontal plane. The feet provide points of firm contact with the ground in this sprawling locomotor style, with forward progression powered by lateral trunk flexion. Most terrestrial tetrapods have raised the trunk off the ground, with the limbs projecting ventrally to support the body. Changes in joint alignment resulted in the limbs and trunk flexing and extending in the sagittal plane.

16.10.1. Adaptations for speed

Animals use various recognizable forms of locomotion, or gaits, for traveling at different speeds. The voluntary selection of a particular gait appears to be linked to reducing locomotor forces on the limb skeleton and minimizing the energetic cost of travel. Obvious modifications to the basic tetrapod skeleton have accompanied the acquisition of high-speed locomotion. The lengthening of limb segments allows for longer strides which, coupled with stride frequency, determine running speed. Limb elongation has been accompanied by a reduction in the number of skeletal elements in running specialists (Fig. 16.6).

The normal pentadactyl (five-digit) limb is seen in plantigrade animals, such as primates and insectivores, where the ankles, wrists, and all bones distal to these joints contact the ground. Humans have a bipedal plantigrade posture. A plantigrade posture typically provides stability (large foot-ground contact area) and good manual or pedal dexterity (useful for climbing, and holding and manipulating objects), but does not provide particularly good running performance (Fig. 16.7).

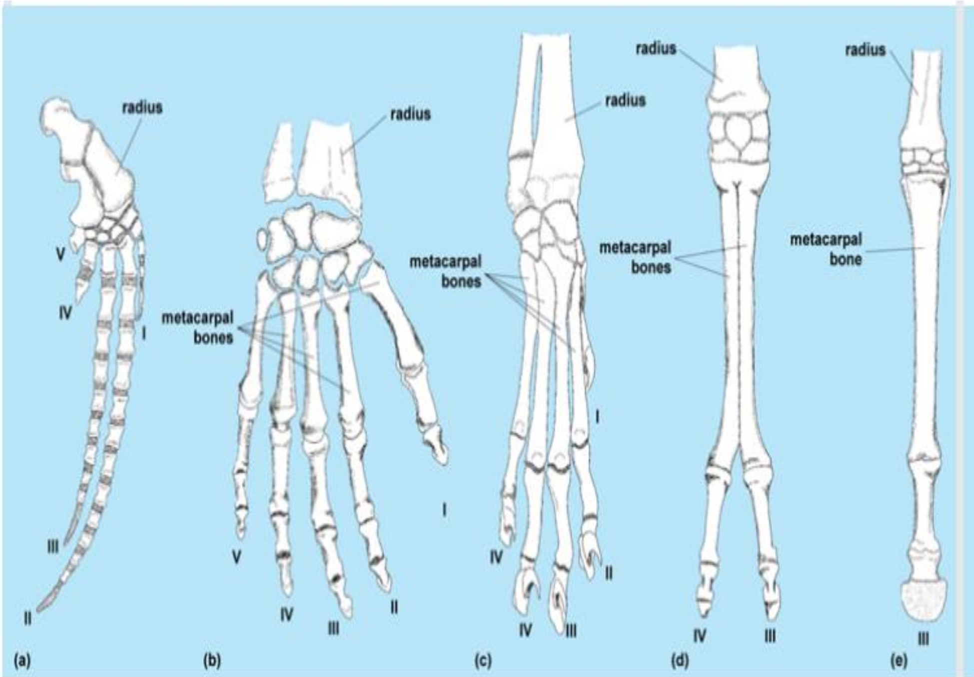


Fig.16.6: Changes in the tetrapod distal limbs in relation to different locomotor requirements. (a) Whale (b) Human; (c) cat; (d) camel; (e) horse

Many of the Carnivora, Rodentia and Lagomorpha have either lost or reduced the first digit. They are digitigrade; that is, they walk and run on four toes, with the metacarpals and tarsals raised off the ground. The functional increase in limb length contributes to their fleetness of foot, useful for catching prey or avoiding capture; and the reduction, particularly of the metacarpals, metatarsals and digits, can be viewed as an adaptation for speed.

Hoofed (unguligrade) animals have further reduced their digits. Even-toed ungulates (sheep, cattle and camel) and odd-toed ungulates (horse and rhinoceros) walk on the tips of the remaining digits. Claws or nails are often expanded to form protective structures such as the horse's hoof. The remaining metatarsals and metacarpals are often very elongate. Digital reduction is extreme in horses, where a single digit (digit III, equivalent to the human middle finger or toe) remains. All limb reduction results in loss of dexterity, and the horse, as an extreme example, cannot use its limbs for any function other than locomotion. However, digital reduction is extremely important for economical locomotion: multiple bones weigh more than a single element of equal strength, and thus limb mass can be reduced by reducing the number of bones without compromising limb strength.

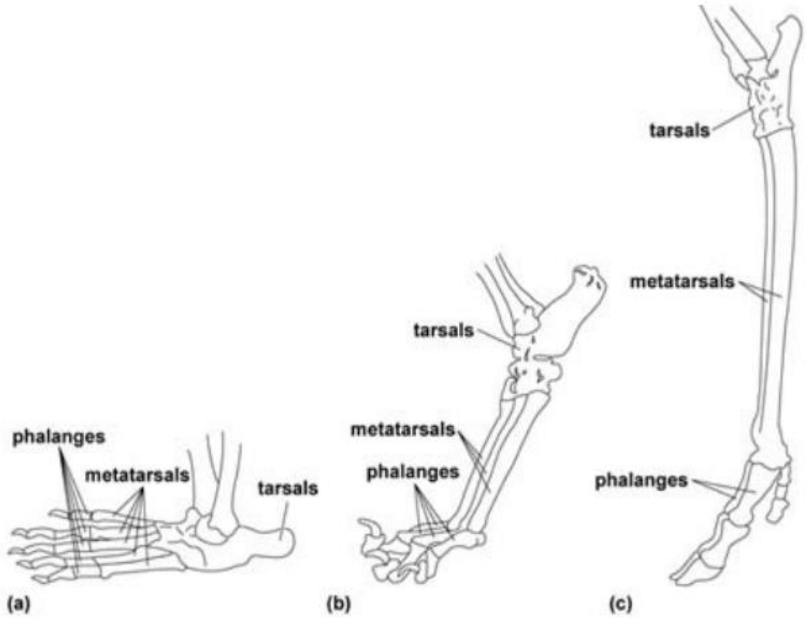


Fig.16.7: Limb postures. (a) Plantigrade. (b) Digitigrade. (c) Unguligrade.

There is a similar trend in birds. The ostrich is the only bird that has two toes (didactyl); rheas, cassowaries, emus, and others have three (tridactyl), whereas most species have four. However, variation in toe number, size and orientation reflects more than just locomotor behavior because there are three-toed species (king fishers, parrots) that are not runners.

Other skeletal adaptations for speed include the loss of clavicle in cats, allowing greater scapular movement which results in greater reach (greater stride length when running) and helps reduce impact forces to the axial skeleton when running; and increased flexibility of the vertebral column in the sagittal plane, another way to increase stride length.

16.10.2. Speed versus power

The speed of movement of limb bones is of fundamental importance for running animals. This depends on the sizes and properties of muscles and where they attach relative to the joints. A muscle that is attached close to a joint has a small moment arm (the perpendicular distance from the line of action of the force to the joint center) and will be able to move the distal end of the bone rapidly when the muscle contracts. The larger its moment arm about the joint, the slower the movement. However, the opposite is true for exertion of force at the distal end of the bone. Thus, skeletal morphologies differ, depending on whether predominantly powerful or rapid movements are required.

16.10.3. Digging and burrowing

Most changes in hole-dwelling animals are related to muscular insertions for increased power in their movements. However, skeletal adaptations occur in the teeth, pectoral and pelvic limbs and vertebral column. Major modifications include limbs becoming shorter and more robust. The medial humeral epicondyle enlarges to accommodate an increased muscle bulk of carpal and digital flexor muscles and forearm pronators. Claws are either sharp to break hard soil or flattened to help shift soft soil, and often have large extensor tubercles on the dorsal surfaces. These act as passive bony stops to prevent overextension of the joints. Many joints are restricted to planar motion (flexion-extension) to increase their stability and make them less likely to dislocate.

16.10.4. Limbless locomotion

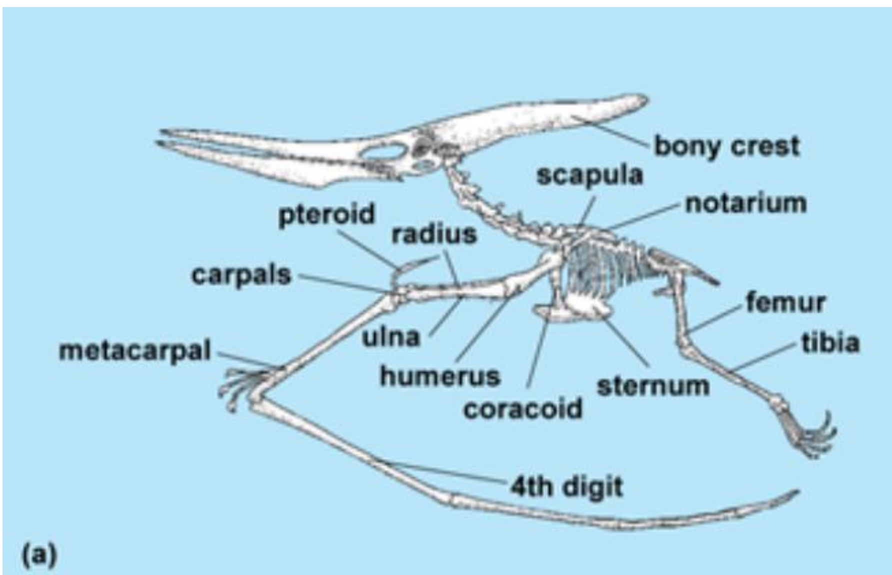
Frogs, birds and terrestrial mammals have never produced limbless forms. Snakes (Ophidia) are the most diverse limbless group, but there are lizards (Sauria) and amphibia (Apoda) that show a reduction or loss of one or both limb pairs and girdles. The main adaptation accompanying limb loss is elongation of the body. More than 500 vertebrae have been documented in a snake. The overlapping bony scales used for protection and to gain purchase for movement are formed secondarily in the skin.

16.10.5. Aerial locomotion

Birds and bats (and possibly the extinct pterosaurs) are the only examples of vertebrates capable of continuous muscle-powered flight. Many others use the more passive gliding or parachuting. Flying fishes (for example, Exocoetidae, Hemirhamphidae) have enlarged pectoral fins enabling them to glide out of water to escape predators. A number of reptiles (for example, Draco spp.) glide with the aid of flight surfaces formed by elongated ribs.

Birds have a highly modified forelimb complex (Fig. 16.8). The humerus, ulna and radius have surface features linked to flight, but the real adaptation of these (and other bird and pterosaur bones) is their air-filled or pneumatic character. This reduces their mass and, therefore, the muscular work involved in moving the wings up and down. In addition, the major wing bones of bats, birds and pterosaurs have relatively large diameters and are relatively thin-walled. These traits maximize torsional strength for any given mass of bone material, which is important for flying animals in which twisting forces on the wing skeleton are commonly encountered. Support of the primary flight feathers is provided by the bones of the carpus, carpometacarpus (a fusion of carpals and metacarpals unique to birds), and manus, which in adult birds has only three digits (recently identified as digits II-III-IV). Wing length is effectively determined by the lengths of the arm, forearm and hand skeleton, but wing shape (breadth and sharpness of wingtips) is determined by feather morphology. Secondary adaptations to flight are seen in the pelvic girdle, with its extensive connection to the synsacrum presumed to be linked to absorbing the shock of landing.

Bats have adopted a different skeletal strategy. They use highly elongated bones (humerus, radius, metacarpals and phalanges) to help support the whole wing, not only the leading edge as seen in birds. These bones are not pneumatic, but contain marrow. Weight savings do occur in distal elements due to a reduction in mineralization. Large pectoral muscles attach to ribs, and there is no massive, keeled sternum as in birds. Pelvic girdle reduction, thinner and straighter limb bones (they no longer have to resist large bending forces), rotation of the limb so the patella faces posteriorly, partial loss of the fibula, and possession of large claws are all skeletal adaptations for a hanging lifestyle.



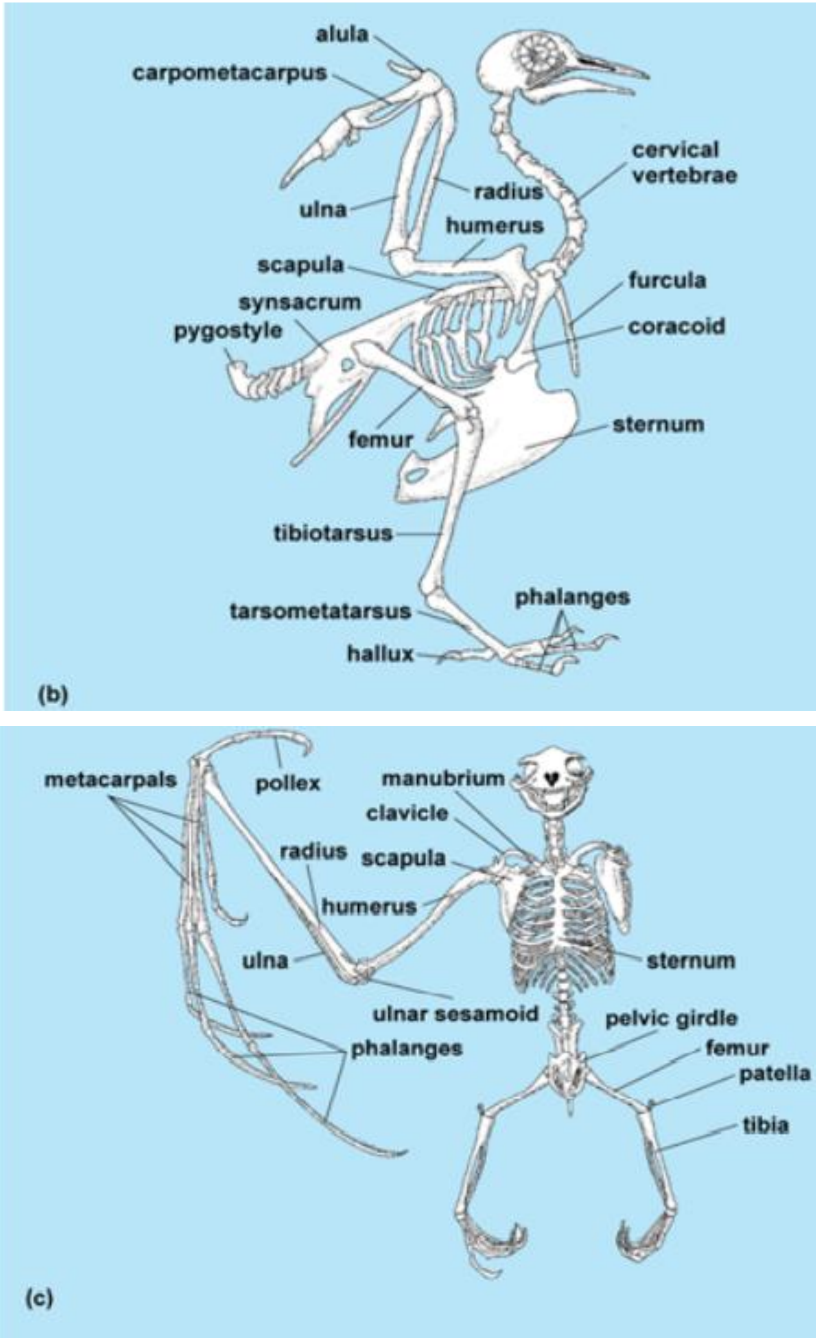


Fig. 16.8: Skeletons of flying vertebrates. (a) Extinct pterosaur (Pteranodon). (b) Typical bird skeleton. (c) Skeleton of a fruit bat or flying fox.

16.10.6. Aquatic locomotion

In contrast to terrestrial locomotion, the limbs of aquatic organisms are hydrofoils or paddles. The skeletal elements are usually the same as typical tetrapods, with altered dimensions. Some specialist swimmers (such as porpoises and whales) have increased the number of phalanges in the hand. The manus is fairly stiff, the bones being bound together with connective tissue. Reduction or loss of the pelvic girdle and limbs has occurred in cetaceans and sirenians, and thrust is supplied by dorsal-ventral flexion of the vertebral column. Seals and walruses retain the pelvic structures, swimming by lateral flexion of the vertebral column.

16.10.7. Skeletal strength

Bones have to be stiff in order to act as levers for effective muscle action, and strong to resist failure. Although the form of the skeleton is genetically determined, the basic plan can be modified within limits by hormone action and the mechanical environment.

The limb skeleton of terrestrial tetrapods is subjected to large dynamic forces during rigorous exercise. For example, the feet of human runners generate loads of two to three times body weight. Even larger forces are applied to the skeleton by muscle action (for example, to the heel bone via the Achilles tendon). Direct measurement of bone deformation under such conditions shows that the limb bones in most animals undergo similar levels of strain (that is, change in specimen length per original length) and are typically three to five times as strong as they need to be to resist failure.

16.10.8. Long bones

Lamellar or cortical bone has the same mechanical properties whether taken from a mouse or an elephant. The strength of whole bones is therefore a function of the amount of bone present and its geometric arrangement. Long bones in tetrapod limbs are typically tubular, even though the marrow contained within the hollow center appears to have little functional use. Why the bones are not solid can be explained by referring to principles of biomechanics. As most bones have a degree of longitudinal curvature, they tend to bend in a predictable direction when loaded, for example, during running. One surface of the bone will tend to be under compression (squashed), and the opposite surface will be under tension (pulled). As there is a gradient across the bone running from compression to tension, there is a position between the surfaces where the forces cancel out (the neutral axis). Bone material along and close to this axis does not contribute much strength to the bone in bending. Such redundant material can be removed (forming the marrow cavity) without compromising bone strength.

16.10.9. Size and the skeleton

The bones of humans and elephants are proportionately more robust than those of mice. This occurs because a doubling in linear dimensions results in a fourfold increase in area and an eightfold increase in mass. If animals simply increased in size, it would result in the bones undergoing larger stresses in bigger animals. To keep bone stresses at the same level as in small animals requires that the bones be made thicker.

Another obvious feature is that small animals adopt crouching (noncursorial) postures, while larger ones are typically cursorial, standing with straighter limbs. A more upright limb posture results in a better alignment of the forces generated during locomotion with the long axes of the bones. This reduces both the forces that muscles need to generate to keep limbs extended, and the bending moments imposed on the bones. Cursorial postures lower stresses on the limb bones but reduce agility.

Let us sum up

Under this unit, we studied about the skeletal system. We also focused in detail about various topics such as support tissues of animals, human skeleton, development of skeleton, vertebrate skeletal anatomy, evolution of neurocranium, dermatocranium and visceral cranium, vertebral column, ribs, sternum, appendicular skeleton, locomotion and skeletal adaptation.

Check your Progress

1) The supportive framework of an animal body is known as __________.
2) __________ is the commonly found inorganic material in invertebrate exoskeleton.
3) The vertebrate endoskeleton is usually constructed of __________ and __________.
4) The three types of cartilage are __________, __________ and __________.
5) __________ is a spongy, lamellar bone found particularly in the expanded ends of the long bones and vertebrae.

Glossaries

1. Cartilage : Non-vascular type of supporting connective tissue that is found throughout the body

2. Diaphysis : The shaft or central part of a long bone.

3. Ossification : Process by which new bone is produced

Suggested readings

1) **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.
2) **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.

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Skeletal system in vertebrates https://youtu.be/44O4ZRNtu-8, https://youtu.be/0xNziSCNqDY

Forms functions and body elements of vertebrates https://youtu.be/f-FF7Qigd3U

Answers to check your progress

1) Skeleton
2) Calcium carbonate
3) Bones and cartilages
4) Fibrocartilage, elastic cartilages and hyalin cartilages
5) Trabecular bone

Unit 17

Jaw Suspension in Vertebrates

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain various types of jaw suspension
- Explain the comparative account on jaw suspension.

OVERVIEW

In this unit, we will study about the jaw suspension in vertebrates. We will also focus on various types of jaw suspension such as amphistylic, autodiastylic, hyostylic, autostylic, monimostylic, holostylic, craniostylic ana comparative account of jaw suspension.

17.1. INTRODUCTION

In vertebrates, the 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 palatopterygoquadrate 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 and are, hence, called branchial arches. Thus, splanchnocranium forms the jaws and suspends them with the chondrocranium.

17.2. Jaw suspension

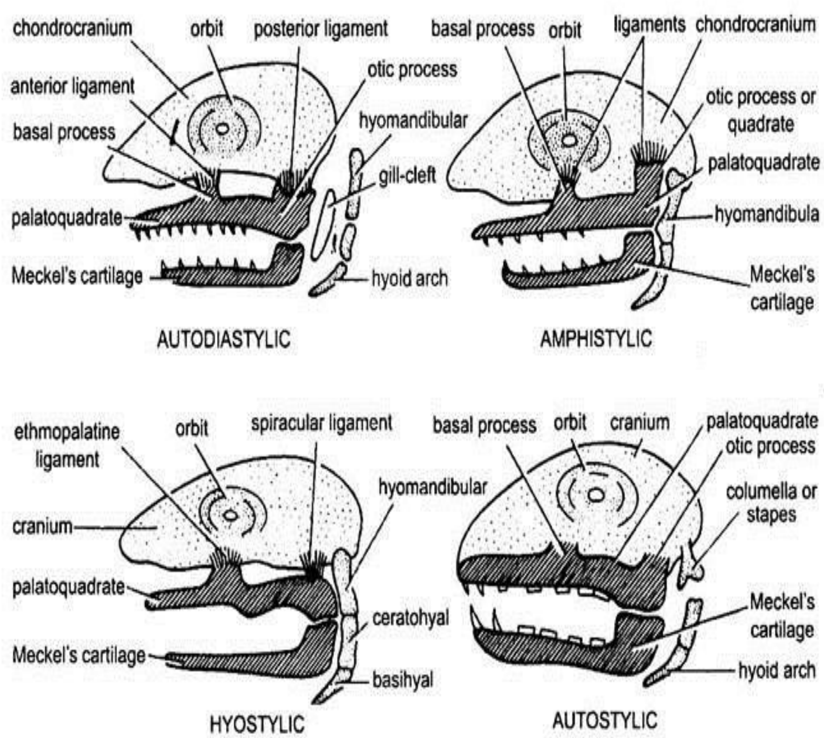

Fig. 17.1: Jaw Suspension in Different Vertebrates

17.2.1. Amphistylic

In primitive elasmobranchs there is no modification of visceral arch and they are made of cartilage. Pterygoqadrate makes the upper jaw and meckel's cartilage makes lower jaw and they are highly flexible. Hyoid arch is also unchanged. Lower jaw is attached to both pterygoqadrate and hyoid arch and hence it is called amphistylic.

17.2.2. Autodiastylic

Upper jaw is attached with the skull and lower jaw is directly attached to the upper jaw. The second arch is a branchial arch and does not take part in jaw suspension.

17.2.3. Hyostylic

In modern sharks, lower jaw is attached to pterygoquadrate which is in turn attached to hyomandibular cartilage of the 2nd arch. It is the hyoid arch which braces the jaw by ligament attachment and hence it is called hyostylic. Methystylic: In bony fishes pterygoquadrate is broken 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 symplectic bone of the hyoid arch to the skull. This is a modified hyostylic jaw suspension that is more advanced.

17.2.4. Autostylic

Pterygoquadrate is modified to form epipterygoid and quadrate, 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.

17.2.5. Monimostylic

This type of suspension is a modification of autosystylic suspension in which quadrate is immovable and not flexible as in amphibia and many reptiles. Hyomandibular is modified as columella bone of the middle ear cavity.

17.2.6. Holostylic

This type is found in lung fishes and Holocephali. Upper jaw is fused with the skull and the lower jaw is attached directly with it. Hyoid arch does not participate in jaw suspension and is a typical branchial arch. There is no columella bone.

17.2.7. Craniostylic

Found in mammals, in this type of jaw suspension, pterygoquadrate is transformed into alisphenoid and incus, while meckel's cartilage is changed into malleus and not available for jaw suspension. Lower jaw is directly attached to the skull bone called squamosal. Monotremes also possess this type of jaw suspension.

17.3. Comparative Account

1) In agnathans, the jaw suspension is in paleostylic stage in which none of the arches attach themselves directly to the skull.
2) In ganathostomes and acanthodians jaw suspension is autodiastylic in which jaws are attached to the cranium by anterior and the posterior ligaments. Hyoid arch remains completely free and does not support the jaws.
3) In primitive sharks the jaw suspension is amphistylic in which the quadrate or the basal and otic processes of upper jaw (mandibular arch) are attached by ligaments to chondrocranium. Similarly the upper end of hyomandibula is also attached to chondrocranium.
4) In modern sharks and all bony fishes the type of jaw suspension is hyostylic, in which the upper jaw (palatoquadrate) is loosely attached by anterior ligament to cranium.both the jaws are suspended from the hyomandibular.since only hyoid arch binds the two jaws against cranium it is called hyostylic jaw.
5) In most tetrapods like amphibians,reptiles and birds hyomandibular does not participate but becomes modified into columella or stapes of middle ear for transmitting sound waves.
6) In most lung fishes upper jaw is firmly fused with skull and lower jaw suspended from it. Hyoid arch is complete independent and not attached to the skull; this is holostylic type of jaw suspension.
7) In many tetrapods monimostylic jaw suspension is seen i.e., hyomandibular forms columella and articlar articulates with quadrates. However, the quadrate remains immovably attached with skull.
8) In some reptiles (lizard, snakes) and birds the type of jaw suspension is streptostylic i.e., quadrate is loosely attached and is movable at both the ends a condition known as streptostylism.

9) In mammals craniostylic type of jaw suspension is seen it is modification of the autostylic suspension. Upper jaw fuses throughout its length with cranium, and hyomandibular forms the ear, ossicle and stapes. But articular and quadrate also become modified into ear ossicles malleus and incus.

Let us sum up

Under this unit, we studied about the jaw suspension. In this unit, we also focused on the various types of jaw suspension such as amphistylic, autodiastylic, hyostylic, autostylic, monimostylic, holostylic, craniostylic ana comparative account of jaw suspension.

Check your Progress

1) The method by which the upper and lower jaws are suspended from the chondocranium is known as __________.
2) The lower jaw that is attached to both pterygoquadrate and hyoid arche is known as __________.
3) __________ is a type of jaw suspension where the pterygoquadrate is transformed into alsphenoid and incus.

Glossaries

1. Ossification : Process by which new bone is produced

2. Diarthrosis : Articulation that permits free movement.

3. Craniostylic : This type is seen in mammals. In mammals the pterygoqodrate transforms into incus and alisphenoid. Meckle's cartilage transforms

Suggested readings

1) **ROMER, A.S** (1974), The Vertebrate Body, W.B. Saunders, London.
2) **WEICHERT, C.K** (1965), Anatomy of the Chordates, McGraw Hill Book Co., New York.

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Comparative account of jaw suspensorium https://youtu.be/Yp1fmLWwKIw

Answers to check your progress

1) Jaw suspension
2) Amphistylic
3) Craniostylic

Unit- 18

Vertebral Column

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain basic structure of vertebral column
- Describe the development of vertebrae.

OVERVIEW

In this unit, we will study about the vertebral column. We will also focus on the development notochord, vertebrae, basic structure of vertebrae, different types of processes, formation of arcualia and centrum along with its types.

18.1. INTRODUCTION

vertebral column, also called spinal column, spine, or backbone, in vertebrate animals, the flexible column extending from neck to tail, made of a series of bones, the vertebrae. The major function of the vertebral column is protection of the spinal cord; it also provides stiffening for the body and attachment for the pectoral and pelvic girdles and many muscles. In humans an additional function is to transmit body weight in walking and standing. Each vertebra, in higher vertebrates, consists of a ventral body, or centrum, surmounted by a Y-shaped neural arch. The arch extends a spinous process (projection) downward and backward that may be felt as a series of bumps down the back, and two transverse processes, one to either side, which provide attachment for muscles and ligaments. Together the centrum and neural arch surround an opening, the vertebral foramen, through which the spinal cord passes. The centrums are separated by cartilaginous intervertebral disks, which help cushion shock in locomotion.

18.2. 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 together and become vacuolated, except 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.

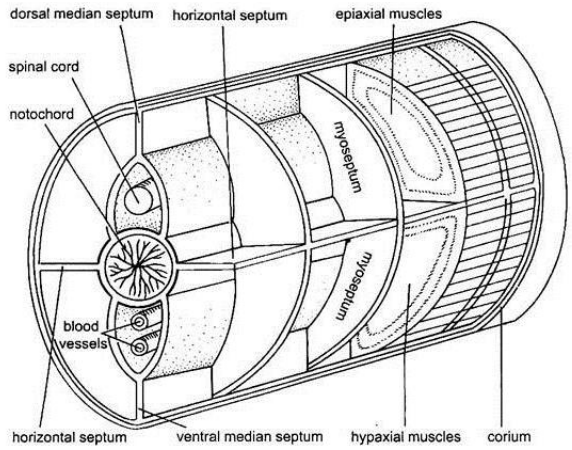

Fig. 18.1: The skeletogenous tissue in the caudal region of a vertebrate.

In protochordates (Amphioxus) and cyclostomes (lamprey) the axial skeleton is primarily the notochord, which persists throughout 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.

They do not meet above to form a neural arch. In some of 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 begin to invade the notochordal sheath.

In most fishes centrum is well developed. In fishes and higher animals, notochord is later surrounded by cartilaginous or bony rings called vertebrae. 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.

18.3. 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 recognisable by the presence of a haemal arch on the underside of centrum or notochord. Centrum in fishes is amphicoelous. In tetrapods vertabral column has five regions- cervical, thoracic, lumbar, sacral and caudal, each have several vertebrae. Amphibians have a single cervical (atlas) and one sacral (9^{th}) vertebra.

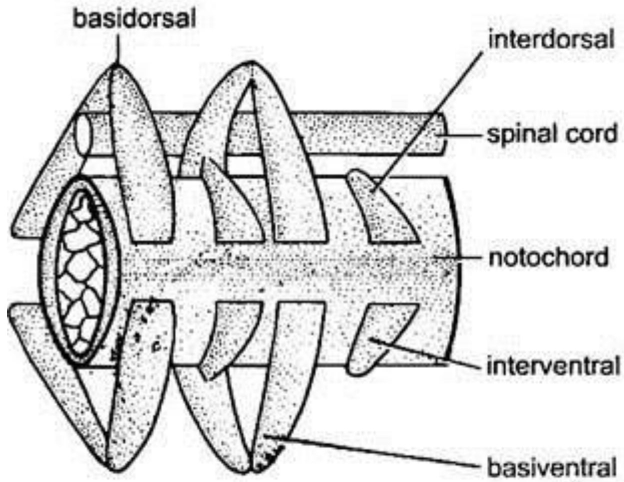

Fig. 18.3: Cartilaginous arcualia formed from sclerostomes

18.3.1. Basic Structure of Vertebra

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.

18.3.1.1. Types of Processes

Various kinds of projections or apophyses arise from a vertebra.

They are:

(i) Zygapophyses present 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- Lateral transverse processes arise from centrum,

(iii) Diapophyses arising from the neural arch or the centrum and serve for attachment of the upper head (tuberculum) of a two-headed (bicipital) rib,

(iv) Parapophyses arise laterally from the centrum for attachment of the ventral head (capitulum) of a bicipital rib,

(v) Basapophyses are ventro-lateral processes of the centrum or haemal arch, they are remnants of a haemal arch or articulate with the haemal arch when present,

(vi) Pleurapophyses are lateral projections to which short ribs are fused,

(vii) Hypapophysis is a mid-ventral projection from the centrum.

18.3.2. 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 this arrangement movement of the vertebral column occurs. The mesenchyme cells of the definite sclerotomes spread to form a skeletogenous layer around the notochord and nerve cord.

18.3.2.1. 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.

18.3.2.2. Formation of Centrum

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. There is another method of formation of centra, in some elasmobranchs cells from the basidorsals and basiventrals penetrate and spread into the secondary notochordal sheath and secrete cartilage to form a ring-shaped centrum around the constricted notochord, such a centrum is called a chordal centrum.

But in other elasmobranchs, bony fishes, and tetrapoda, the arcualia grow around the notochord outside the notochordal sheaths to form a centrum known as a perichordal centrum which later grows and obliterates the notochord. In both cases the centrum becomes fused to the neural and haemal arches.

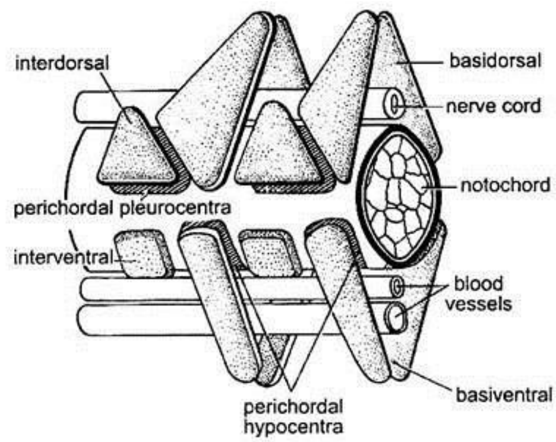

Fig. 18.4: Components in formation of two vertebrae of tetrapoda

The centrum is not always formed from arcualia only, there is another method of centrum formation. The mesenchyme lying between the definite sclerotomes and notochord, internal to the arcualia, is called the perichordal mesenchyme.

In tetrapoda 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.

The pleurocentrum piece increases and the hypocentrum piece decreases to form the centrum of amniotes, but in amphibians the hypocentrum forms the centrum, while the pleurocentrum decreases or disappears.

18.3.2.3. Types of Centrum

The parts forming a centrum are not always homologous and different lines of evolution are seen.

1. In crossopterygians and some fossil amphibians the two hypocentra fuses to 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.

2. 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 single neural arch, this is an embolomerous vertebra, it was evolved from a rachitomous vertebra.

3. 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.

4. The embolomerous vertebra gave rise to 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 it is changed to form an intervertebral disc (mammals).

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. It is found in the tail of some fishes (Amia), some extinct amphibians, and some lizards. A second type of diplospondyly is seen in the tail region of some elasmobranchs in which each segment has two complete vertebrae with two centra, two neural arches, and two haemal arches.

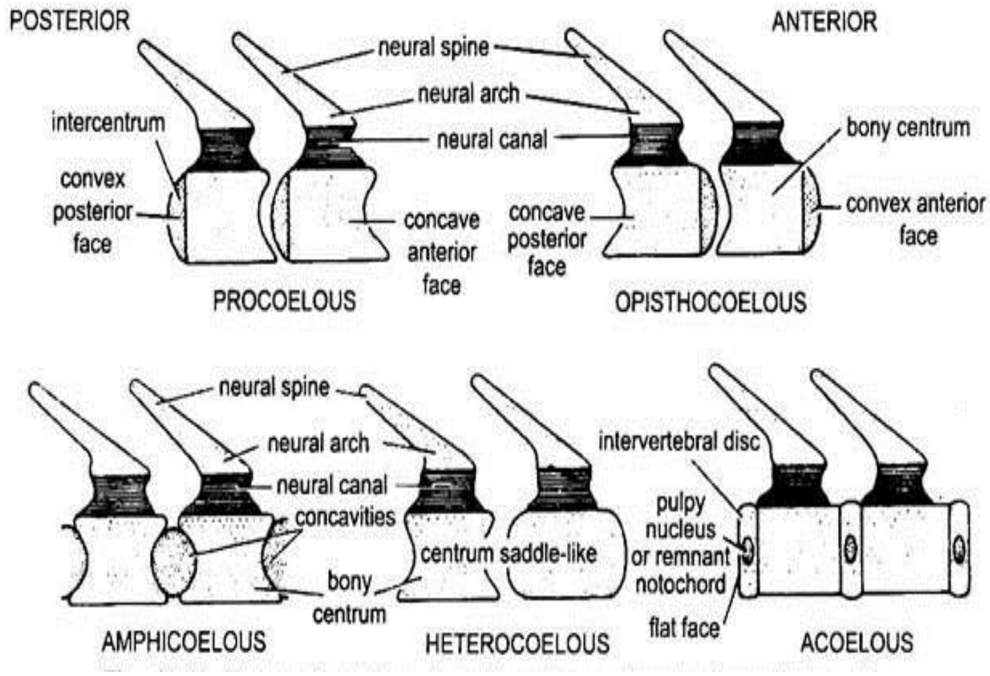

Fig. 18.5: Types of vertebrae based on shape of centra in sagittal section

18.3.2.4. Types of Centra and Vertebrae:

The centra of vertebra are placed end to end in a row, the shape of the ends of centra is of importance for articulation. There are six principal shapes of centra.

1. Amphicoelous:

Vertebra has its centrum concave at both ends. This is the most primitive type and is found in nearly all fishes.

2. Procoelous:

Vertebra has its centrum concave at the anterior end and convex at the posterior end. It is found in frogs and most reptiles.

3. Opisthocoelous:

Vertebra has a centrum convex at the anterior end and concave posteriorly. It is not characteristic of any group but occurs in all classes.

4. Heterocoelous:

Vertebra has the centrum saddle-shaped transversely. The anterior end is convex dorsoventrally and concave sideways, while the posterior end is opposite of the anterior end. This is the most specialised vertebra and is found in neck region of birds.

5. Amphiplatyan or Acoelous:

Vertebra has its centrum flat at both ends and is found in mammals.

6. Biconvex:

Centrum is convex at both the ends. It is found in the 9th (sacral) vertebra of frog.

18.4. Ribs

Ribs are cartilaginous or bony structures, which are either fused to or articulated with vertebrae. Typically there is one pair of ribs to each vertebra.

In fishes there are two kinds of ribs,

(i) Dorsal or intermuscular ribs extend from transverse processes into a skeletogenous septum between two successive myotomes.

(ii) The second kind are ventral or pleural ribs which arise from the centrum and lie between the body wall muscles and parietal peritoneum.

Most fishes have either dorsal or ventral ribs, but some have both kinds, e.g., Polypterus and many teleosts. In elasmobranchs only dorsal ribs are present, while most teleosts have only ventral ribs. In tetrapoda there is one pair of ribs to each vertebra; it is now believed that they represent the ventral ribs of fishes.

All ribs are short in tetrapoda, except those in the thorax. In amniotes the ribs of the thoracic region unite ventrally with the sternum and dorsally articulate with the vertebrae by two heads. In these two-headed or bicipital ribs the tuberculum or upper head articulates with a process of the neural arch called diapophysis, while the capitulum or lower head articulates with a process of the centrum called parapophysis (Fig. 18.6).

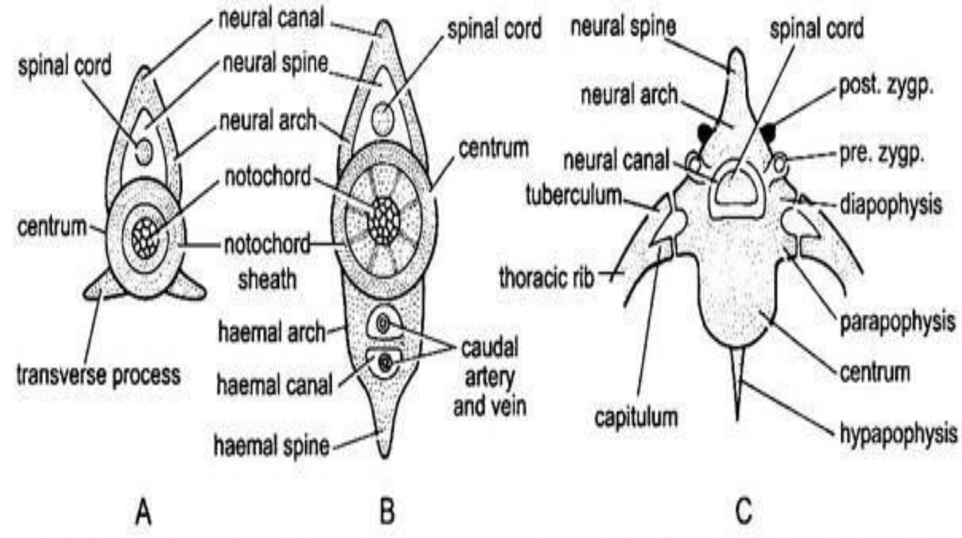

Fig. 18.6: Structure of vertebra showing processes in cephalic view, A. Trunk vertebra of shark; B. Caudal vertebra of shark; C. Typical tetrapod vertebra.

In the cervical region where ribs are fused with vertebrae, the space between the two heads of a rib is a vertebrarterial canal through which a nerve and blood vessels pass.

Abdominal ribs are also called gastralia or ventral ribs. There are V-shaped dermal bones in the ventral region of the abdomen extending postero-dorsally with their apices pointing in front. Gastralia were present in some fossil amphibians, in Sphenodon and crocodilians. They are dermal elements, while true ribs are endoskeleton structures.

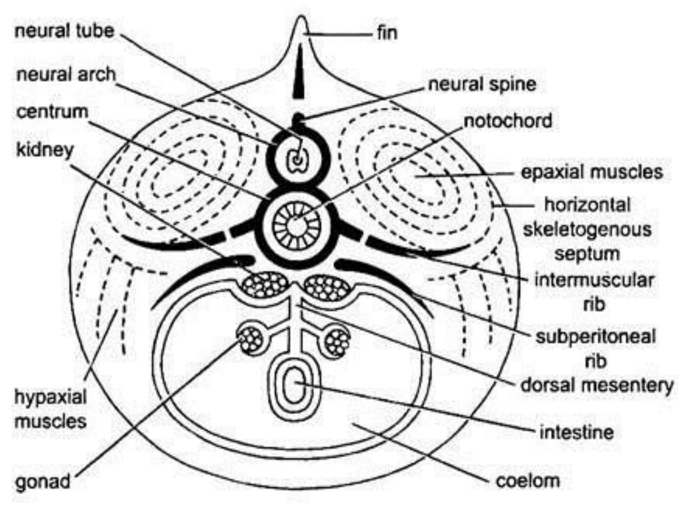

Fig. 18.7: T.S of trunk region of a vertebrate showing dorsal and ventral ribs.

Let us sum up

Under this unit, we studied about the development of vertebral column. We also focus on development notochord, vertebrae, basic structure of vertebrae, different types of processes, formation of arcualia and centrum along with its types.

Check your Progress

1) The notochord is formed of the __________ cells.
2) The notochord is enclosed in an inner and outer elastic fibrous sheath of connective tissue called __________.
3) The arcualia that forms two centra and only one neural arche is one segment, this is known as __________.

Glossaries

1. Craniostylic : This type is seen in mammals. In mammals the pterygoqodrate transforms into incus and alisphenoid. Meckle's cartilage transforms

2. Infundibulum: The hollow stalk which connects the hypothalamus and the posterior pituitary gland.

3. Parapophysis: Transverse processes that project from the centrum of each vertebra of many lower vertebrates.

Suggested readings

1) **COLBERT, H. EDWIN** (1989), Evolution of the Vertebrates, II Ed., Wiley Eastern Limited, New Delhi.
2) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.

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Comparative account of vertebral column https://youtu.be/eQ6D6hdNvdU

Answers to check your progress

1) Chordameso cell
2) Elastica
3) Displospondyly

Unit- 19

Limbs and girdles, Evolution of urinogenital system in vertebrate series

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the structure of limb and appendicular skeleton
- Describe the evolution of urinogenital system in vertebrates.

OVERVIEW

In this unit, we will study about the limbs, gridles and evolution of urinogenital system in vertebrates.

19.1. INTRODUCTION

The shoulder girdle or pectoral girdle is the set of bones in the appendicular skeleton which connects to the arm on each side. In humans it consists of the clavicle and scapula; in those species with three bones in the shoulder, it consists of the clavicle, scapula, and coracoid. Some mammalian species (such as the dog and the horse) have only the scapula. The pectoral girdles are to the upper limbs as the pelvic girdle is to the lower limbs; the girdles are the parts of the appendicular skeleton that anchor the appendages to the axial skeleton. In humans, the only true anatomical joints between the shoulder girdle and the axial skeleton are the sternoclavicular joints on each side. No anatomical joint exists between each scapula and the rib cage; instead the muscular connection or physiological joint between the two permits great mobility of the shoulder girdle compared to the compact pelvic girdle; because the upper limb is not usually involved in weight bearing, its stability has been sacrificed in exchange for greater mobility. In those species having only the scapula, no joint exists between the forelimb and the thorax, the only attachment being muscular.

19.2. Limbs

The pectoral fin of the elasmobranchs possesses basal cartilages that articulate with the pectoral girdle. They carry a number of radial cartilages consisting of varying numbers of short segments; beyond these are located delicate fin rays.

The proximal segment of the pelvic fin of sharks is supported by a single basal cartilage and by one or two radialia. In the pectoral fin of the primitive ray-finned fish *Polypterus*, three elements constitute the proximal segment of the fin: two bony rods, the propterygium and the metapterygium, on the margins and an intermediate partly ossified cartilage, the mesopterygium.

The adoption of an upright position of the trunk, as seen in certain lemurs and in the great apes, has brought about further modification. In humans the lower limbs are used for bipedal locomotion, thus freeing the upper limbs for prehensile use. Many of the great apes have developed the use of the upper limb for an arboreal life; therefore, they are sometimes distinguished as brachiators (i.e., animals whose locomotion is by swinging with the arms from branches or other supports).

The skeleton of the free limb of the land vertebrate is divisible into three segments: proximal, medial and distal.

The proximal segment consists of a single bone (the humerus in the forelimb, the femur in the hind limb). The humerus articulates by its rounded head with the glenoid cavity of the scapula and by condyles with the bones of the forearm. Its shaft is usually twisted and has ridges and tuberosities for the attachment of muscles.

The femur is essentially cylindrical; the ends are expanded. At the proximal end, for articulation with the acetabulum, is the rounded head; near it are usually two elevations (trochanters) for muscle attachment. Three trochanters are characteristic of certain mammals (e.g., horse, rhinoceros). Distally, the femur expands into two condyles for articulation with the tibia. In many types there is an articular facet on the lateral surface for the head of the fibula.

The medial segment of the limb typically contains two bones: the radius and the ulna in the forelimb and the tibia and the fibula in the hind limb. In the forelimb the radius is anterior or preaxial (i.e., its position is forward to that of the ulna), in the adjustment of the limb for support and locomotion on land. Mammals in which the radius is fixed in pronation- i.e., in which the forelimb is rotated so that the shaft of the radius crosses in front of that of the ulna are called pronograde. The radius transmits the weight of the forepart of the body to the forefeet, but it is the ulna that makes the elbow joint with the humerus; into its proximal end are inserted the flexor and extensor muscles of the forelimb.

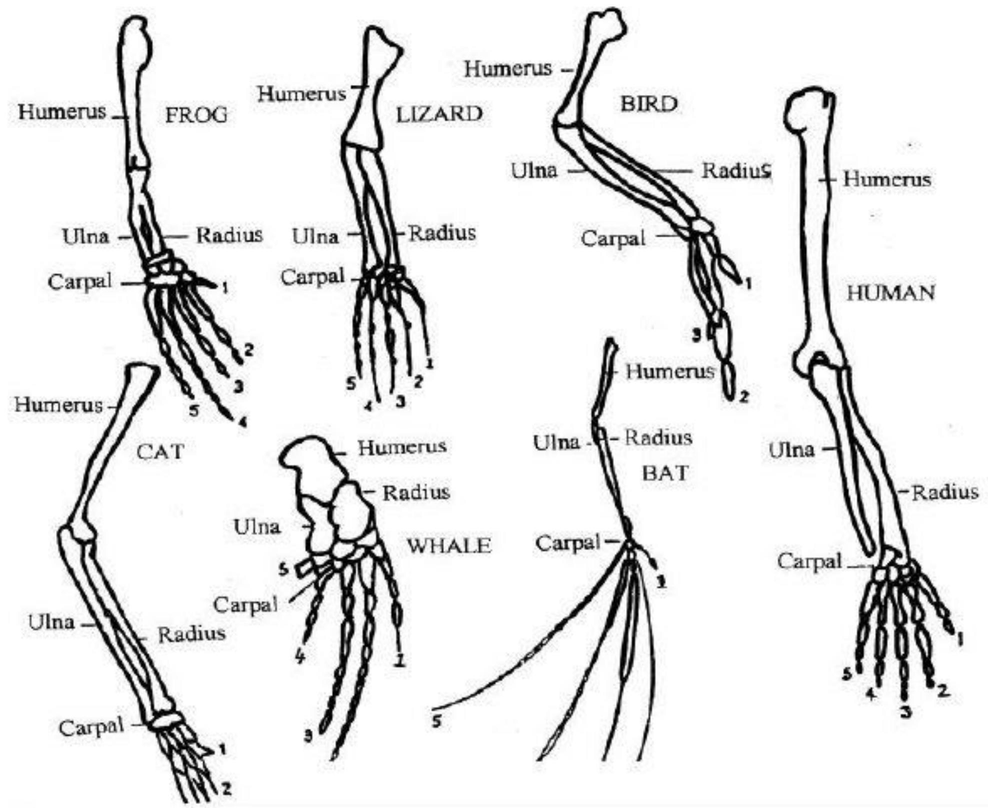


Fig. 19.1. Comparative anatomy of vertebrate limbs

The tibia and fibula are separate in salamanders and newts, united in frogs and toads. In land reptiles the tibia articulates with both condyles of the femur and with the tritibiale of the ankle. The fibula articulates with the postaxial femoral condyle and with the tritibiale and fibulare. The tibia of birds is long, the fibula reduced. In mammals the fibula is generally reduced and may be fused with the tibia and excluded from the knee joint.

The distal segment of the limb comprises the carpus, metacarpus and phalanges in the forelimb and the tarsus, metatarsus and phalanges in the hind limb. A typical limb has five digits (fingers or toes), which contain the phalanges.

The carpus and the tarsus of the higher vertebrates have probably been derived from a primitive structure by the fusion or suppression of certain of its elements. The bones of a generalized carpus (or tarsus) end in three transverse rows: a proximal row of three bones, the radiale (or tibiale), intermedium, and ulnare (or fibulare); a distal row of five carpalia (or tarsalia), numbered one to five from the radial (or tibial) margin; and an intermediate row of one or two centralia.

In many urodele amphibians (e.g., salamanders), the carpus is generalized. In the frogs and toads, however, it is more specialized; only six carpals are present, the third, fourth and fifth carpalia probably having fused with either or both centralia. In birds the radiale and ulnare are distinct, but the distal bones are fused with the metacarpus to form a carpometacarpus. In mammals various examples of fusion and suppression occur. In humans the radiale forms the scaphoid bone; the intermedium forms the lunate bone; the ulnare forms the triquetral. The pisiform bone in humans is probably the remains of an extra digit. It may, however, be a sesamoid bone (i.e., an ossification within a tendon). The trapezium and trapezoid are carpalia 1 and 2; the capitate is derived from carpal 3; carpalia 4 and 5 have fused to form the hamate. An os centrale is present in the carpus of many monkeys. In mammals the number of digits varies, but the number of phalanges in each digit present usually corresponds with that of humans. In some species, however, the phalanges are more numerous, as when the limb is modified to form a paddle (e.g., in whales).

The tarsus of urodele amphibians has the typical arrangement of bones. In the frogs and toads the intermedium is absent; two long bones are the tibiale and fibulare. Among the reptiles there is much variation in the composition of the tarsus. Generally, the joint of the ankle is intratarsal, the row of tarsalia being distal to the hinge. In most modern reptiles the tibiale and intermedium fuse to form the talus. In birds the ankle hinge is of the reptilian pattern in being intratarsal. The three tarsal cartilages of the embryo fuse to form the talus, which fuses with the tibia to form the tibiotarsus. The tarsalia fuse with the ends of the united metatarsals to make a tarsometatarsus. In the mammalian tarsus the talus is generally composed of the fused tibiale and intermedium, but in some a centrale is included to form a tritibiale. The ankle joint is not intratarsal but is located between the bones of the leg and the first row of tarsal bones, usually the tibia and the talus.

Suppression of digits in hoofed mammals frequently has occurred in the following sequence: the pollex (first digit) is the first to be suppressed, then the minimus (fifth digit), the index (second digit), and finally the annularis (fourth digit). Among the even-toed ungulates (artiodactyls; e.g., the pig and the hippopotamus) the pollex has disappeared, and the other four digits are present, although the second and fifth digits are much reduced. In the camel only the third and fourth digits persist and are of equal importance. Among the odd-toed ungulates (perissodactyls; e.g., the horse) the right digit is dominant; the others are reduced to rudiments or splints.

19.3. Appendicular skeleton

Paired appendages are not found in ancestral vertebrates and are not present in the modern cyclostomes (e.g., lampreys, hagfishes). Appendages first appeared during the early evolution of the fishes. Usually two pairs of appendages are present, fins in fish and limbs in land vertebrates. Each appendage includes not only the skeletal elements within the free portion of the limb but also the basal supporting structure, the limb girdle. This portion of the appendage lies partly or wholly within the trunk and forms a stable base for the fin or limb. Each girdle consists of ventral and dorsal masses. In lower fishes these are composed of cartilage; in bony fishes and in land vertebrates they become partly or completely ossified.

The anterior appendages, the pectoral fins or forelimbs, articulate with the pectoral girdle. The pectoral girdle is situated just behind the gill region in fish and in a comparable position at the junction of the neck and thorax in land vertebrates.

The posterior appendages, called pelvic fins or hind limbs, articulate with the pelvic girdle, which is situated in the trunk region usually just in front of the anus or cloaca (the ventral posterior body opening in many lower vertebrates). It is by way of the girdles that the weight of the body of land vertebrates is transmitted to the limbs. Because the hind limb is usually of greater importance in weight bearing, especially in bipedal vertebrates, it articulates with the vertebral column by means of the costal elements of the sacral vertebrae. The vertebrae to which the pelvic girdle are attached usually fuse together to form the sacrum. In fishes, however, a sacrum as such does not develop, owing to the fact that the posterior appendages usually do not support the body weight but are used only in locomotion.

The origin of paired fins has been much debated, and many theories have been put forward in explanation. According to the widely accepted fin-fold theory, the paired limbs are derived from the local persistence of parts of a continuous fold that in ancestral vertebrates passed along each side of the trunk and fused behind the anus into a single fin. The primitive paired fins were attached to the body by a broad base and carried no weight. Their main function, it would appear, was to act as horizontal stabilizing keels, which tended to prevent rolling movements and possibly also front-to-back pitching movements.

Most authorities agree that the limbs of land vertebrates evolved from the paired fins of fishes. Limbs and fins are thought to have their ancestral counterparts in the fins of certain lobe-finned fishes (Crossopterygii, a nearly extinct group of which the coelacanth is a living example). The skeleton of the primitive fin consists of a series of endoskeletal rods, each of which undergoes subdivision into a series of three or four pieces. The basal pieces tend to fuse into larger pieces. The most anterior of the basal pieces fuses across the midline with its fellow of the opposite side to form a primitive girdle that is in the form of a cartilaginous bar. The more distal basal pieces remain separate, forming the dermal (i.e., on or near the body surface) fin rays.

19.3.1. Pectoral girdle

In a cartilaginous fish, such as the dogfish, the pectoral girdle consists of a U-shaped endoskeletal, cartilaginous, inverted arch with its ends extending dorsally.

In all other major groups of vertebrates, the pectoral girdle is a composite structure. It consists of endoskeletal structures to which secondary dermal components are added as the result of ossification of dermal elements. The components become ossified to form dermal bones. In primitive bony fishes- such as the lungfishes, sturgeon, and coelacanths- the main element added is a vertically placed structure, the cleithrum, which supports the scapula. The cleithrum may be joined by a supracleithrum, which in turn is surmounted by a post temporal element (i.e., at the rear of the skull). The most ventral of the added dermal bones are the clavicles, which unite below the gill chambers with each other or with the sternum. In the holostean fishes (e.g., gar) the clavicle is lost, leaving only the cleithrum.

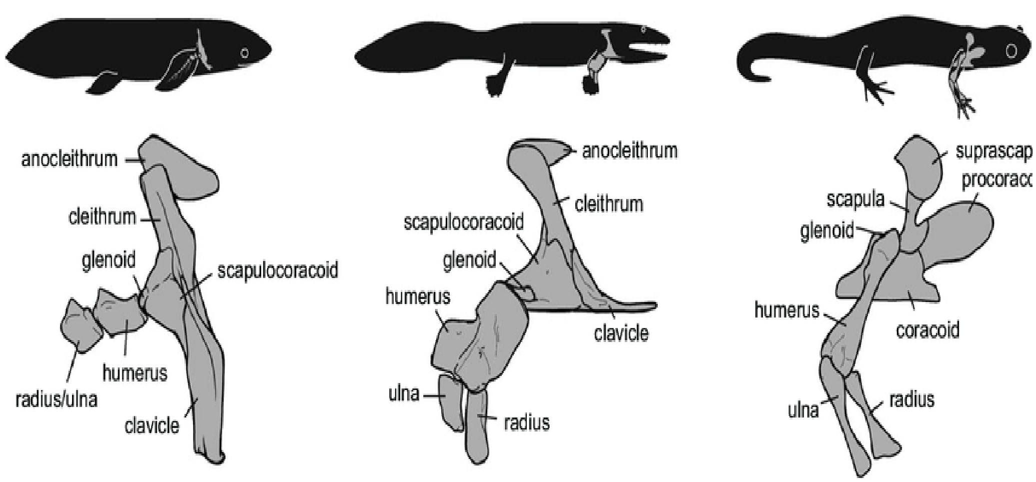


Fig. 19.2. Pectoral girdle in fishes, amphibians and reptile

In tailed amphibians, such as newts and salamanders, the dermal elements of the pectoral girdle have been completely lost, and only the endoskeletal parts remain, mainly in the form of cartilaginous bars. This retrogression is probably the result of their adaptation chiefly to an aquatic mode of life, in which less support is required by the girdles. The ventral part of the girdle forms the coracoid process, and the dorsal part forms the scapula; the latter is the only part that ossifies. Only a rudimentary sternum develops.

In most reptiles the primary girdle for the forelimb consists of a scapula and a single coracoid process. The pectoral girdle of the lizard consists of bones formed in cartilage- the scapula and the large coracoid process, forming the glenoid cavity (i.e., the cup-shaped structure in which the humerus articulates) and the dermal bones- the clavicle and interclavicle. The latter is a single T-shaped bone, with the stem in the midline; it is in contact with the sternum. The curved clavicles articulate with each other at their medial ends (i.e., toward the body midline). The cartilaginous suprascapula is present.

In birds the pectoral girdle is essentially similar to that in reptiles. The precoracoid process forms a stout bar that reaches to the sternum. The wishbone or furcula, which forms from the dermal part of the girdle, consists of two clavicles united in the midline by the interclavicle. Carinate birds (those with a keeled sternum) possess a sabre-shaped scapula and a stout coracoid process, joined by ligaments at the point at which is found the glenoid cavity for articulation with the humerus. The coracoid process is joined to the sternum; at its dorsal end is the acrocoracoid process. The furcula stands in front of the coracoid processes. The furcula's ends are connected by ligaments with the acrocoracoid process and with the rudimentary acromion process of the scapula. The girdle of the flightless ratite birds (those with a flat sternum) is little developed. The girdle is represented by an ankylosed, or fused, scapula and coracoid process.

Among mammals, the monotremes have two coracoid processes, which articulate medially with the presternum and laterally with the scapula. The coracoids enter into the formation of the glenoid cavity. Also present are an interclavicle (episternum) and an investing clavicle, resembling the bones in reptiles. The clavicle articulates with the acromion process of the scapula. In the opossum the scapula has a spine ending in the acromion, with which the clavicle articulates. A much-reduced coracoid fuses with the scapula and does not meet the sternum. The scapula of placental mammals has a spine ending, generally, in an acromion; the body of the bone is triangular. In mammals that use the forelimb for support in standing, the vertebral margin is the shortest, and the long axis of the scapula runs from it to the glenoid cavity; but in those whose forelimb is used for prehension, or grasping, such as in the primates, or for flight, such as in the bats, the vertebral margin is elongated, and the distance from it to the glenoid cavity is decreased. The long axis is thus parallel with that of the body instead of being transverse. In the placental mammals the coracoid, although developing independently, has dwindled to a beaklike process and fuses with and becomes part of the scapula. It does not articulate with the sternum.

The clavicle is present generally in those placental mammals (primates, many rodents and marsupials, and others) that have prehensile (i.e., capable of grasping) forelimbs or whose forelimbs are adapted for flying (e.g., bats). In many mammals it is suppressed or reduced, as in cats or absent, as in whales, sea cows and hoofed animals.

19.3.2. Pelvic girdle

The pelvic girdle of the elasmobranch fishes (e.g., sharks, skates and rays) consists of either a curved cartilaginous structure called the puboischial bar or a pair of bars lying transversely in the ventral part of the body anterior to the cloaca; projecting dorsally on each side is a so-called iliac process. Connected with the process is a basal cartilage. The basal cartilage carries a series of radialia, the skeleton of the paired pelvic fins. The pelvic girdles of many bony fishes are situated far forward, near the gills.

There are marked variations in the form of the pelvic girdle in the amphibians. In the frog the three parts of the hip bone (ilium, ischium and pubis) are present. The pubic elements, however, remain wholly cartilaginous. The hip bone is characterized by the great length and forward extension of the ilium. The girdle is connected with the costal element of one vertebra, thus establishing a sacral region of the vertebral column. The acetabulum (the cup-shaped structure in which the femur articulates) is situated at the junction of the three elements.

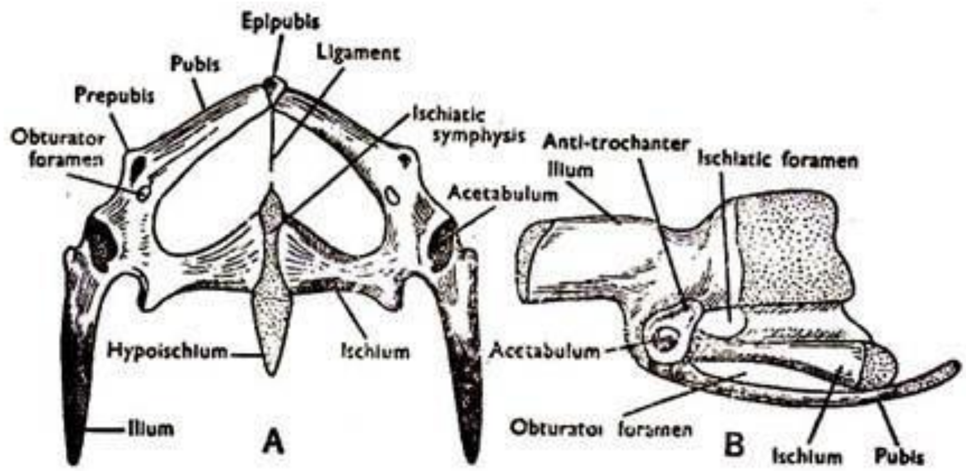


Fig. 19.3. Pelvic girdle of A) calotes B) columba

The pelvic girdle of some reptiles has a loose connection with the spine. In most reptiles the ilium is joined to two sacral vertebrae. Both the pubic and the ischial parts usually meet in the so-called ventral symphysis, from which a cartilage or a bone, the hypoischium, projects backward to support the margin of the cloacal orifice, and another, the epipubis, projects forward. A few snakes (e.g., boas) retain vestiges of a pelvic girdle and limb skeleton.

In most birds the ilium extends forward and backward and is fused with the many vertebrae, forming a synsacrum. The slender ischia and pubes do not form symphyses except in the ostrich.

In most mammals the ilium articulates with the sacrum, and the pubes meet in a symphysis anteriorly. A cotyloid bone, formed in the cartilage in the bottom of the acetabulum, is usually found. The symphysis pubis is not present in certain mammals (e.g., moles). In monotremes and marsupials the marsupial bones that support the pouch have been regarded as part of the epipubis.

19.4. Evolution of urinogenital system in vertebrates

Gonads are cytogenic sex glands. They are paired testes in males and ovaries in females because all vertebrates are dioecious with the exception of the hermaphrodite cyclostomes and some bony fishes.

In hagfishes the anterior part of gonad produces ova and the posterior part sperm. In any one individual, however, the gonad at maturity functions only as an ovary or testis, not as both. The gonads are not paired in cyclostomes and ducts are absent. The ova or sperm pass directly into the coelom and to the outside through genital pores.

Most bony fishes that are functionally hermaphroditic are marine, although a few are freshwater, such as killifish (Rivulus marmoratus) and the Asiatic synbranchid (Monopterus albus). Some are like the hagfish, they function first as one sex, and then transform into the opposite sex. Other possess ovotestes in which the mature ova are fertilized by sperm produced within the same organ before they are laid.

The mesodermal coelomic epithelium forms a pair of thick, elevated, elongated genital ridges lying longitudinally along the dorsal surface ofthe coelom near the developing kidneys. Genital ridges are much longer than the adult gonads. 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 oftissue known as mesorchium in the male and mesovarium in the female.

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. The germinal epithelium of testes lines theirseminiferous tubules, hence, spermatozoa are released into the lumen of seminiferous tubules.

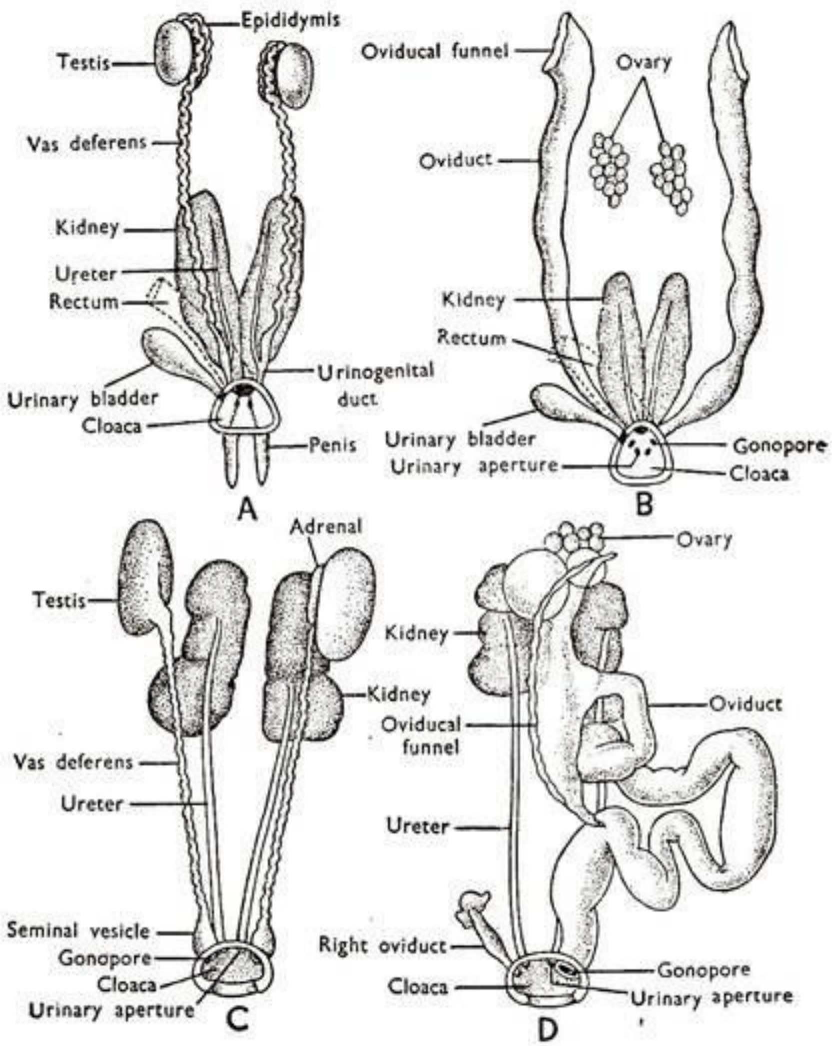


Fig. 19.4. Urinogenital system A) male calotes B) female calotes C) male columba D) female columba

19.4.1. Testes and Male Genital Ducts

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 thegerminal epithelium. In dogfish, the testes are elongated structures.

In anamniotes the anterior portion of the mesonephric kidney comesto 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 ofadjacent testis. Thus, the mesonephric kidney of adult anamniotes hasan anterior genital portion and a posterior renal portion. Themesonephric duct is a urinogenital duct in male, it serves both as aurinary duct for urine and as a vas deferens for sperms. But in manyelasmobranchs (e.g., dogfish) special accessory urinary ducts areformed, one for each kidney to drain urine from kidney to cloaca andthe mesonephric duct is only genital in function and is a vas deferens.The anterior genital part of kidney with a part of mesonephric ductforms the epididymis.

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. Insome toads there is a structure called Bidders organ located anterior toeach testis. Under certain circumstances this may develop into an ovary. In male amniotes the adult functional kidneys are metanephroi,each has its own ureter for conducting urine, hence, the persistentmesonephric 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 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. Inducks and geese, a single penis-like structure, similar to that of turtles is present. It is derived from the anteroventral wall of the cloaca.

The mammalian testes are either situated posteriorly in the body or they are outside the body cavity in a sac called the scrotum. In certain species testes descend into the scrotal sac only during the breeding season. The male possesses a single penis, which in monotremes is located on the floor of the cloaca.

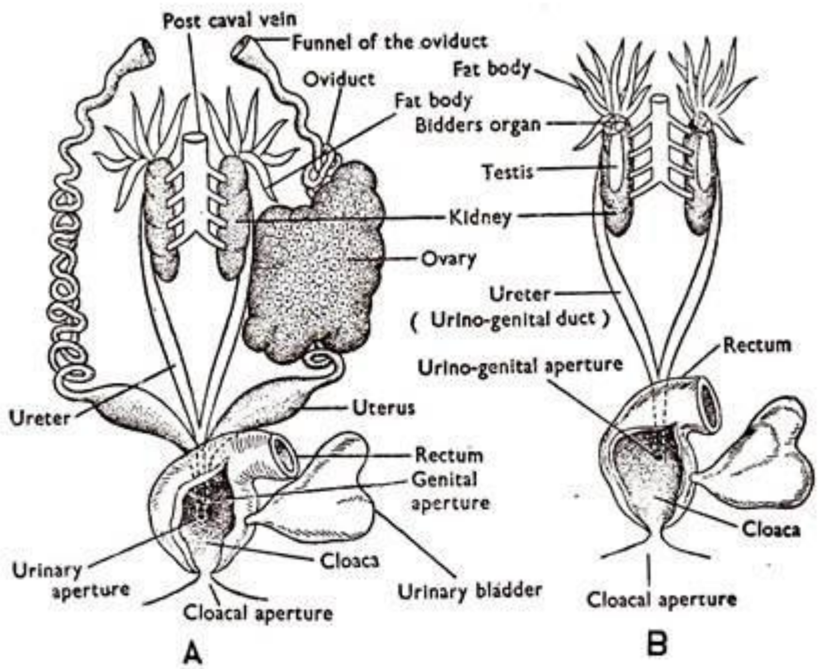


Fig. 19.5. Urinogenital system of bufo A) female B) male

19.4.2. Ovaries and Female Genital Ducts

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 inmost vertebrates, hence, ova pass into the coelom after 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 Mullerianduct which lies on the outer side of the mesonephric duct and runsbackwards to join the cloaca. A Mullerian duct also appears in themale, but it is suppressed by androgens and it soon becomes vestigial.Thus, there are two ducts on each side in female anamniotes, aMullerian duct acting as an oviduct and a mesonephric duct serving as a ureter.

In most elasmobranchs the original pronephric duct splits longitudinally to form two ducts, one becoming the mesonephric duct for urine and the other forming an oviduct for ova which appropriates one or more peritoneal funnels to form its opening into the coelom. The method of formation of elasmobranch oviduct is considered to indicate its origin in vertebrates.

In cartilaginous and bony fishes, the female usually has two oviducts.In elasmobranchs the upper ends of these oviducts are fused so thatthere is a single funnel-like opening or ostium into which eggs fromthe ovaries may pass. Also in this group each oviduct possesses a shellgland, since the eggs are fertilized internally and then encased in a horny shell.

In most vertebrates the ovary is not directly connected with the oviduct so that the eggs enter the coelom and then pass into the ostium. In some bony fishes, however, where huge number of eggs is produced during the short breeding season, the ovaries are continuouswith the oviducts so as to prevent the ova from escaping into thecoelom. In many teleosts the lower parts of the paired oviducts are fused. Most bony fishes are oviparous, but there are some in which eggs hatch internally.

The amphibian ovaries are paired and contain a cavity within them that is filled with lymph. The oviducts are also paired although in some forms the lower ends are fused together. Frequently the lower end of each oviduct is enlarged into a uterus-like structure or ovi sac which serves as a temporary storage space for ova before they are shed.Glands that secrete a jelly-like covering for eggs are usually situated along the oviduct.

In reptiles also paired ovaries contain cavities filled with lymph as in amphibians, or may be solid as in birds and mammals. Paired oviductsopen separately into the cloaca. The albumen and shell producingglands are located along the oviducts. Archinephric or Wolffian duct degenerates in female reptiles.

In most birds the right ovary and oviduct, although present in embryonic development, become vestigial so that only the left genital system is functional. Along the course of oviduct are several glands which secrete membranes over the eggs, including layers of albumen, shell membranes and a calcareous shell.

In female amniotes the development of mesonephric and Mullerian ducts is the same as in anamniotes, but the adult kidneys are metanephroi, each with its own ureter, hence, mesonephros and its duct degenerate leaving only vestiges. The Mullerian duct acts as an oviduct and the metanephric duct as the ureter on each side. In most vertebrates an oviduct is not differentiated into parts, and the two oviducts remain separate and open into the cloaca, but in mammals each oviduct is differentiated into two or three parts- (i) a narrow anterior Fallopian tube, (ii) wide posterior uterus whose posterior partmay be differentiated as a vagina.

In monotremes the two oviducts are separate so that there are two separate uteri opening into the cloaca. Monotremes have no vagina.With the separation of urinary and genital systems from the rectum,the cloaca is eliminated in marsupials and eutherians. In marsupialsthere are two uteri (hence, Didelphia), and the terminal portions of oviducts are differentiated as vaginae. The two vaginae are separatebut joined along the median line. They receive the penis of the male. But in eutherian mammals the two vaginae fuse into a single tube.

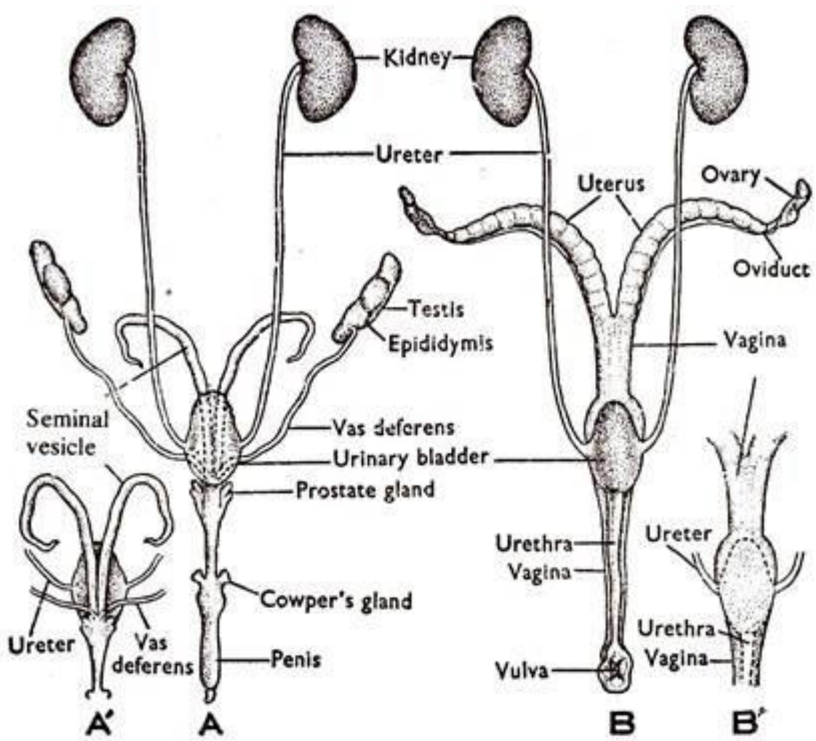


Fig.19.6. Urinogenital system of cavia A) male B) female

The two uteri may fuse partly or completely, thus, four kinds ofuteri are recognized in Eutheria:

1) Duplex uterus found in rodents, elephants, and some bats. The twouteri do not fuse but enter and open separately in the vagina.
2) Bipartite uterus found in carnivores, pigs and cattle. The lower endsof the two uteri fused together so that they open by a single aperture (os uterus) into the vagina.
3) 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 singlecavity.
4) 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.

Let us sum up

Under this unit, we studied about the limbs, gridles and evolution of urinogenital system in vertebrates.

Check your Progress

1) The pectoral fin of the elasmobranche possesses ___________ that articulate with the pectoral girdle.
2) The skeleton of the free limb of the land vertebrate is divisible into three segments, ___________, ___________ and ___________.
3) The ___________ is a urinogenital duct in male, that serves as both urinary and a vas deference for sperms.
4) The ___________ are generally mass of connective tissue within an outer germinal epithelium.
5) The ___________ uterus is found in ungulates whales and bats.

Glossaries

1. Diarthrosis :	Articulation that permits free movement.
2. Craniostylic :	This type is seen in mammals. In mammals the pterygoqodrate transforms into incus and alisphenoid. Meckle's cartilage transforms
3. Infundibulum:	The hollow stalk which connects the hypothalamus and the posterior pituitary gland.

4. Parapophysis: Transverse processes that project from the centrum of each vertebra of many lower vertebrates.

Suggested readings

1) **NEWMAN, N.H** (1961), Phylum Chordate, The University of Chicago Press, Chicago.
2) **WATERMAN, A.J** (1971), Chordate Structure and Function, The Macmillan Company.

Weblink

Limbs and girdles of vertebrates https://youtu.be/RTmvtBFF_WY

Evolution of urinogenital system in vertebrates
https://youtu.be/y3vqI_RbyHY

Answers to check your progress

1) Basal cartilages
2) Proximal, medial and distal
3) Mesonephric duct
4) Ovaries
5) Bicornuate

Unit 20

Sense Organs: Simple Receptors, Organs of Olfaction and Taste

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the sense organs
- Classify receptors of sensory organs
- List out the various sense organs and its functions.

OVERVIEW

In this unit, we will study about the sense organs, simple receptors, organs of olfaction and taste. We will also focus on the classification of receptors by stimulus, simple receptors, complex receptors and receptors of taste and smell.

20.1. INTRODUCTION

A sensory receptor is a specialized nerve cell that responds to a stimulus in the internal or external environment by generating a nerve impulse. The nerve impulse then travels along the sensory (afferent) nerve to the central nervous system for processing and to form a response.

20.2. Classification of receptors by Stimulus

Sensory receptors are primarily classified by the type of stimulus that generates a response in the receptor. Broadly sensory receptors respond to one of the five primary stimuli:

- **Photoreceptors** detect and respond to light. Most photoreceptors are found in the eyes and are needed for the sense of vision.
- **Chemoreceptors** respond to certain chemicals. They are found mainly in taste buds on the tongue — where they are needed for the sense of taste — and in nasal passages, where they are needed for the sense of smell.
- **Mechanoreceptors** respond to mechanical forces, such as pressure, roughness, vibration and stretching. Most mechanoreceptors are found in the skin and are needed for the sense of touch. Mechanoreceptors are also found in the inner ear, where they are needed for the senses of hearing and balance.
- **Thermoreceptors** respond to variations in temperature. They are found mostly in the skin and detect temperatures that are above or below body temperature.
- **Nociceptors (Pain)** respond to potentially damaging stimuli, which are generally perceived as pain. They are found in internal organs, as well as on the surface of the body. Different nociceptors are activated depending on the particular stimulus. Some detect damaging heat or cold, others detect excessive pressure, and still others detect painful chemicals (such as very hot spices in food).

20.3. Classification by encapsulation of nerve endings

20.3.1. Simple Receptors (nerve endings in tissues)

Unencapsulated receptors - free nerve endings (mechanoreceptors, thermoreceptors, nociceptors) – in skin, joints, viscera and oral cavity.

Encapsulated receptors - tissue-associated nerve endings

• Pacinian corpuscles – in deep dermis, hypodermis, viscera, joint capsules.

• Meissner's corpuscles – in dermal papillae near epidermis.

20.3.2. Complex Receptors (Special Senses)

Olfactory, Taste, Labyrinth (equilibrium/balance, hearing), Eye

Distribution of Receptors in the body: Special Senses

- mediated by relatively complex sense organs of the head, innervated by cranial nerves
- vision, hearing, equilibrium, taste and smell

General (somesthetic, somatosensory)

- receptors widely distributed in skin, muscles, tendons, joints, and viscera
- they detect touch, pressure, stretch, heat, cold and pain, blood pressure

20.3.3. Special Senses Sensation and perception

- Vision – Eye
- Hearing – Ear
- Equilibrium – Ear
- Taste – Taste receptors
- Smell – Olfactory system

General Senses

- Skin – Hot, cold, pressure, pain
- Muscles, joints, and tendons – proprioceptors- stretch receptors respond to stretch or compression
- Pain Receptors – somatic or visceral

All sensory receptors rely on one of these five capacities to detect the changes in the environment, but may be tuned to detect specific characteristics of each to perform a specific sensory function.

These receptors perform countless functions in our body. During vision, rod & cone photoreceptors respond to light intensity and color. During hearing, mechanoreceptors in hair cells of the inner ear detect vibrations conducted from the eardrum. During taste, sensory neurons in our taste buds detect chemical qualities of our foods including sweetness, bitterness, sourness, saltiness etc. During smell, olfactory receptors recognize molecular features of odors. During touch, mechanoreceptors in the skin and other tissues respond to variations in the pressure.

In our study, we look olfactory and taste senses.

Taste and smell are both abilities to sense chemicals, so both taste and olfactory (odor) receptors are chemoreceptors. Both types of chemoreceptors send nerve impulses to the brain along sensory nerves, and the brain "tells" us what we are tasting or smelling.

Taste receptors are found in tiny bumps on the tongue called taste buds**.** You can see a diagram of a taste receptor cell and related structures. Taste receptor cells make contact with chemicals in food through tiny openings called taste pores. When certain chemicals bind with taste receptor cells, it generates nerve impulses that travel through afferent nerves to the CNS. There are separate taste receptors for sweet, salty, sour, bitter and meaty tastes. The meaty, or savory taste is called umami.

20.3.3.1. Taste and Smell – Chemical Receptors

Taste buds: The mouth contains around 10,000 taste buds, most of which are located on and around the tiny bumps on your tongue.

• Every taste bud detects five primary tastes:

- Sour
- Sweet
- Bitter
- Salty
- Umami - salts of certain acids (for example monosodium glutamate or MSG)

• Each of your taste buds contains 50-100 specialized receptor cells.

• Sticking out of every single one of these receptor cells is a tiny taste hair that checks out the food chemicals in your saliva.

• When these taste hairs are stimulated, they send nerve impulses to your brain.

• Each taste hair responds best to one of the five basic tastes.

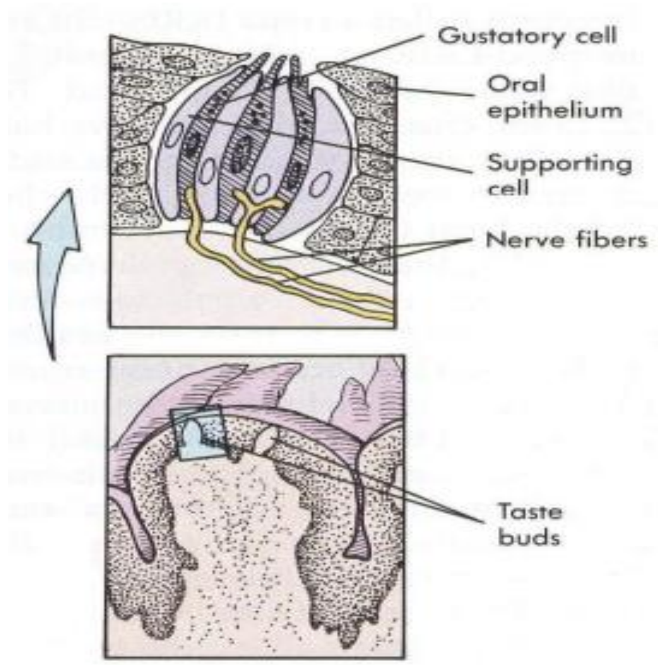


Fig. 20.1: Taste Buds

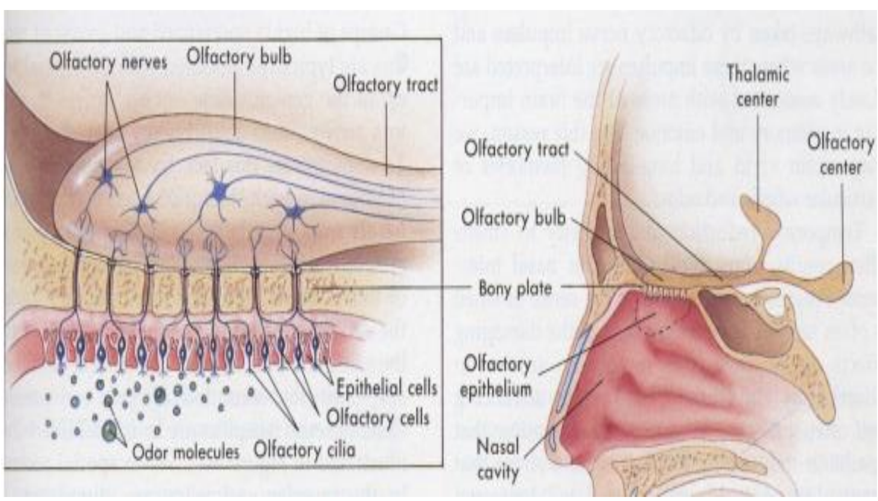
20.3.3.2. Smell Receptors or Olfactory receptors

Olfactory receptors in vertebrate Olfactory Receptors (ORs), also known as odorant receptors, are expressed in the cell membranes of olfactory receptor neurons and are responsible for the detection of odorants which give rise to the sense of smell. Activated olfactory receptors trigger nerve impulses which transmit information about odor to the brain. These receptors are members of the rhodopsin-like family of G protein coupled receptors (GPCRs).

The olfactory receptors form a multigene family consisting of around 800 genes in humans. Location: In vertebrates, the olfactory receptors are located in both the cilia and synapses of the olfactory sensory neurons and in the epithelium of the human airway. Mechanism: Rather than binding specific ligands, olfactory receptors display affinity for a range of odor molecules, and conversely a single odorant molecule may bind to a number of olfactory receptors with varying affinities, which depend on physiochemical properties of molecules like their molecular volumes. Once the odorant has bound to the odor receptor, the receptor undergoes structural changes and it binds and activates the olfactory type G protein on the inside of the olfactory receptor neuron. The G protein (Golf and/or Gs) in turn activates the lyase -

adenylate cyclase - which converts ATP into cyclic AMP (cAMP). The cAMP opens cyclic nucleotide-gated (CNG) ion channels which allow calcium and sodium ions to enter into the cell, depolarizing the olfactory receptor neuron and beginning an action potential which carries the information to the brain.

- Humans able to detect thousands of different smells.
- Olfactory receptors occupy a stamp-sized area in the roof of the nasal cavity, the hollow space inside the nose.
- Tiny hairs, made of nerve fibers, dangle from all your olfactory receptors. They are covered with a layer of mucus.
- If a smell, formed by chemicals in the air, dissolves in this mucus, the hairs absorb it and excite your olfactory receptors.
- A few molecules are enough to activate these extremely sensitive receptors.
- Olfactory Hairs easily fatigued so you do not notice smells.
- Linked to memories - when your olfactory receptors are stimulated, they transmit impulses to your brain and the pathway is directly connected to the limbic system - the part of your brain that deals with emotions so you usually either like or dislike a smell.
- Smells leave long-lasting impressions and are strongly linked to your memories.



A. B.

Fig. 20.2: Olfactory sense.

A. Molecular pathway of olfaction in the cilia through GPCR.

B. Anatomy of the nasal with different parts and olfactory neurons.

Let us sum up

Under this unit, we studied about the sense organs, simple receptors, organs of olfaction and taste. We also focused on the classification of receptors by stimulus, simple receptors, complex receptors and receptors of taste and smell.

Check your Progress

1) The nerve impulse travels along the afferent nerve to the central nervous system for processing and to form a ___________.
2) ___________ detect and response to light.
3) ___________ responds to certain chemicals.
4) ___________ respond to potential damaging stimuli.
5) ___________ receptors are free nerve endings in skin, joints, viscera and oral cavity.

Glossaries

1. Neuromasts: Consist of sensory cells, which detect water movement by deflection of cilia.

2. Columba : Columba comprises a group of medium to large pigeon.

Suggested readings

1) **ROMER, A.S** (1979), Hyman's Comparitive Vertebrate Anatomy, III Ed., The University of Chicogo Press, London.
2) **WEICHERT, C.K** (1965), Anatomy of the Chordates, McGraw Hill Book Co., New York.

Weblink

Sense organs in vertebrates https://youtu.be/WLswe4albqU

Simple receptors of vertebrates https://youtu.be/NOxljsBqTlE

Organ of olfaction of vertebrates https://youtu.be/IwF0BxizoFw

Organ of taste of vertebrates https://youtu.be/K9JSBzEEA0o

Answers to check your progress

1) Response
2) Photoreceptors
3) Chemoreceptors
4) Nociceptors
5) Unencapsulated receptors

Unit 21

Lateral Line System

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the anatomy of lateral line system
- Describe the electroreception.

OVERVIEW

In this unit, we will study about the lateral line system. We will also focus on the anatomy and functions of lateral line system and electroreception.

21.1. INTRODUCTION

Lateral line system or **lateralis system**, also called lateral line organ (LLO), is a system of sensory organs found in aquatic jawed vertebrates. A system of tactile sense organs, unique to aquatic vertebrates from cyclostome fishes (lampreys and hagfishes) to amphibians, that serves to detect movements and pressure changes in the surrounding water. It is made up of a series of mechanoreceptors called neuromasts (lateral line organs) arranged in an interconnected network along the head and body. This network is typically arranged in rows; however, neuromasts may also be organized singly. At its simplest, rows of neuromasts appear on the surface of the skin; however, for most fishes, they lie embedded in the floor of mucus-filled structures called lateral line canals. These canals are placed just underneath the skin, and only the receptor portion of each neuromast extends into the canal. In amphibians the lateral line system occurs only in larval forms and in adult forms that are completely aquatic.

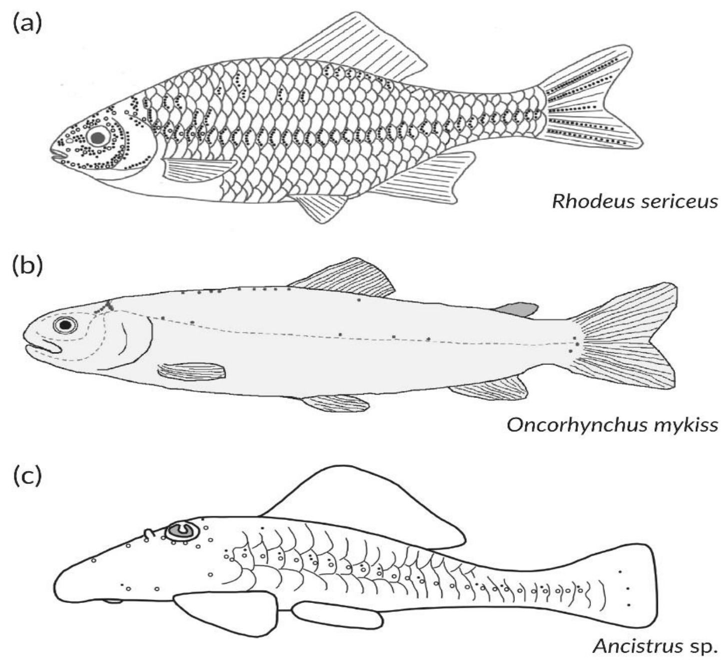


Fig. 21.1: Lateral line system in different fishes.

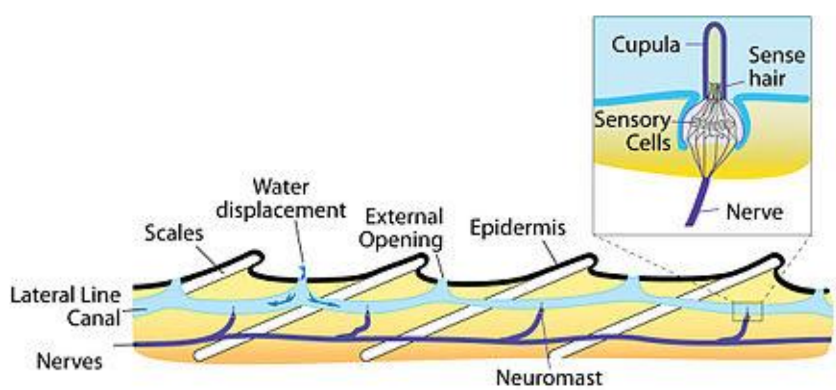


Fig.21.2: Lateral line system with neuromast

Neuromasts are made up of a cluster of sensory and support cells encapsulated within a jellylike sheath called the cupula. Each sensory cell, or hair cell, bears several small cilia, and each cilium may be stimulated by water movement or pressure from a single direction. The lateral line system allows the fish to determine the direction and rate of water movement. The fish can then gain a sense of its own movement, that of nearby predators or prey, and even the water displacement of stationary objects.

21.2. Anatomy of Lateral line System

The major unit of functionality of the lateral line is the neuromast. The neuromast is a mechanoreceptive organ which allows the sensing of mechanical changes in water. There are two main varieties of neuromasts located in animals, canal neuromasts and superficial or freestanding neuromasts. Superficial neuromasts are located externally on the surface of the body, while canal neuromasts are located along the lateral lines in subdermal, fluid filled canals. Each neuromast consists of receptive hair cells whose tips are covered by a flexible and jellylike cupula. Hair cells typically possess both glutamatergic afferent connections and cholinergic efferent connections (Russell, 1971). The receptive hair cells are modified epithelial cells and typically possess bundles of 40-50 microvilli "hairs" which function as the mechanoreceptors (Flock, 1967). These bundles are organized in rough "staircases" of hairs of increasing length order (Peach and Rouse, 2000). The hair cells are stimulated by the deflection of these hair bundles in the direction of the tallest stereocilia. The deflection allows cations to enter through a theoretical mechanically gated channel, causing depolarization of the hair cell. This depolarization opens $Ca_v1.3$ channels in the basolateral membrane (Baker, Clare, 2018). This use of mechanosensitive hairs is homologous to the functioning of hair cells in the auditory and vestibular systems, indicating a close link between these systems (Flock, 1967)

Hair cells utilize a system of transduction that uses rate coding in order to transmit the directionality of a stimulus. Hair cells of the lateral line system produce a constant, tonic rate of firing. As mechanical motion is transmitted through water to the neuromast, the cupula bends and is displaced. Varying in magnitude with the strength of the stimulus, shearing movement and deflection of the hairs is produced, either toward the longest hair or away from it. This results in a shift in the cell's ionic permeability, resulting from changes to open ion channels caused by the deflection of the hairs. Deflection towards the longest hair results in depolarization of the hair cell, increased neurotransmitter release at the excitatory afferent synapse, and a higher rate of signal transduction. Deflection towards the shorter hair has the opposite effect, hyperpolarizing the hair cell and producing a decreased rate of neurotransmitter release (Flock, 1967). These electrical impulses are then transmitted along afferent lateral neurons to the brain.

While both varieties of neuromasts utilize this method of transduction, the specialized organization of superficial and canal neuromasts allow them different mechanoreceptive capacities. Located at the surface of an animal's skin, superficial organs are exposed more directly to the external environment. Though these organs possess the standard "staircase" shaped hair bundles, overall the organization of the bundles within the organs is seemingly haphazard, incorporating various shapes and sizes of microvilli within bundles. This suggests a wide range of detection, potentially indicating a function of broad detection to determine the presence and magnitude of deflection caused by motion in the surrounding water (Peach and Rouse, 2000). In contrast, the structure of canal organs allow canal neuromasts to be organized into a network system that allows more sophisticated mechanoreception, such as the detection of pressure differentials. As current moves across the pores of a canal, a pressure differential is created over the pores. As pressure on one pore exceeds that of another pore, the differential pushes down on the canal and causes flow in the canal fluid. This moves the cupula of the hair cells in the canal, resulting in a directional deflection of the hairs corresponding to the direction of the flow. This method allows the translation of pressure information into directional deflections which can be received and transduced by hair cells.

21.3. Electroreception

In sharks and rays, some neuromasts have been evolutionarily modified to become electroreceptors called Ampullae of Lorenzini. These receptors are concentrated on the heads of sharks and can detect the minute electrical potentials generated by the muscle contractions of prey. Ampullae of Lorenzini can also detect Earth's electromagnetic field, and sharks apparently use these electroreceptors for homing and migration.

The mechanoreceptive hair cells of the lateral line structure are integrated into more complex circuits through their afferent and efferent connections. The synapses that directly participate in the transduction of mechanical information are excitatory afferent connections that utilize glutamate (Flock, and Lam, 1974). However, a variety of different neuromast and afferent connections are possible, resulting in variation in mechanoreceptive properties. For instance, a series of experiments on the superficial neuromasts of *Porichthys notatus* revealed that neuromasts can exhibit a receptive specificity for particular frequencies of stimulation (Weeg and Bass, 2002). Using an immobilized fish to prevent extraneous stimulation, a metal ball was vibrated at different frequencies. Utilizing single cell measurements with a microelectrode, responses were recorded and used to construct tuning curves, which revealed frequency preferences and two main afferent nerve types. One variety is attuned to collect mechanoreceptive information about acceleration, responding to stimulation frequencies between 30–200 Hz. The other type is sensitive to velocity information and is most receptive to stimulation below <30 Hz. This suggests a more intricate model of reception than was previously considered (Weeg and Bass, 2002).

The efferent synapses to hair cells are inhibitory and utilize acetylcholine as a transmitter. They are crucial participants in a corollary discharge system designed to limit self-generated interference (Montgomery and Bodznick, 1994). When a fish moves, it creates disturbances in the water that could be detected by the lateral line system, potentially interfering with the detection of other biologically relevant signals. To prevent this, an efferent signal is sent to the hair cell upon motor action, resulting in inhibition which counteracts the excitation resulting from reception of the self-generated stimulation. This allows the fish to retain perception of motion stimuli without interference created by its own movements.

After signals transduced from the hair cells are transmitted along lateral neurons, they eventually reach the brain. Visualization methods have revealed that the area where these signals most often terminate is the medial octavolateralis nucleus (MON). It is likely that the MON plays an important role in the processing and integration of mechanoreceptive information (Maruska and Tricas, 2009) This has been supported through other experiments, such as the use of Golgi staining and microscopy by New & Coombs to demonstrate the presence of distinct cell layers within the MON. Distinct layers of basilar and non-basilar crest cells were identified within the deep MON. Drawing a comparison to similar cells in the closely related electrosensory lateral line lobe of electric fish, it seems to suggest possible computational pathways of the MON. The MON is likely involved in the integration of sophisticated excitatory and inhibitory parallel circuits in order to interpret mechanoreceptive information.

Let us sum up

Under this unit, we studied about the lateral line system in fishes. We also studied about the anatomy and mechanism of lateral line system and electroreception.

Check your Progress

1) ___________ is a system of sensory organs found in aquatic jawed vertebrates.
2) ___________ sense organs which is unique to aquatic animals that helps in detecting the movement and pressure change of surrounding water.
3) Neuromasts are made up of cluster of ___________ and ___________ cells.
4) The afferent synapses to hair cells are inhibitory and utilize ___________ as a transmitter.
5) The synapses that directly participate in the transduction of mechanical information are excitatory afferent connections that utilize ___________.

Glossaries

1. Columba : Columba comprises a group of medium to large pigeon.

2. Telencephalon: The most highly developed and anterior part of the forebrain, consisting chiefly of the cerebral hemispheres.

Suggested readings

1) **KENT, G.C** (1976), Comparitive anatomy of the Vertebrates, McGraw Hill Book Co., Inc., New York.
2) **ROMER, A.S** (1974), The Vertebrate Body, W.B. Saunders, London.

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Lateral line system in vertebrates https://youtu.be/dB6DRqNrJ24

Electroreception in vertebrates https://youtu.be/3t8rr4iukVM

Answers to check your progress

1) Lateral line organ
2) Tactile
3) Sensory and support cells
4) Acetylcholine
5) Glutamate

Unit 22

Nervous System

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the nervous system
- Describe the organization on nervous system
- Illustrate the structure of brain
- Explain the comparative anatomy of brain in various mammals.

OVERVIEW

In this unit, we will study about the nervous system. We will also focus on the organization of nervous system, neurons, dendrites, axon, neurotransmitters, human brain- structure and functions, and comparative anatomy of brain in vertebrates such as elasmobranch, amphibia, reptile, birds and mammals.

22.1. INTRODUCTION

The nervous system is the part of an animal's body that coordinates the voluntary and involuntary actions of the animal and transmits signals between different parts of its body. Nervous tissue first arose in wormlike organisms about 550 to 600 million years ago. In most types of animals it consists of two main parts, the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS contains the brain and spinal cord. The PNS consists mainly of nerves, which are long fibers that connect the CNS to every other part of the body. The PNS includes motor neurons, mediating voluntary movement, the autonomic nervous system, comprising the sympathetic nervous system and the parasympathetic nervous system and regulating involuntary functions, and the enteric nervous system, a semi-independent part of the nervous system whose function is to control the gastrointestinal system.

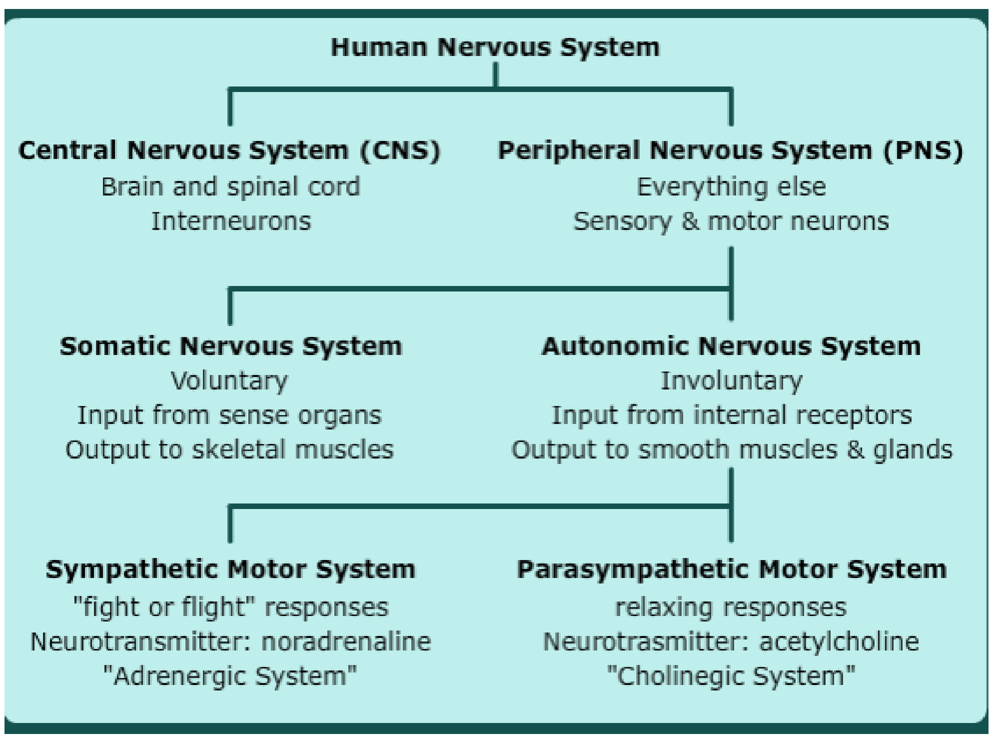
At the cellular level, the nervous system is defined by the presence of a special type of cell, called the neuron, also known as a "nerve cell". Neurons have special structures that allow them to send signals rapidly and precisely to other cells. They send these signals in the form of electrochemical waves traveling along thin fibers called axons, which cause chemicals called neurotransmitters to be released at junctions called synapses. A cell that receives a synaptic signal from a neuron may be excited, inhibited, or otherwise modulated. The connections between neurons form neural circuits that generate an organism's perception of the world and determine its behavior. Along with neurons, the nervous system contains other specialized cells called glial cells (or simply glia), which provide structural and metabolic support.

Nervous systems are found in most multicellular animals, but vary greatly in complexity. The only multicellular animals that have no nervous system at all are sponges, placozoans and mesozoans, which have very simple body plans.

The nervous systems of ctenophores (comb jellies) and cnidarians (e.g., anemones, hydras, corals and jellyfishes) consist of a diffuse nerve net. All other types of animals, with the exception of a few types of worms, have a nervous system containing a brain, a central cord (or two cords running in parallel), and nerves radiating from the brain and central cord. The size of the nervous system ranges from a few hundred cells in the simplest worms, to on the order of 100 billion cells in humans.

22.2. Organization of Nervous System

The nervous system can be divided anatomically into the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS is made up of the brain and spinal cord, whereas nerves make up the PNS.



The central nervous system: The central nervous system (CNS) is the part of the nervous system consisting of the brain and spinal cord. It is opposed to the peripheral nervous system (or PNS), which is composed of nerves leading to and from the CNS, often through junctions known as ganglia. The central nervous system is so named because it integrates information it receives from, and coordinates and influences the activity of, all parts of the bodies of bilaterally symmetric animals—that is, all multicellular animals except sponges and radially symmetric animals such as jellyfish, and it contains the majority of the nervous system. Arguably many consider the retina and the optic nerve (2^{nd} cranial nerve) as well as the olfactory nerves (3^{rd}) and olfactory epithelium as parts of the CNS, synapsing directly on brain tissue without intermediate ganglia. Following this classification the olfactory epithelium is the only central nervous tissue in direct contact with the environment, which opens up for therapeutic treatments. The CNS is contained within the dorsal cavity, with the brain in the cranial cavity and the spinal cord in the spinal cavity. In vertebrates, the brain is protected by the skull, while the spinal cord is protected by the vertebrae, both enclosed in the meninges.

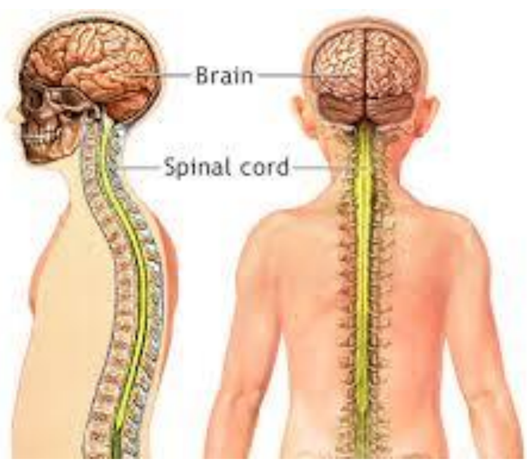


Fig. 22.1: The central nervous system

22.2.1. Neuron

A neuron is a nerve cell that is the basic building block of the nervous system. Neurons are similar to other cells in the human body in a number of ways, but there is one key difference between neurons and other cells. Neurons are specialized to transmit information throughout the body. These highly specialized nerve cells are responsible for communicating information in both chemical and electrical forms. There are also several different types of neurons responsible for different tasks in the human body.

Sensory neurons carry information from the sensory receptor cells throughout the body to the brain. Motor neurons transmit information from the brain to the muscles of the body. Interneurons are responsible for communicating information between different neurons in the body.

Neurons vs. Other Cells

Similarities with other cells:

Neurons and other body cells both contain a nucleus that holds genetic information. Neurons and other body cells are surrounded by a membrane that protects the cell. The cell bodies of both cell types contain organelles that support the life of the cell, including mitochondria, Golgi bodies, and cytoplasm. Differences that make neurons unique: Unlike other body cells, neurons stop reproducing shortly after birth. Because of this, some parts of the brain have more neurons at birth than later in life because neurons die but are not replaced. While neurons do not reproduce, research has shown that new connections between neurons form throughout life.

Neurons have a membrane that is designed to sends information to other cells. The axon and dendrites are specialized structures designed to transmit and receive information. The connections between cells are known as synapses. Neurons release chemicals known as neurotransmitters into these synapses to communicate with other neurons.

22.2.2. Structure of a Neuron

There are three basic parts of a neuron: the dendrites, the cell body and the axon. However, all neurons vary somewhat in size, shape, and characteristics depending on the function and role of the neuron. Some neurons have few dendritic branches, while others are highly branched in order to receive a great deal of information. Some neurons have short axons, while others can be quite long. The longest axon in the human body extends from the bottom of the spine to the big toe and averages a length of approximately three feet.

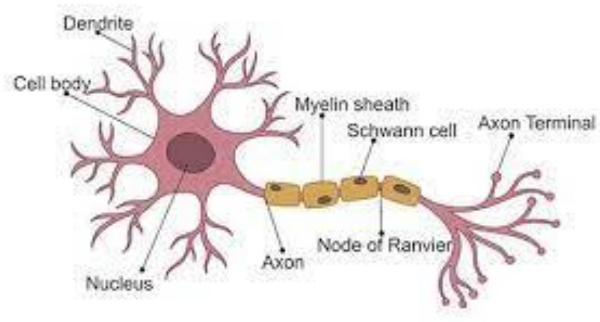


Fig. 22.2: Structure of Neuron

22.2.3. Dendrites

Dendrites are treelike extensions at the beginning of a neuron that help increase the surface area of the cell body. These tiny protrusions receive information from other neurons and transmit electrical stimulation to the soma. Dendrites are also covered with synapses.

Characteristics of Dendrites

- Most neurons have many dendrites
- However, some neurons may have only one dendrite
- Short and highly branched
- Transmits information to the cell body.

The soma is where the signals from the dendrites are joined and passed on. The soma and the nucleus do not play an active role in the transmission of the neural signal. Instead, these two structures serve to maintain the cell and keep the neuron functional. The support structures of the cell include mitochondria, which provide energy for the cell, and the Golgi apparatus, which packages products created by the cell and secretes them outside the cell wall.

22.2.4. Axon

The axon hillock is located at the end of the soma and controls the firing of the neuron. If the total strength of the signal exceeds the threshold limit of the axon hillock, the structure will fire a signal known as an action potential down the axon.

The axon is the elongated fiber that extends from the cell body to the terminal endings and transmits the neural signal. The larger the axon, the faster it transmits information. Some axons are covered with a fatty substance called myelin that acts as an insulator. These myelinated axons transmit information much faster than other neurons.

Characteristics of Axon

- Most neurons have only one axon

- Transmit information away from the cell body

- May or may not have a myelin covering

The terminal buttons are located at the end of the neuron and are responsible for sending the signal on to other neurons. At the end of the terminal button is a gap known as asynapse. Neurotransmitters are used to carry the signal across the synapse to other neurons.

22.2.5. Neurotransmitters

Neurotransmitters are an essential part of our everyday functioning. While it is not known exactly how many neurotransmitters exist, scientists have identified more than 100 of these chemical messengers. What effects do each of these neurotransmitters have on the body? What happens when disease or drugs interfere with these chemical messengers? The following are just a few of the major neurotransmitters, their known effects, and disorders they are associated with.

Acetylcholine: Associated with memory, muscle contractions, and learning. A lack of acetylcholine in the brain is associated with Alzheimer's disease.

Endorphins: Associated with emotions and pain perception. The body releases endorphins in response to fear or trauma. These chemical messengers are similar to opiate drugs such as morphine, but are significantly stronger.

Dopamine: Associated with thought and pleasurable feelings. Parkinson's disease is one illness associated with deficits in dopamine, while schizophrenia is strongly linked to excessive amounts of this chemical messenger.

22.3. The Brain (Human)

The anatomy of the brain is complex due its intricate structure and function. This amazing organ acts as a control center by receiving, interpreting, and directing sensory information throughout the body. The brain and spinal cord are the two main structures of the central nervous system.

22.3.1. Functions of Brain

The brain is a complex organ that controls thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger and every process that regulates our body.

22.3.2. Anatomy of the Brain

There are three major divisions of the brain. They are the forebrain, the midbrain and the hindbrain.

Divisions of Brain

The forebrain is responsible for a variety of functions including receiving and processing sensory information, thinking, perceiving, producing and understanding language, and controlling motor function. There are two major divisions of forebrain: the diencephalon and the telencephalon. The diencephalon contains structures such as the thalamus and hypothalamus which are responsible for such functions as motor control, relaying sensory information, and controlling autonomic functions. The telencephalon contains the largest part of the brain, the cerebrum. Most of the actual information processing in the brain takes place in the cerebral cortex.

The midbrain and the hindbrain together make up the brainstem. The midbrain is the portion of the brainstem that connects the hindbrain and the forebrain. This region of the brain is involved in auditory and visual responses as well as motor function.

The hindbrain extends from the spinal cord and is composed of the metencephalon and myelencephalon. The metencephalon contains structures such as the pons and cerebellum. These regions assist in maintaining balance and equilibrium, movement coordination, and the conduction of sensory information. The myelencephalon is composed of the medulla oblongata which is responsible for controlling such autonomic functions as breathing, heart rate, and digestion.

Brain Lobes:

The **frontal lobe** is located at the front of the brain and is associated with reasoning, motor skills, higher level cognition, and expressive language. At the back of the frontal lobe, near the central sulcus, lies the motor cortex. This area of the brain receives information from various lobes of the brain and utilizes this information to carry out body movements. Damage to the frontal lobe can lead to changes in sexual habits, socialization, and attention as well as increased risk-taking.

The **parietal lobe** is located in the middle section of the brain and is associated with processing tactile sensory information such as pressure, touch and pain. A portion of the brain known as the somatosensory cortex is located in this lobe and is essential to the processing of the body's senses. Damage to the parietal lobe can result in problems with verbal memory, an impaired ability to control eye gaze and problems with language.

The **temporal lobe** is located on the bottom section of the brain. This lobe is also the location of the primary auditory cortex, which is important for interpreting sounds and the language we hear. The hippocampus is also located in the temporal lobe, which is why this portion of the brain is also heavily associated with the formation of memories. Damage to the temporal lobe can lead to problems with memory, speech perception and language skills.

The **occipital lobe** is located at the back portion of the brain and is associated with interpreting visual stimuli and information. The primary visual cortex, which receives and interprets information from the retinas of the eyes, is located in the occipital lobe. Damage to this lobe can cause visual problems such as difficulty recognizing objects, an inability to identify colors and trouble recognizing words.

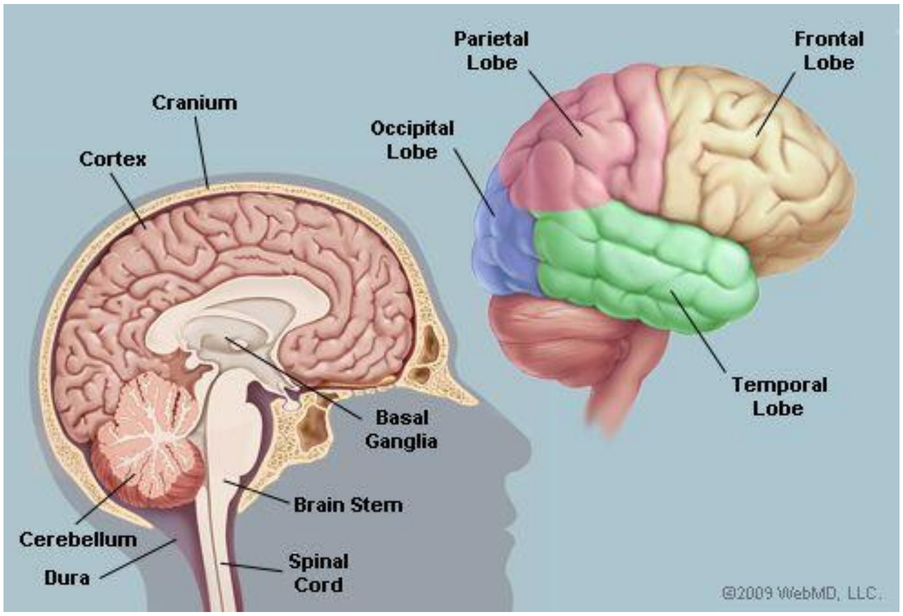


Fig. 22.3: Structure of Brain

Brain areas:

- Cerebrum
- Cerebellum
- Limbic System
- Brain Stem

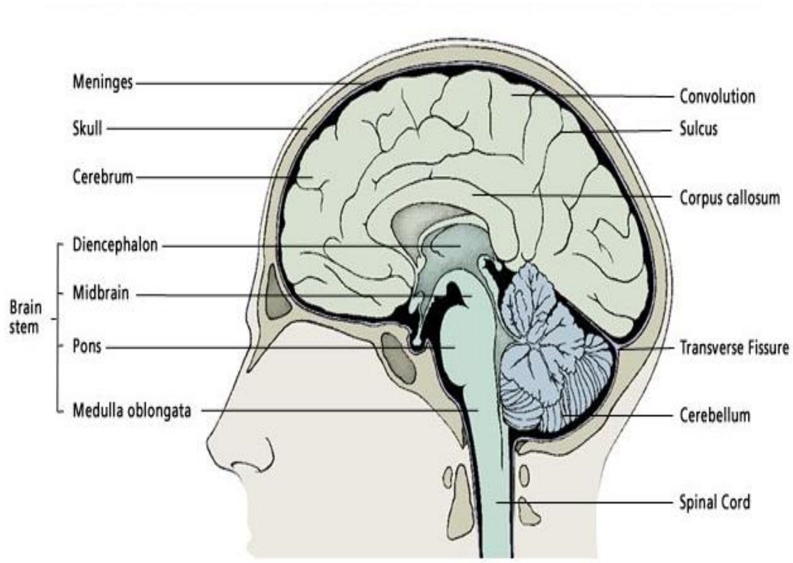


Fig. 22.4: Structure of Brain Stem

The Cerebrum:

The cerebrum or cortex is the largest part of the human brain, associated with higher brain function such as thought and action. The cerebral cortex is divided into four sections, called "lobes": the frontal lobe, parietal lobe, occipital lobe and temporal lobe.

The cerebral cortex is highly wrinkled. Essentially this makes the brain more efficient, because it can increase the surface area of the brain and the amount of neurons within it. We will discuss the relevance of the degree of cortical folding.

A deep furrow divides the cerebrum into two halves, known as the left and right hemispheres. The two hemispheres look mostly symmetrical yet it has been shown that each side functions slightly different than the other. Sometimes the right hemisphere is associated with creativity and the left hemisphere is associated with logic abilities. The corpus callosum is a bundle of axons which connects these two hemispheres.

Nerve cells make up the gray surface of the cerebrum which is a little thicker than your thumb. White nerve fibers underneath carry signals between the nerve cells and other parts of the brain and body. The neocortex occupies the bulk of the cerebrum. This is a six-layered structure of the cerebral cortex which is only found in mammals. It is thought that the neocortex is a recently evolved structure, and is associated with "higher" information processing by more fully evolved animals.

Cerebellum:

The cerebellum or "little brain", is similar to the cerebrum in that it has two hemispheres and has a highly folded surface or cortex. This structure is associated with regulation and coordination of movement, posture and balance.

In other words, animals which scientists assume to have evolved prior to humans, for example reptiles, do have developed cerebellums. However, reptiles do not have neocortex. Limbic System:

The limbic system, often referred to as the "emotional brain", is found buried within the cerebrum. Like the cerebellum, evolutionarily the structure is rather old. This system contains the thalamus, hypothalamus, amygdala, and hippocampus. Here is a visual representation of this system, from a mid-sagittal view of the human brain:

- Thalamus
- Hypothalamus
- Amygdala
- Hippocampus

Brain Stem:

Underneath the limbic system is the brain stem. This structure is responsible for basic vital life functions such as breathing, heartbeat, and blood pressure. Scientists say that this is the "simplest" part of human brains because animals' entire brains, such as reptiles (who appear early on the evolutionary scale) resemble our brain stem.

The brain stem is made of the midbrain, pons and medulla.

22.4. Comparison of Brain in Various Vertebrates

22.4.1. Fishes - Elasmobranch

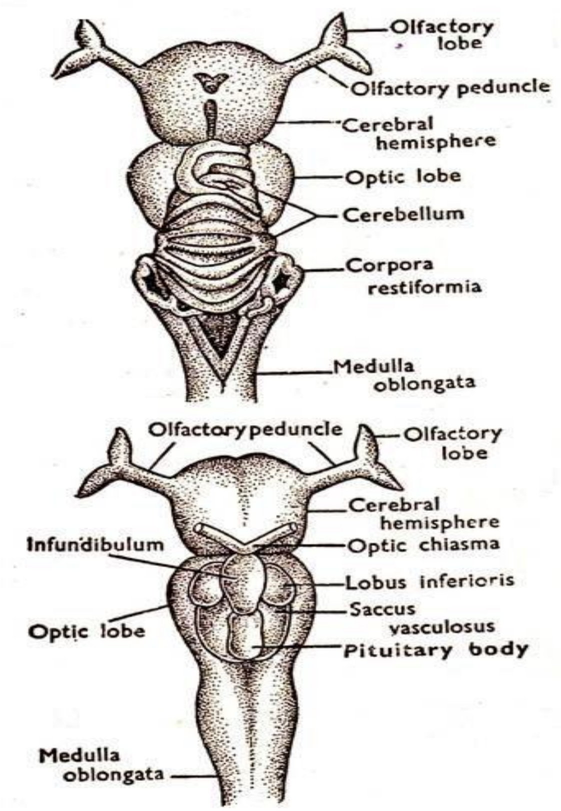


Fig. 22.5: Brain of Elasmobranch, Top - Dorsal view; Botton – Venteral view

1. The brain is enclosed within a cartilaginous cranium. It is divisible into a forebrain, made up of telencephalon and thalamencephalon; a midbrain or mesencephalon and a hindbrain consists of metencephalon and myelencephalon. The various lobes of the brain are situated in a straight line.
2. Olfactory lobes – The two olfactory lobes are large and anteriorly connected with the cerebral hemispheres by a stalk-like olfactory peduncle. It is concerned with the sense of small. The nasal sacs are large. Evidently, the olfactory sense is highly developed. The corpus striatum is bulging.
3. Cerebral hemisphere – It is undivided and without any median groove. The cerebral hemisphere is thickened both in the floor and in the roof. It is the seat of memory, intelligence and consciousness.

4. Thalamencephalon – It is posterior to the fore brain. On the nonnervous vascular roof is a small rounded pineal body representing the third ancestral eye. The floor bears the infundibulum with a pituitary body. The pituitary body is glandular and secretes different hormones of varied functions.
5. The two sides of the infundibulum bear two thin walled oval sacs, the lobi-inferiores, which are produced posteriorly into sacci vasculosi. It is believed to act as pressure receptor. An optic chiasma is present in front of the infundibulum.
6. Mesencephalon – It is very large, bears a pair of oval optic lobes dorsally and longitudinal nerve fibres like crura cerebri of higher animals ventrally. The optic lobes control vision.
7. Metencephalon – It consists of a very large dorsal cerebellum. It overlaps the potic lobes in front and medulla oblongata behind. It is the centre for coordination of muscular movement and partly for balance also.
8. Myelence phalon – It is also known as medulla oblongata. It gradually tapers behind to end in the spinal cord. Anteriorly, It is produced into ear-shaped lappets, the corpora restiforma.
9. The brain is hollow and bears several intercommunicated cavities of unequal dimensions. Cerebrospinal fluid circulates through these cavities or ventricles and the spinal cord. The cavities in the cerebral hemispheres are called first and second ventricles, connected with the third ventricle of the thalamencephalon by a narrow foramen of Monro.
10. The third ventricle is connected with the optocoeles in the optic lobes and with the fourth ventricle in the medull oblonagata by a narrow aqueduct of sylvius or iter.
11. Ten pairs of cranial nerves arise from the brain.

22.4.2. Amphibians - Bufo

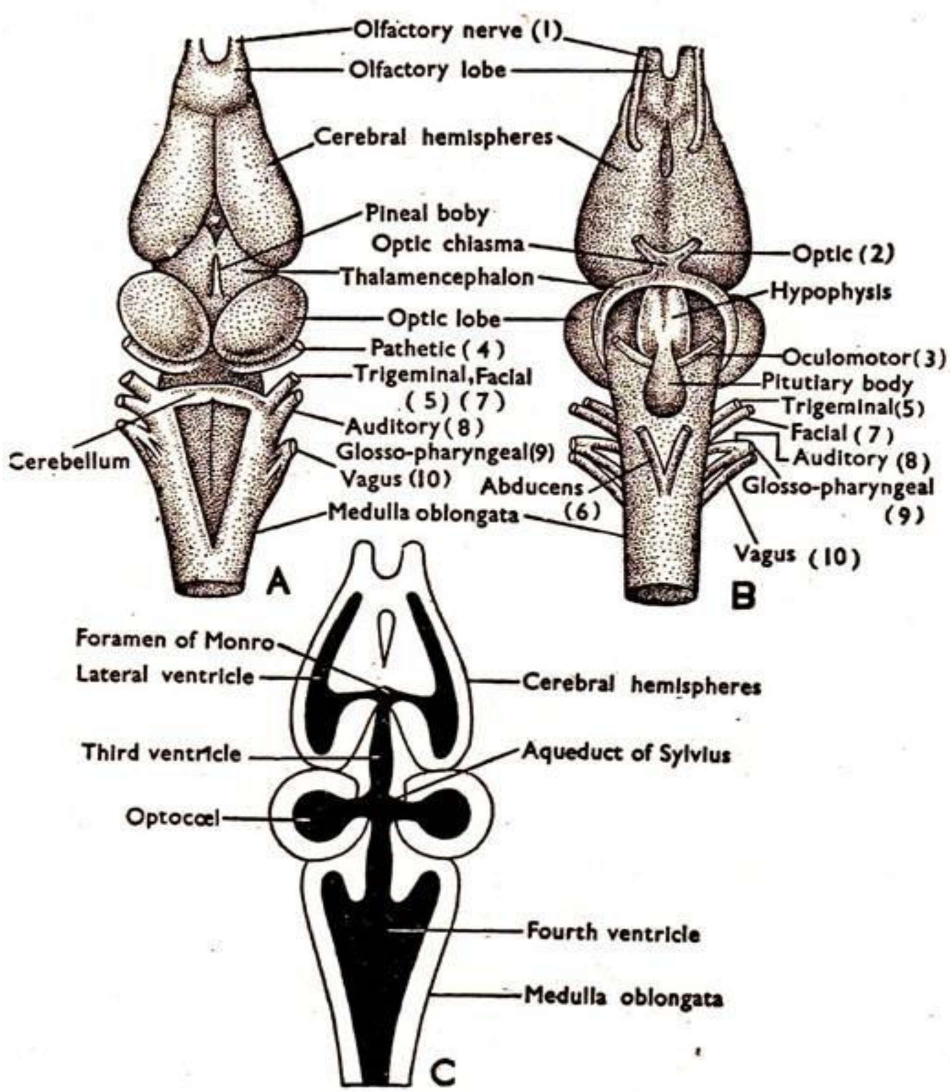


Fig. 22.6: Brain of Bufo A. Dorsal view; B. Ventrail view; C. L.S showing ventricles

1. The brain is enclosed within a bony cranium. It is divisible into a forebrain, made up of telencephalon and thalamencephalon; a midbrain or mesencephalon and a hindbrain consists of metencephalon and myelencephalon. The various lobes of the brain are situated in a straight line.
2. Olfactory lobes – The telencephalon has a nonnervous roof and the olfactory bulbs are placed in front of the cerebral hemispheres. It is concerned with the sense of smell.

3. Cerebral hemispheres – These are two, elongateoval and well-developed. (Rest as in teleost).
4. Thalamencephalon – It is well developed and the sides are produced into optic thalami, the seat of vision and possibly balance also. The floor and the roof both are thin. On the roof, is a thin stalk, the epiphysis bearing a small rounded pineal body, representing the third ancestral eye.
5. On the floor, is a hypophysis bearing a pituitary body, which is glandular and secretes different hormones of varied functions. An optic chiasma is present in front of the hypophysis.
6. Mesencephalon – It bears a paired of rounded optic lobes dorsally constituting the corpora bigemina and two longitudinal bands, crura cerebriventrally. The optic lobes control vision.
7. Metencephalon – It consists of a narrow, dorsal transverse band placed just behind the optic lobes and known as cerebellum. It is the centre for coordination of muscular movement and partly for balance also.
8. Myelencephalon – It gradually tapers behind to end in the spinal cord. The roof of the myelencephalon is open.
9. The brain is hollow and bears several intercommunicated cavities of unequal dimensions. Cerebrospinal fluid circulates through these cavities or ventricles and the spinal cord. The cavities in the cerebral hemispheres are called first and second ventricles, connected with the third ventricle of the thalamencephalon by a narrow foramen of Monro.
10. The third ventricle is connected with the optocoeles in the optic lobes and with the fourth ventricle in the medull oblonagata by a narrow aqueduct of sylvius or iter.

22.4.3. Reptiles - Calotes

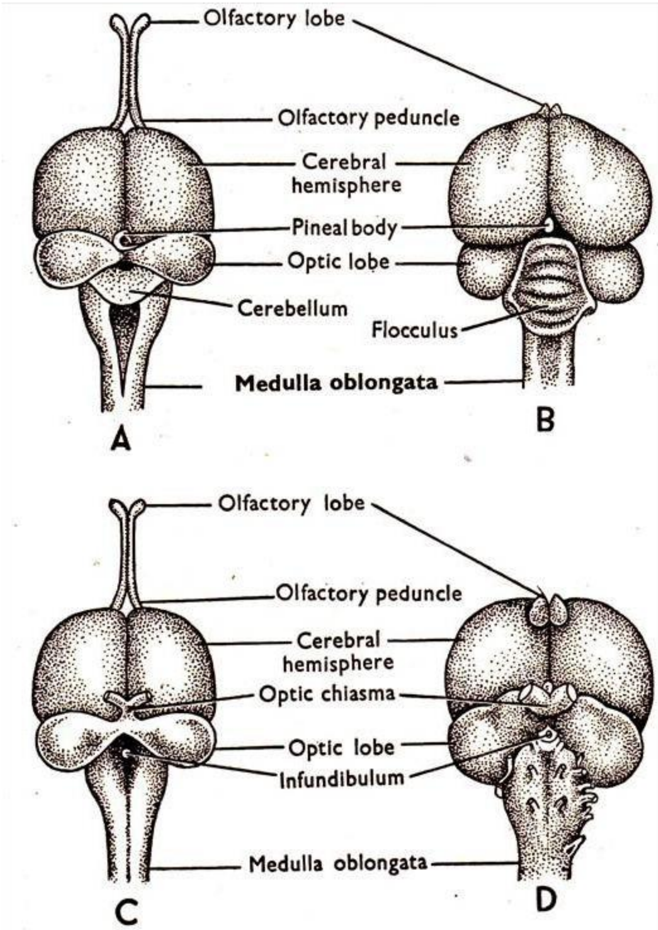


Fig. 22.7: Brain of Calotes and Columba

A. Calotes - Dorsal view ; B: Columba dorsal view

C. Calotes - Ventral view ; D. Columba - Ventral view

1. The brain is enclosed within a bony cranium. It is divisible into a forebrain, made up of telencephalon and thalamencephalon; a midbrain or mesencephalon and a hindbrain consists of metencephalon and myelencephalon. The various lobes of the brain are situated in a straight line.

2. Olfactory lobes – The telencephalon has a nonnervous roof and the olfactory lober are connected with the anterior ends of the cerebral hemispheres by long and slender peduncles.

3. Cerebral hemispheres – These are two, almost semicircular and well developed. (Rest as in teleost).

4. Thalamencephalon – It is well developed and the sides are produced into optic thalami, the seat of vision and possibly balance also. The floor and the roof both are thin. On the roof, is a thin stalk, the epiphysis bearing a small rounded pineal body, representing the third ancestral eye.
5. On the floor, is a hypophysis bearing a pituitary body, which is glandular and secretes different hormones of varied functions. An optic chiasma is present in front of the hypophysis.
6. Mesencephalon – It bears a paired of rounded optic lobes dorsally constituting the corpora bigemina and two longitudinal bands, crura cerebriventrally. The optic lobes control vision.
7. Metencephalon – It consists of a small semicircular flap, the cerebellum which partly overlaps the medulla oblongata posteriorly. It is the centre for coordination of muscular movement and partly for balance also.
8. Myelencephalon – It is also known as medulla oblongata. It gradually tapers behind to end in the spinal cord. The roof of the myelencephalon is open.
9. The brain is hollow and bears several intercommunicated cavities of unequal dimensions. Cerebrospinal fluid circulates through these cavities or ventricles and the spinal cord. The cavities in the cerebral hemispheres are called first and second ventricles, connected with the third ventricle of the thalamencephalon by a narrow foramen of Monro.
10. The third ventricle is connected with the optocoeles in the optic lobes and with the fourth ventricle in the medull oblonagata by a narrow aqueduct of sylvius or iter.
11. Twelve pairs of cranial nerves arise from the brain.

22.4.4. Aves - Columba

1. The brain is enclosed within a bony cranium. It is divisible into a forebrain, made up of telencephalon and thalamencephalon; a midbrain or mesencephalon and a hindbrain consists of metencephalon and myelencephalon. The various lobes of the brain are situated in a straight line.
2. The brain is more compact due to the appearance of flexure.

3. Olfactory lobes – The telencephalon has a non-nervous roof and the olfactory lobes are connected with the anterior ends of the cerebral hemispheres, which are poorly developed.
4. Cerebral hemispheres – These are two, large and extend behind to meet the cerebellum, covering the thalamencephalon dorsally. These are the seat of memory, consciousness and intelligence.
5. Thalamencephalon – It is well developed and the sides are produced into optic thalami, the seat of vision and possibly balance also. The floor and the roof both are thin. On the roof, is a thin stalk, the epiphysis bearing a small rounded pineal body, representing the third ancestral eye.
6. Mesencephalon – It bears a pair of large, rounded laterally placed optic lobes constituting the corporabigemina and two longitudinal brand, cruracerebri ventrally. The optic lobes control vision.
7. Metencephalon – It consists of a comparatively large elongated cerebellum and is divisible into a large middle lobe, the surface of which is marked by grooves and a pair of small lateral lobes or floccule. It is the centre for coordination of muscular movement and partly for balance also. The 4^{th} ventricle is hidden by the cerebellum.
8. Myelencephalon – It is also known as medulla oblongata. It gradually tapers behind to end in the spinal cord. It has a well-marked ventral flexure. The fourhte ventricle is without any roof.
9. The brain is hollow and bears several intercommunicated cavities of unequal dimensions. Cerebrospinal fluid circulates through these cavities or ventricles and the spinal cord. The cavities in the cerebral hemispheres are called first and second ventricles, connected with the third ventricle of the thalamencephalon by a narrow foramen of Monro.
10. The third ventricle is connected with the optocoeles in the optic lobes and with the fourth ventricle in the medull oblonagata by a narrow aqueduct of sylvius or iter.
11. Twelve pairs of cranial nerves arise from the brain.

22.4.5. Mammals - Cavia

1. The brain in Cavia is similar to that in a bird.
2. Olfactory lobes – The telencephalon has a nonnervous roof and the olfactory lobes are connected with the anterior ends of the cerebral hemispheres, which are poorly developed.
3. Cerebral hemispheres – The two cerebral hemispheres are large, long and narrow in front and posteriorly cover the optic lobes. The surface of the hemispheres is marked into convolutions by depressions or fissures and the lobes are frontal, temporal, parietal and occipital. The two hemispheres are connected by a transverse band of fibres, the corpus callosum. Corpus striatum is another band of connective nerve tissue below the ventricles. These are the seat of memory, intelligence and consciousness.

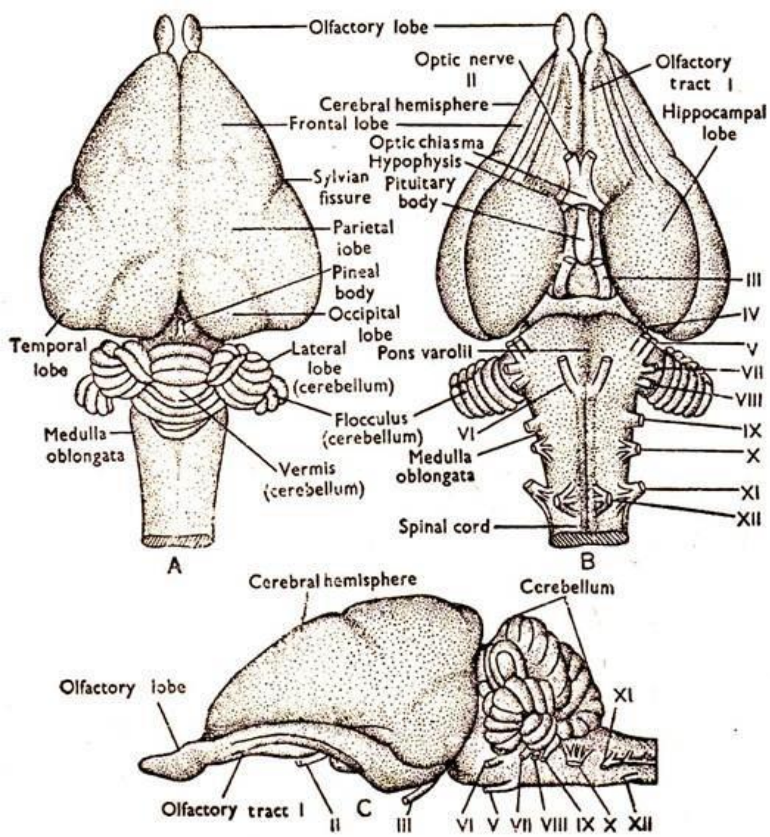


Fig. 22.8: Brain of Cavia. A. Dorsal view; B. Ventral view; C. Side view

4. Thalamencephalon – It is small and thick as the side walls are produced into large optic thalami, the seat of vision and possibly balanced also. On the roof, is an epiphysis bearing the pineal body, representing the third

ancestral eye. On the floor, is a hypophysis bearing a glandular pituitary body which secretes different hormones of varied functions. A rounded elevation, the corpus geniculatum is placed anterior to each optic thalamus. The hypophysis is prolonged posteriorly into a rounded mass, the corpus mammilare.

a. Mesencephalon – It bears a pair of large rounded dorsal optic lobes, the corpora quadrigemina and two prominent, ventral longitudinal bands, the crura cerebri. The optic lobes control vision.

b. Metencephalon – It consists of a comparatively large, elongated cerebellum subdivided into a median vermis and two lateral lobes. The vermis is marked by grooves and the lateral lobes bear floccule. A abnd of transverse fibres connect the two halves of the cerebellum and is known as pons varoli. The metencephalon is the centre for coordination of muscular movement and partly for balance also.

c. Myelencephalon – It is also known as medulla oblongata. It gradually tapers behind to end in the spinal cord. It has a well-marked ventral flexure. The fourhte ventricle is without any roof.

d. The brain is hollow and bears several intercommunicated cavities of unequal dimensions. Cerebrospinal fluid circulates through these cavities or ventricles and the spinal cord. The cavities in the cerebral hemispheres are called first and second ventricles, connected with the third ventricle of the thalamencephalon by a narrow foramen of Monro.

e. The third ventricle is connected with the optocoeles in the optic lobes and with the fourth ventricle in the medull oblonagata by a narrow aqueduct of sylvius or iter.

f. Twelve pairs of cranial nerves arise from the brain.

Let us sum up

Under this unit, we studied about the nervous system in vertebrates. We also focused on the organization of nervous system, neurons, dendrites, axon, neurotransmitters, human brain- structure and functions, and comparative anatomy of brain in vertebrates such as elasmobranch, amphibia, reptile, birds and mammals.

Check your Progress

1) The nervous system is divided into 2 types of nervous system they are ___________ and ___________.
2) The brain is protected by ___________ and the spinal cord is protected by ___________.
3) ___________ is a nerve cell that are the basic building blocks of the nervous system.
4) ___________ are the tree like extensions at the beginning of a neuron that helps in increasing the surface area of the cell body.
5) ___________ is a chemical that is associated with memory, muscle contraction and learning.

Glossaries

1. Hippochampal	:	Relating to the hippocampus (in the brain)
2. Somites	:	One of a longitudinal series of block like segments into which the mesoderm.

Suggested readings

1) **HARREY POUGH, JOHN B. HEISHER, WILLIAM N. McFARLAND** (1990), Vertebrate Life, Macmillan Publishing Co., New York.
2) **JOLLIE, M** (1962), Chordate Morphology, Reinholt Publishing Corporation, NewYork.

Weblink

Nervous system of vertebrates https://youtu.be/6mFThnV1WOk

Comparative anatomy of brains in vertebrates
https://youtu.be/T0dSejm_Zoc

Answers to check your progress

1) Central nervous system and peripheral nervous system
2) Skull and vertebrae
3) Neuron
4) Dendrites
5) Acetylcholine

Unit 23

Comparative Anatomy of Spinal Cord

STRUCTURE

OBJECTIVES

After completing this unit, the students will be able to

- Explain the anatomy of spinal cord.
- Describe the anatomy of nervous system
- Give a detailed description on comparative histology.

OVERVIEW

In this unit, we will study about the spinal cord. We will also focus on the spinal pattern, medullar pattern, cerebellar pattern, tectal pattern, diencephalic pattern, telencephalic pattern, comparative histology of neuron, connective tissue cells, brain, spinal cord, cranial nerves, spinal nerves and anatomic nervous system.

23.1. INTRODUCTION

The cells, tissues, and organs of the vertebrate nervous system collectively coordinate the body and allow an organism to sense and respond to stimuli. The vertebrate nervous system includes the brain, brainstem, spinal cord, cranial and peripheral nerves, and ganglia. The vertebrate brain consists of three basic divisions: prosencephalon, mesencephalon, and rhombencephalon. Vertebrates have common morphological patterns in the development and function of the nervous system, including spinal, medullar, cerebellar, tectal, diencephalic, and telencephalic patterns. A neuron (nerve cell) consists of a cell body, one to several cytoplasmic processes called dendrites, and one process called an axon. Signals are transmitted from one neuron to another across a synapse.

Embryologically, the nervous system arises from the outer germ layer (ectoderm). A neural plate is formed first, which eventually closes to form a neural tube from which the adult nervous system develops.

The assemblages of cells that are specialized by their shape and function to act as the major coordinating organ of the body comprise the nervous system. Nervous tissue underlies the ability to sense the environment, to move and react to stimuli, and to generate and control all behavior of the organism. In general, an environmental stimulus causes a response in an organism when specialized structures (receptors) are excited. Excitations are conducted by nerves to effectors that act to adapt the organism to the changed conditions of the environment. With regard to the vertebrates, the nervous system (Fig. 23.1) consists of the brain, brainstem, spinal cord, cranial and peripheral nerves and ganglia. The brain and spinal cord together comprise the central nervous system, whereas the nerves and ganglia that leave the brain and spinal cord constitute the peripheral nervous system.

The brain of all vertebrates, including humans, consists of three basic divisions: prosencephalon, mesencephalon and rhombencephalon (Fig. 23.2). The indication is that these divisions of the vertebrate brain have evolved along several functional lines and perform very different functions.

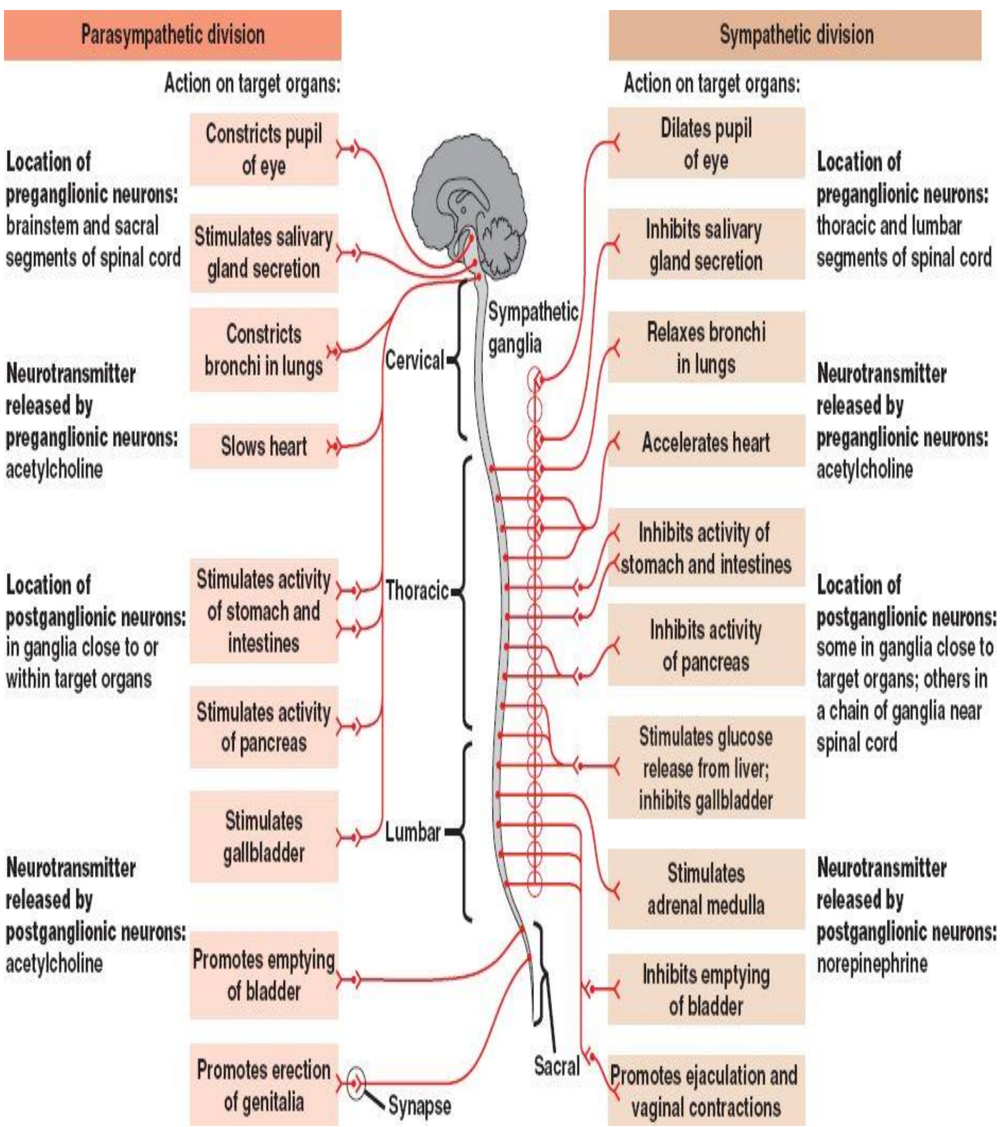


Fig. 23.1 Schematic diagram of vertebrate brain and peripheral nerves

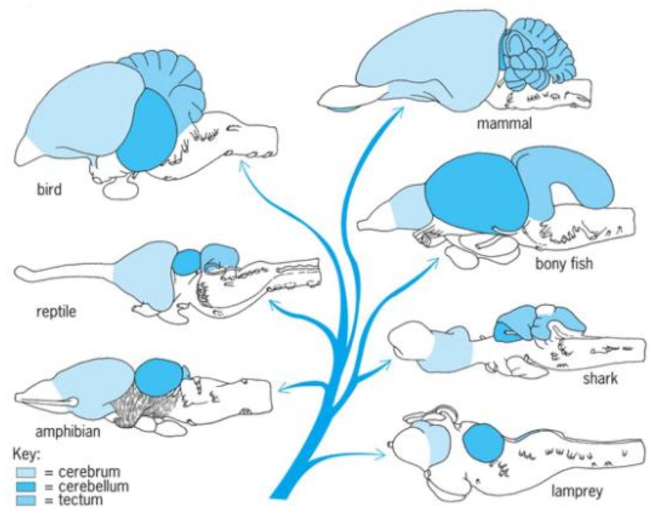


Fig. 23.2 Lateral views of several vertebrate brains showing evolutionary relationships.

The nervous system of ancestral vertebrates apparently consisted of a single hollow neural tube (dorsally placed and running the length of the animal), which was probably structured in a manner similar to the spinal cord in living vertebrates (Fig. 23.3). It consisted of a central gray region that contained most of the cell bodies of the neurons (nerve cells) and was surrounded by a superficial white region containing the axons and dendrites of the neurons running to and from the tube. Each region of the tube was primarily concerned with the functions of that immediate region of the body to which its nerves projected. Neural functions were mediated at a segmental level rather than specialized in one specific region. Each region of the neural tube also contained neural cells that interconnected adjacent regions. This primitive condition still persists in a few living forms.

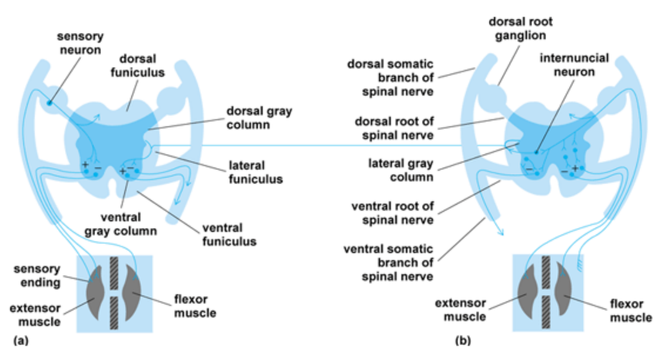


Fig. 23.3 Spinal cord: (a) monosynaptic arcs; (b) multisynaptic arcs.

As vertebrates evolved, structures in the head region became specialized for sensing the outside world and capturing food. This specialization was reflected in the neural tube, and its anterior region enlarged to permit analysis of the environment and integration of behavior. This enlargement of the neural tube is called a brain, and its divisions represent regions of different specialization. Each of the three primitive brain divisions was concerned with analysis and integration of a single type of sensory information. The rhombencephalon analyzed changes in the flow and pressure of water on an animal; the mesencephalon analyzed changes in the pattern and intensity of light; and the prosencephalon analyzed changes in the chemical composition of water. All vertebrates use these three types of information as clues in regulating their behavior. The individual divisions or patterns of the brain do not function separately to bring about a final response; rather, each pattern acts on a common set of connections in the spinal cord.

23.1.1. Spinal patterns

Spinal patterns are the final common patterns used by all higher brain pathways to influence all organs of the body. These reflexes are divided into two basic patterns: the monosynaptic arc and the multisynaptic arc (Fig. 23.3). The monosynaptic arc, or myotatic reflex, maintains tonus and posture in vertebrates and consists of two neurons—a sensory neuron and a motor neuron. The multisynaptic arc or flexor reflex, is the pattern by which an animal withdraws a part of its body from a noxious stimulus. Both sensory neurons and internuncial neurons send information to brain centers (Fig. 23.3). Coordinated limb movement is based on a connective pattern of neurons at the spinal level.

The structure of the spinal cord and its connections are basically similar among all vertebrates, and myotatic and flexor reflexes occur in all vertebrates. The major evolutionary changes in the spinal cord have been the increased segregation of cells and fibers of a common function from cells and fibers of other functions, and the increase in the length of fibers that connect brain centers with spinal centers.

23.1.2. Medullar patterns

The rhombencephalon of the brain is subdivided into a roof or cerebellum, and floor or medulla oblongata. The medulla is similar to the spinal cord and is divided into a dorsal sensory region and a ventral motor region. It is an integrating and relay area between higher brain centers and the spinal cord. In addition to these nuclei and their connections, the medulla consists of both ascending and descending pathways to and from higher brain centers. The same basic connections occur throughout vertebrates.

23.1.3. Cerebellar patterns

In all vertebrates, the cerebellum is divided into two major divisions: the two lateral flocculonodular lobes and a central corpus cerebelli. The flocculonodular lobes are functionally referred to as the vestibulocerebellum and regulate vestibular reflexes underlying posture. The corpus cerebelli is subdivided into two lateral zones (the cerebrocerebellum) and a central zone (the somatocerebellum). In mammals, the lateral zones regulate corrective reflexes of posture and time muscular contractions of voluntary actions. The medial zone in mammals regulates reflex tonus of postural muscles by acting on the myotatic reflex. Note that, in mammals, the cerebellum does not initiate movement; it only times the length of muscle contractions and orders the sequence in which muscles should contract to bring about a movement. The command to initiate a movement is received from the cerebral cortex via the middle cerebellar peduncle (Fig. 23.4). Similarly, the cerebral cortex receives information regarding limb position and the state of muscular contraction to ensure that its commands can be carried out by the cerebellum.

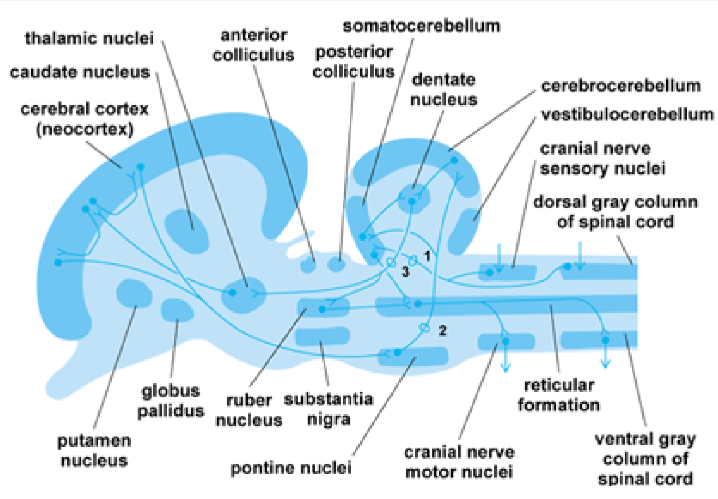


Fig. 23.4. Mammalian brain in sagittal section. Cerebellar patterns: tract 1, posterior cerebellar peduncle; tract 2, middle cerebellar peduncle; tract 3, anterior cerebellar peduncle.

23.1.4. Tectal patterns

The mesencephalon is divided into a roof or optic tectum, and a floor or tegmentum. The tegmentum contains the nuclei of the oculomotor and trochlear cranial nerves and a rostral continuation of the sensory nucleus of the trigeminal cranial nerve. Two motor nuclei dominate the tegmentum: the rubber nucleus and the substantia nigra. These nuclei are elements in the telencephalic and cerebellar motor systems.

23.1.5. Diencephalic patterns

In the evolution of vertebrates, the prosencephalon develops as two major divisions: the diencephalon and the telencephalon. The diencephalon retains the tubular form and serves as a relay and integrating center for information passing to and from the telencephalon and lower centers. The telencephalon is divided into a pair of cerebral hemispheres and an unpaired telencephalon medium.

There are three divisions of the diencephalon in all vertebrates: an epithalamus, which forms the roof of the neural tube; a thalamus, which forms the walls of the neural tube; and a hypothalamus, which forms the floor of the neural tube. The epithalamus and hypothalamus are primarily concerned with autonomic functions, including homeostasis. The thalamus is subdivided into dorsal and ventral regions. The dorsal region relays and integrates sensory information, whereas the ventral thalamus relays and integrates motor information.

23.1.6. Telencephalic patterns

The telencephalon is the most complex brain division in vertebrates. It is divided into a roof or pallium and a floor or basal region. The pallium is divided into three primary divisions: a medial PI or hippocampal division; a dorsal PII or general pallial division; and a lateral PII division, often called the pyriform pallium. The basal region is divided into three areas: the first is a medial BIII area called the septum, whereas a ventral BII area and a lateral BI area form a region often called the corpus striatum.

The most striking change in the telencephalon of land vertebrates involves the PIIIa component, often called the dorsal ventricular ridge. In reptiles and birds, this region has proliferated into the ventricle of the telencephalon to produce a large cellular mass. In mammals, it has proliferated with the PIIb component of the dorsal pallium to produce the mammalian neocortex. In all land vertebrates except amphibians, the PIIb and the PIIIa components, along with the corpus striatum (BI and BII), are the highest centers for the analysis of sensory information and motor coordination. The PI, PIIa, PIIIb, BIII, and posterior parts of BI and BII form part of the limbic system, which is concerned with behavioral regulation.

23.2. Comparative histology

The basic microscopic anatomy of nervous tissue is essentially similar in all vertebrates, although variations do exist. Nervous tissue has the quality of irritability. It is also characterized by the quality of conductivity, which conveys the resulting excitation to other structures of the nervous system. The functional roles of nervous tissue include the capabilities to sense, through specialized receptors, environmental energies both internal and external to the organism; to conduct the resulting nerve impulses as coded input to centers in the nervous system; to process this input within these centers; to generate sensations and psychological expressions; and to produce such active responses as the contraction of muscles or the secretions of glands. In effect, nervous tissue reacts to environmental stimuli and regulates many bodily processes so as to maintain functional integrity of an organism. It is within the morphological, physiological and chemical matrices of nervous tissue that the substrates for memory, behavior and personality reside.

23.2.1. Neuron

(See in the previous unit)

23.2.2. Connective tissue cells

Nerve fibers of a peripheral nerve are bound together into small bundles by connective tissue cells, fibroblasts, and their fibrous products. The entire nerve is in turn surrounded by more connective tissues, within which are plexuses of blood vessels. Although the connective tissues are sparse within the central nervous system, the blood plexuses of the brain and spinal cord are most extensive. There are three layers of connective tissue membranes—the meninges—covering the brain and spinal cord: the innermost layer, the pia mater; the middle layer, the arachnoid; and the outermost layer, the dura mater. Between the pia mater and the arachnoid is the subarachnoid space; this space and the ventricular cavities within the brain are filled with an extracellular fluid called the cerebrospinal fluid.

23.2.3. Brain

In spite of the extraordinary variation in adult morphology of the vertebrate brain in different species, the early phases of development are essentially similar. The brain vesicle stages of a reptile, bird and mammal are much alike; however, owing to varying growth rates of different parts and to specialization processes, the different patterns of the adult brains are formed.

23.2.4. Spinal cord

Nerve cord or spinal cord is formed from the neural tube behind the brain. The nerve cord is a cylindrical tube somewhat flattened dorso ventrally. Its anterior end is wide where it is continuous with medulla, the posterior end generally tapers to a fine thread, the filum terminale. In fishes it extends to the posterior end of the tail.

It extends the full length of the vertebral column in amphibians, reptiles and birds, but in mammals it is short and does not extend into the tail. In cyclostomes, fishes and limbless amphibians the nerve cord has a uniform diameter, but in tetrapoda it has two enlargements called cervical (brachial) and lumbar enlargements. They are formed due to a larger number of nerve cell bodies whose fibres form nerves going to limbs.

The spinal cord remains as a comparatively slightly differentiated tube. The primary lumen is secondarily reduced by the fusion of the side walls into a narrow central canal.

23.2.5. Cranial nerves

The cranial or cerebral nerves are the peripheral nerves of the head that are related to the brain. The number of nerves and the degree of development of the nerves vary in different species. The functional quality of the different nerves also varies. Twelve pairs of cranial nerves are distinguished in human anatomy, and they are numbered rostrally to caudally as follows: (I) olfactory nerve, fila olfactoria; (II) optic nerve, fasciculus opticus; (III) oculomotor nerve; (IV) trochlear nerve; (V) trigeminal nerve (in most vertebrates, this is divided into three branches: ophthalmic, maxillary, and mandibular); (VI) abducens nerve; (VII) facial nerve; (VIII) statoacoustic nerve; (IX) glossopharyngeal nerve; (X) vagus nerve; (XI) accessory nerve; and (XII) hypoglossal nerve. The varied morphological significance of the cranial nerves is evident from their embryology.

23.2.6. Spinal nerves

The spinal ganglia are formed from the neural crest, which grows out like a continuous sheet from the dorsal margin of the neural tube and is secondarily split up into cell groups (the ganglia) by a segmentating influence from the somites. Fibers grow out from the ganglionic cells and form the sensory fibers of the spinal nerves. Motor nerve fibers emerge from cells situated in the ventral horns of the spinal cord. The ventral motor fibers and the dorsal sensory fibers fuse to form a common stem, which is again laterally divided into branches, innervating the corresponding segment of the body.

23.3. Autonomic nervous system

The autonomic nervous system functions primarily at a subconscious level. It is traditionally partitioned into the sympathetic system and the parasympathetic system. The ganglia of the sympathetic nervous system develop ventrolateral to the spinal cord as neural crest derivatives. At first, a continual column of sympathetic nerve cells is formed; it later subdivides into segmental ganglia. The parasympathetic system is made up of preganglionic fibers emanating as general visceromotor fibers from the brain and from sacral segments of the spinal cord. Cells migrate to form the peripheral ganglia along them.

23.3.1. Peripheral Nervous System

The peripheral nervous system consists of nerves connected to or arising from the central nervous system, it has cranial and spinal nerves. All the nerves arise in pairs. Cranial nerves originate from brain and emerge through foramina of the skull. Except the first four pairs of cranial nerves, the rest arise from the medulla oblongata (Table 1).

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 cranial nerves do not show a clear metameric arrangement, yet they represent a regular series of segmental dorsal and ventral roots of the segments of the head, but the dorsal and ventral roots do not join. Table 2, summarizes the cranial nerves of vertebrates showing their serial numbers, names, origin from brain, distribution, nature and functions.

Table 1: Showing the head segments and their dorsal and ventral roots.

Head segment	Dorsal root	Ventral root
1. Premandibular	Ophthalmic profundus of V	Oculomotor III
2. Mandibular	Ophthalmic superficialis, maxillary and mandibular of V	Trochlear VI
3. Hyoid	Facial VII, Auditory VIII	Abducens VI
4. First branchial	Glossopharyngeal IX	Nil
5. Second to fifth branchials	Vagus X and Spinal accessory XI	Hypoglossal XII

Spinal Nerves:

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:

(i) 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 fibres.

(ii) A ventral root (motor) arising from the ventral horn of the gray matter. The nerve cell bodies of motor fibres are always located in the brain or spinal cord.

Table 2: Cranial Nerves of Vertebrates

S.No.	Name	Origin	Distribution	Nature	Functions
I.	**Olfactory**	Olfactory lobe or bulb	Olfactory epithelium in nasal cavity	*Sensory*	Smell
II.	**Optic**	Optic lobe on midbrain	Retina of eye	*Sensory*	Sight
III.	**Oculomotor**	Floor of midbrain	Eye, 4 muscles of eyeball	Motor	Movement of eyeball, iris, lens, eyelid
IV.	**Trochlear**	Floor of midbrain	Eye, superior oblique muscles of eyeball	Motor	Rotation of eyeball
V.	**Trigeminal**	Side of medulla	Head, face, jaws, teeth	*Sensory* Motor	Forehead, scalp, upper eyelid, side of nose, teeth, Movement of tongue, jaw muscles for chewing
VI.	**Abducens**	Side of medulla	External rectus muscle of eyeball	Motor	Rotation of eyeball
VII.	**Facial**	Side and floor of medulla	Anterior 2/3 tongue. Muscles of face, neck and chewing.	*Sensory* Motor	Taste. Facial expression. chewing. movement of neck
VIII.	**Auditory (acoustic)**	Side of medulla	Organ of Corti in cochlea Semicircular canals	*Sensory*	Hearing Equilibrium
IX.	**Glossopha-ryngeal**	Side of medulla	Posterior 1/3 tongue, mucous membrane and muscles of pharynx	*Sensory* Motor	Taste & touch, Movements (swallowing) of pharynx
X.	**Vagus (pneumo-gastric)**	Side and floor of medulla	Muscles of pharynx, vocal cords, lungs, heart, oesophagus, stomach, intestine	*Sensory* Motor	Vocal cords, lungs Respiratory reflexes, peristaltic movements, speech, swallowing, secretion of gastric glands, inhibition of heart beat.
XI.	**Spinal accessory**	Floor of medulla	Muscles of palate, larynx, vocal cords, neck, shoulder	Motor	Muscles of pharynx, larynx, neck, shoulder movements
XII.	**Hypoglossal**	Floor of medulla	Muscles of tongue, neck	Motor	Movements of tongue.

The roots have different embryonic origin- the dorsal roots arise from neural crests, while the ventral roots arise from the gray matter of the spinal cord. In an amniota, the dorsal roots contain somatic sensory, visceral sensory and visceral motor fibres.

In amniota the dorsal roots have only somatic sensory and visceral sensory fibres. The ventral roots have visceral motor and somatic motor fibres in all. Except in some cyclostomes, 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. In lampreys, they remain separate and emerge alternately from the spinal cord, whereas in hagfishes there may be an incomplete union.

In all other fishes the dorsal sensory root and ventral motor root unite with each other outside the vertebral column to form a common trunk. In amphibians dorsal and ventral roots of the spinal nerves unite 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 intermixing of fibres from the ventral branches of spinal nerves are found. These are differentiated into cervical, brachial, lumbar and sacral plexuses.

Each spinal nerve divides into three branches 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.

A ramus communicans has two parts, a white ramus and a gray ramus. There are no gray rami in elasmobranchs. The white ramus has medullated visceral sensory and visceral motor fibers. The axons of visceral motor fibers go to autonomic ganglia and form synapses with non- medullated fibres of the gray ramus.

The medullated visceral motor fibers are called preganglionic fibers because they terminate in autonomic ganglia where they form synapses with non-medullated postganglionic fibers of the gray ramus.

These fibers enter the spinal nerves and pass into the dorsal ventral rami to supply structures under involuntary control. In brief the white ramus of ramus communicans carries medullated visceral sensory fibers and medullated preganglionic motor fibers, the gray ramus carries only non-medullated postganglionic autonomic motor fibers (Fig. 23.5).

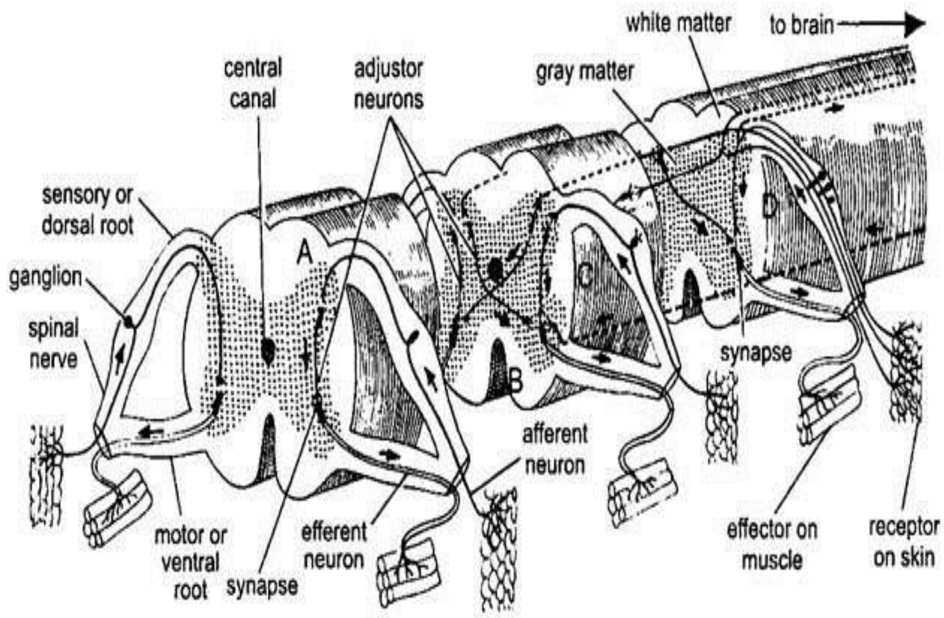


Fig. 23.5: Simplified image of vertebrate spinal cord and nerves to show relations of neuron involved in reflex arcs. A. Simple reflex arch; B. Reflex arch with one adjuctor neuron; C- Reflex arc with cross connections; D. Reflex arc with cross connections and also others to and from the brain

Autonomic Nervous System:

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 pre-vertebral ganglion ramus, cranial nerves.

Cranial and spinal somatic nerves mainly innervate the voluntary (skeletal) muscles of the animal. While the autonomic nerves and ganglia innervate the smooth or involuntary muscles of the viscera (alimentary canal, heart, etc.) and glands, and, thus, control the internal environment of the body. Little is known about the autonomic nervous system in cyclostomes although sympathetic ganglia are present. The digestive system and heart are supplied by the vagus nerve.

In elasmobranchs, an irregular series of sympathetic ganglia lies along the body wall. Fibers from these ganglia connect both to the spinal cord and to the smooth muscles of the digestive and circulatory systems. In bony fishes autonomic nervous system is more advanced i.e., the sympathetic ganglia are arranged in a chain extending forward to the trigeminal nerve.

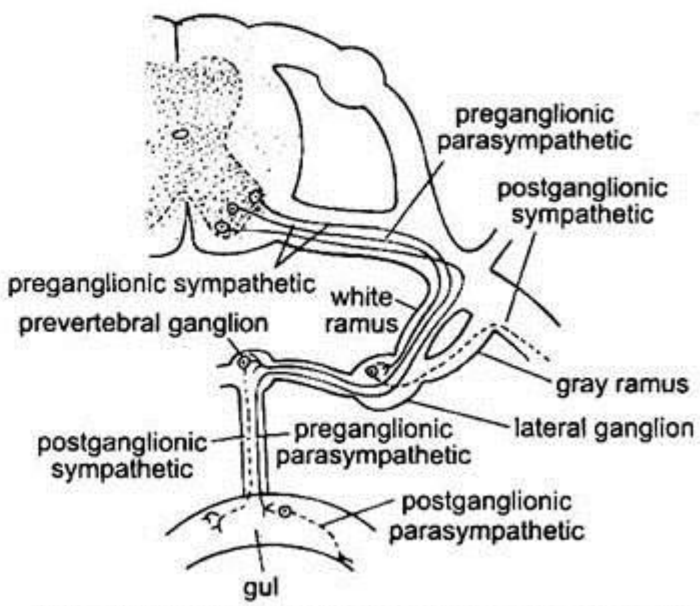


Fig. 46.11. T.S. of spinal cord showing distribution of autonomic nerve fibres.

Fig. 23.6: Showing T.S of spinal cord of autonomic nerve fibers.

Let us sum up

Under this unit, we studied about the comparative anatomy of spinal cord. We also studied in detail about the spinal pattern, medullar pattern, cerebellar pattern, tectal pattern, diencephalic pattern, telencephalic pattern, comparative histology of neuron, connective tissue cells, brain, spinal cord, cranial nerves, spinal nerves and anatomic nervous system.

Check your Progress

1) __________ is the final common patter used by all the higher brain pathway to influence all organs of the body.
2) The __________ of the brain is subdivided into a roof or cerebellum and medulla oblongata.
3) The two major divisions of cerebellum are __________ and __________.
4) The dorsal thalamus region relays and integrates __________ and the ventral thalamus region relays and integrates __________.
5) The ventral BII area and lateral BI area forms a region called __________.

Glossaries

1. Neuromasts: Consist of sensory cells, which detect water movement by deflection of cilia.

2. Columba : Columba comprises a group of medium to large pigeon.

3. Telencephalon: The most highly developed and anterior part of the forebrain, consisting chiefly of the cerebral hemispheres.

Suggested readings

1) **WATERMAN, A.J** (1971), Chordate Structure and Function, The Macmillan Company.
2) **COLBERT, H. EDWIN** (1989), Evolution of the Vertebrates, II Ed., Wiley Eastern Limited, New Delhi.

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Answers to check your progress

1) Spinal pattern
2) Rhombencephalon
3) Flocculonodular lobes and central corpus cerebelli
4) Sensory information and motor information
5) Corpus striatum

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