

URINOGENITAL SYSTEM|

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6.1 INTRODUCTION

Excretion and osmoregulation as you may be aware are two homeostatic processes performed by the kidneys and urinary ducts, which form the **urinary system**. This system is closely associated both anatomically, and in terms of embryonic origin with the **genital system**. The genital system includes the gonads which produce gametes and the paired genital ducts that serve as passages for the gametes – sperms in males and ova in females. Though functionally different the two organ systems, the urinary and the genital system are treated together as the **urinogenital system**, since both develop from the same segmental blocks of trunk mesoderm or adjacent tissues and share many of the ducts. Thus the two systems having nothing common functionally are closely associated in their use of common ducts and are studied under the broad heading of urinogenital system. In this unit, you will learn about the embryonic development of the urinogenital system, its basic plan and the variations on this basic plan in different chordate groups.

Objectives

After studying this unit you should be able to:

- ❖ describe and illustrate the basic plan of urinogenital system in vertebrates;
- ❖ explain the origin and embryonic development of kidneys, gonads and their associated ducts;
- ❖ discuss the morphological and physiological adaptations of the urinogenital system of vertebrates.

6.2 THE URINARY SYSTEM IN VERTEBRATES

The basic plan of urinary system is common to all vertebrates. The urinary organ-system lies in the abdominal region and consists of paired kidneys which are the principal organs of excretion and osmoregulation. For example, the urinary tract in male and female in humans (Fig. 6.1) is made up of: i) paired kidneys and paired ureters, ii) single bladder, and iii) single urethra.

The paired kidneys lie dorsal to the coelom (retroperitoneal), one on each side of the dorsal aorta. The basic units of the kidney are the minute, uriniferous tubules that end blindly and receive filtrate from the blood. The uriniferous tubule consists of two parts, the **nephron** (from Greek *nephros*, meaning "kidney") and the **collecting tubule**. The primary function of the uriniferous tubules is removing excess water, salts, waste metabolites and foreign substances from the blood. Numerous such tubules of each kidney connect to form a urinary or excretory duct system called **ureter** which carries urine from the kidney. The ureter of each kidney opens into a urinary bladder which in most adult tetrapods (four limbed vertebrates) is a single median structure and the urinary bladder acts as a reservoir which stores urine prior to its removal through the urethra. The urethra is thus, a small tube which arises from the bladder and opens by a single, urinary opening either into the cloaca or directly to the outside.

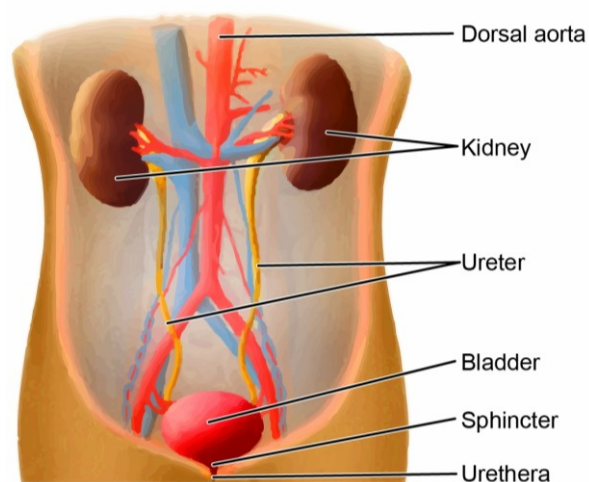


Fig. 6.1: Ventral view of the human urinary systems.

6.2.1 Embryonic Development of the Urinary System

The urinogenital system is mesodermal in origin. We know that the mesoderm or intra embryonic mesoderm is subdivided into paraxial mesoderm, an

intermediate mesoderm and lateral mesoderm. The intermediate mesoderm which is located in the dorsal and posterior body wall of the embryo forms the 'paired organs namely,' the kidneys, adrenals and the gonads. During embryonic development, at the onset of its differentiation into the paired kidneys, the posterior region of the intermediate mesoderm expands to form a **nephric ridge** that protrudes slightly from the dorsal wall of the body cavity (Fig. 6.2). The nephric ridge buds into paired blocks of tissue, giving rise to the paired nephrotomes which are destined to differentiate into nephrons or renal tubules. The nephrons or renal tubules are the structural and functional units of the kidney. Each nephrotome contains a nephrocoel, which is a coelomic chamber that opens into the coelom by means of a ciliated peritoneal funnel (Fig. 6.2). The median wall of the nephrotome widens to form a thin walled renal capsule which receives dense capillary network from the dorsal aorta to form the glomerulus (plural: glomeruli). The renal capsule with its glomerulus constitute the site of filtration of blood to form urine. The lateral end of each block of the nephrotome grows out forming a tubule. The tubule from each segment unites to form a longitudinal duct, called the nephric duct which runs the length of the coelomic cavity. Each nephrotome is now properly called a nephric tubule and may retain its connection with the coelom through the persistent peritoneal funnel. Thus the fundamental plan underlying the excretory system consists of paired and segmented nephric tubules that open on one end into the coelom and on the other end into the nephric duct with a glomerulus in between. In most adult vertebrates, however, there is no connection with the coelom through peritoneal funnel.

This type of kidney is considered to be the primitive type and is known as **holonephric** or the **archinephric** kidney and is seen only in larval hagfishes (6.3a). Not all of the segments of this kidney have remained active during the evolution. During the course of evolution, three different types of kidneys arise and a number of different ducts or tubules from different location of the **holonephric** or the **archinephric** kidney. In the next section you will learn how different types of kidneys arise from the primitive type of kidney, during the course of evolution in the different vertebrates.

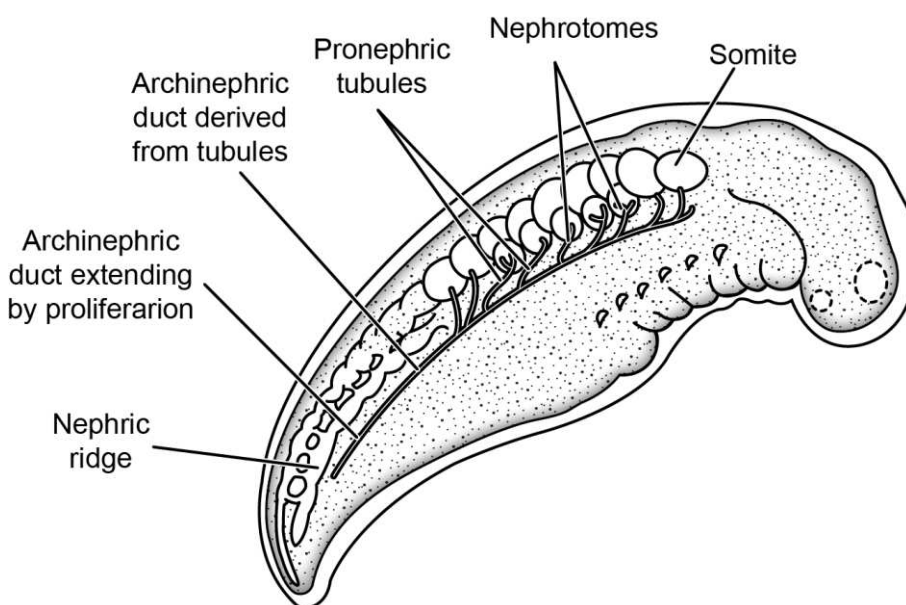


Fig. 6.2: Embryonic development of nephric tubules in vertebrates. Embryo showing location of developing kidney (nephric ridge) and the appearance of segmental nephrotome in the posterior part of the intermediate mesoderm.

6.2 .2 Phylogeny and Succession of Kidneys

Comparative studies of vertebrate development indicate that the ancestral kidney called archinephros (ancient kidney) of the earliest vertebrates extended along the length of the coelomic cavity and was made up of segmentally arranged tubules, each resembling an invertebrate nephridium. Evolution of the vertebrate kidney is interesting. The kidney in various classes of vertebrates has evolved depending on the osmotic environment and different problems encountered by them for the maintenance of internal water balance and the excretion of nitrogenous wastes. The kidneys of living vertebrates evolved from the primitive plan of archinephros (ancient) kidney, also known as holonephros. As vertebrates evolved, the evolution of their kidneys went through a series of stages and the kidneys in the adults were recognized according to the part of the nephric ridge from which they were formed, as pronephros (anterior nephric ridge), mesonephros (middle nephric ridge), and metanephros (posterior nephric ridge).

As mentioned in the previous section, the kidney in all vertebrates develops from the intermediate mesoderm or nephrogenic mesoderm. The segmental nephrotomes are formed in succession from the anterior end to the posterior in the holonephric kidney. Each nephrotome has its individual glomerulus, nephrocoel and nephric tubule and all these tubules unite to form the archinephric duct (see Fig 6.2 again) and the kidney develops from the entire length of the nephric ridge during embryonic development, the three types of kidneys pronephros, mesonephros and metanephros (Fig. 6.3) appear in succession. Some, but not all of these kidneys are observed in various vertebrate classes.

During the embryonic life of the amniote vertebrates (reptiles, birds, mammals), the three types of kidneys pronephros, mesonephros and metanephros (Fig. 6.3a) appear in succession during the development of the kidney. The first to develop is the pronephric kidney which is the largest to develop and develops most anteriorly. As mentioned earlier, the pronephros is part of “**head kidney**” present only in the adult hagfishes (anamniote) and in the embryos of other vertebrates. Mesonephros is the functional kidneys of **embryonic** amniotes (reptiles birds and mammals) and contributes to the **adult** kidney (called an opisthonephros) in anamniotes, namely, jawless vertebrates, fishes and amphibians. The third kidney or metonephros develops posterior to the mesonephros, and is called the metanephric kidney. The adult kidney of amniotes is the metanephros. Let us study the developmental stages of kidney in detail.

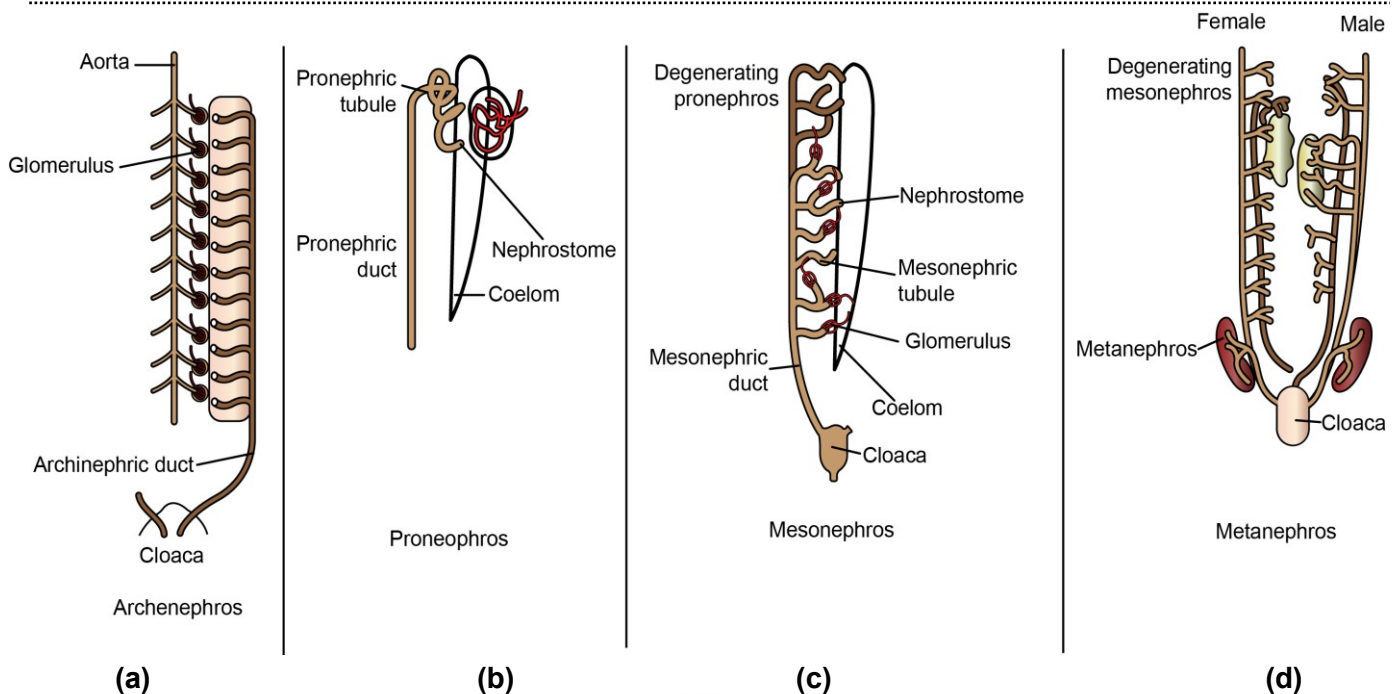


Fig. 6.3: Comparative development of male vertebrate kidney. (a) archinephros; (b) pronephros; (c) mesonephros; (d) metanephros.

(1) Pronephros

The pronephros is the first kidney to be formed in a vertebrate embryo, and lies dorsal to the pericardial cavity. The pronephros are located at the anterior part of the kidney and segmentally arranged. One end of these tubules opens into the coelom by a nephrostome while the other end opens into the archinephric duct which in this case is called pronephric duct. The two pronephric ducts, one on each side extend posteriorly and open into the cloaca.

Only in the adult hagfishes (anamniote) does the pronephros become part of the persistent kidney also called “**head kidney**”. In all other vertebrates except adult hagfishes (Fig. 6.3b) it degenerates during development and is replaced by a more centrally located mesonephros.

(2) Mesonephros

In the vertebrate embryo, tubules arising from the middle of the nephric ridge constitute the mesonephros or mesonephric kidney (Fig. 6.3 c). Mesonephros is sometimes known as the **Wolffian body**. In the beginning mesonephric kidney are segmentally or metamerically arranged but as more tubules arise, metamerism is lost. The tubules open into an already existing pronephric duct and no new duct is formed. When the pronephros degenerates the persistent pronephric duct is called **mesonephric duct or the Wolffian duct**. The mesonephric duct may enlarge at its posterior end to form the (i) urinary bladder for storage of urine or (ii) the seminal vesicle for storage of sperms.

The mesonephros is the functional kidneys of **embryonic** amniotes the reptiles birds and mammals. The mesonephros along with some tubules from the posterior nephric ridge forms the **adult** kidney in anamniotes, (lampreys which are jawless vertebrates, fishes and amphibians) (Fig. 6.3c). This kidney is called **opisthonephros or opisthonephric kidneys**.

The term archinephric duct is applied to the kidney duct in anamniotes. The name wolffian duct is given to the duct in amniotes which forms in connection with the pronephros and mesonephros.

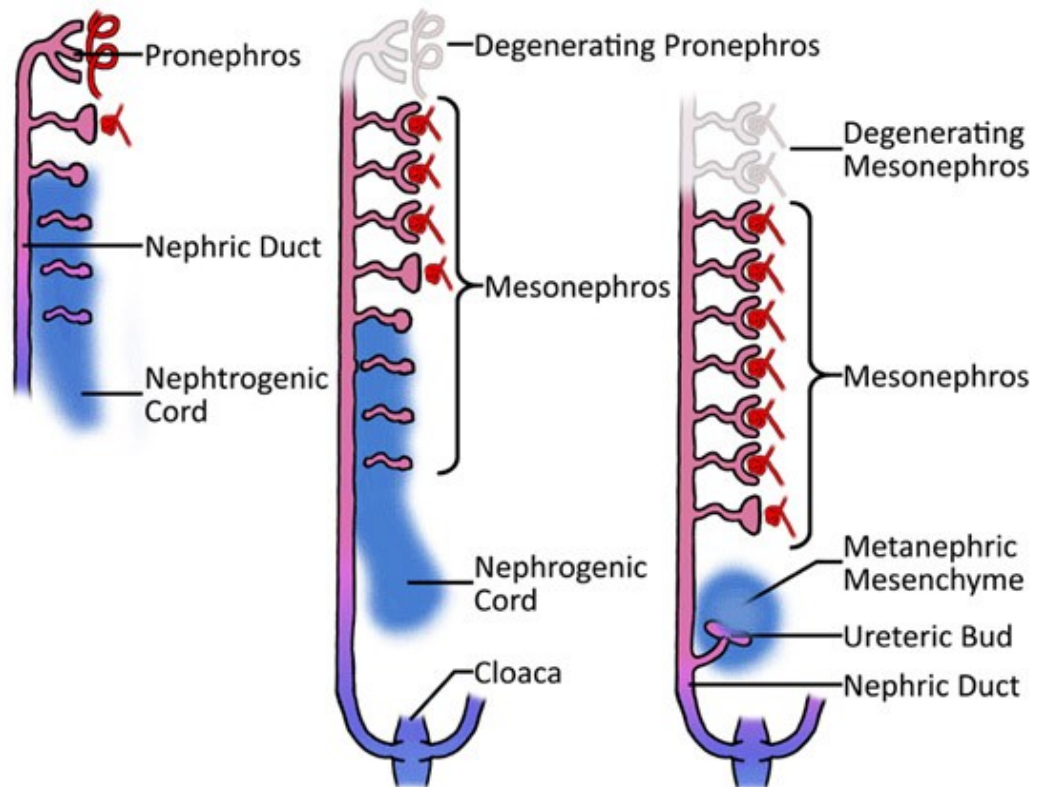


Fig. 6.4: Diagram shows the sequential development and degeneration of the pronephros and mesonephros, and the induction of the ureteric bud and metanephric mesenchyme during kidney development in mammals.

Among amniotes mesonephros may persist after birth in reptiles, the egg laying mammals (Prototheria) and pouched mammals (the Metatheria). Parts of the male genital ducts such as epididymis and ductus deferens as well as the seminal vesicles develop from mesonephric tubules.

(3) Metanephros

During embryonic development of amniotes – (the reptiles, birds and mammals) the three kidneys, namely, pronephros, mesonephros and metanephros appear in succession. The adult kidney of amniotes is the metanephros (Fig. 6.3 d). The metanephros develops as the posterior part of the nephric ridge and during development, it gets displaced anteriorly and laterally. The displaced metanephros develops its own new duct, the metanephric duct or the ureter. The dilated tip of metanephric duct becomes the renal pelvis.

The metanephros is distinguished in several ways from pronephros and mesonephros. It is more caudally (posteriorly) located and is a much larger more compact structure containing a very large number of nephric tubules. It is drained by a new duct, the ureter, which develops when the mesonephric duct (Wolffian duct) is relinquished to the reproductive system of the male as urinogenital duct for sperm transport. In females this duct degenerates. Thus in higher vertebrates, the kidney passes through both pronephros and mesonephros stages that succeed each other during the embryological development before being stabilized into the adult metanephric type of kidney and this succession is also seen to some extent phylogenetically in amniotes (Fig. 6.4).

SAQ 1

1. Describe the basic plan of urinary system in vertebrates.
 2. Discuss the tripartite concept of kidney.
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6.3 THE KIDNEY

The kidneys are paired, specialized organs that maintain the optimum levels of solutes and water in the body and excrete wastes of protein metabolism and thus play a vital role in osmoregulation. The kidneys of vertebrates are especially important in removing excess water and divalent ions (Ca^{2+} , Mg^{2+}) and conserving solutes. In this section we will deal with the kidney and the urinary system of vertebrates. Let us begin by examining the form and position of the kidneys in vertebrates in general. After which we will describe the detailed structure of the human kidney as an example of a mammalian kidney.

6.3.1 Structure and Position of Kidneys

The paired kidneys in vertebrates are compact structures. A close relationship exists between the form of the kidney and body shape of the animal.

The kidneys of cyclostomes are long and strap like since their bodies are long eel like. In fishes the kidneys in general run along the entire length of the body often extending into the tail musculature. In fishes wherever the swim bladder is present the kidney shape is modified to accommodate it. Among amphibians, Gymnophiona and other long bodied urodeles, have elongated kidneys narrow at the anterior end and broad in the posterior; while in anurans they are more rounded and compact. In reptiles such as snakes the kidneys are elongated and are not arranged side by side, instead they are placed one behind the other. Birds have elongated lobular kidneys. However, the kidneys of mammals are the most compact. Some mammals have lobed kidneys. The lobed condition is seen in human embryos as well but it disappears soon after birth.

The kidneys are located close to the dorsal side of the body outside the peritoneum. In fishes and birds they lie close to the backbone but in amphibians, reptiles and mammals they are slightly away from the dorsal wall of the body cavity.

In humans, the right kidney is located a little higher than the left kidney. Each kidney is a bean-shaped organ attached to the dorsal wall and is retroperitoneal in position. It is concave at its medial side with a cavity or depression called hilum or hilus through which the ureter leaves the kidney. At the exit point of the ureter, a renal vein also leaves the kidney and a renal artery and renal nerve enters it.

A section of the of the human kidney (Fig. 6.5) reveals that it is surrounded by a capsule of connective tissue. Internal to the capsule of connective tissue are two regions; a) an **outer cortex** just under the connective tissue capsule and

b) a **deeper medulla** beneath the cortex . Medulla which is immediately beneath cortex is striated in appearance and contains the loop of Henle and collecting tubules The medulla is partially composed of large areas known as medullary pyramids or **renal pyramids**. The renal pyramids are made up of parallel tubules called medullary rays. Parts of the cortex between the medullary rays form the **renal column** of **Bertini** which contains masses of blood vessels made up of branches of renal artery and vein that enter the glomerulus in each nephron. The outer borders of the pyramids are subdivided into smaller units called lobules. These ducts widen near tips of renal pyramids. The inner portion of each pyramid is in the form of a blunt papilla and projects into an out pocketing of the pelvis known as **minor calyx** (plural: calyces). Several minor calyces join together to enter the **major calyx**, which in turn opens into the renal pelvis. Urine produced by the kidney enters the minor and then major calyx (Fig. 6.5). The pelvis leads to the ureter which empties into the urinary bladder (cloaca in egg laying mammals, the monotremes). Urine which is stored temporarily in the bladder passes to the outside through the urethra.

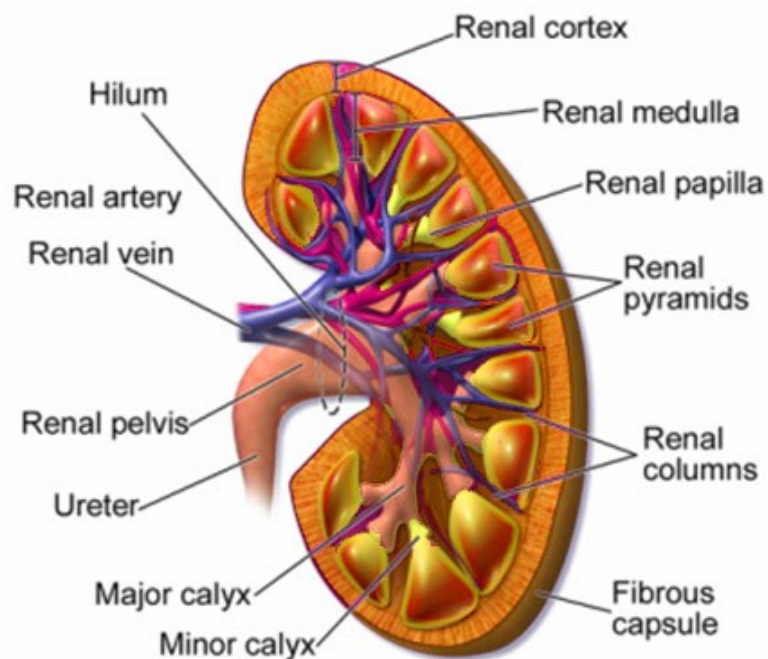


Fig. 6.5: Section of mammalian kidney showing cortex, medulla and departure of ureter.

SAQ2

Fill in the blanks:

- Kidney has two regions an outer just under the connective tissue capsule and a deeper
- Parts of the cortex between the medullary rays form the
- Kidney's medial side is concave with a cavity or depression called through which the ureter leaves the kidney.

6.3.2 Uriniferous Tubules

The functional units of the kidney as mentioned earlier in this unit, are the minute **uriniferous tubules** (Fig. 6.6), the structure of which are shown in Figure 6.6. Each uriniferous tubule is made up of (i) **nephron** (nephric tubule which is the excretory unit) and (ii) the **collecting duct** into which the nephron empties. Nephron concentrates urine and passes it through the collecting tubule. The collecting tubule affects the concentration of urine and conveys it to the minor calyx, (see Fig. 6.5) which is the beginning of the excretory duct.

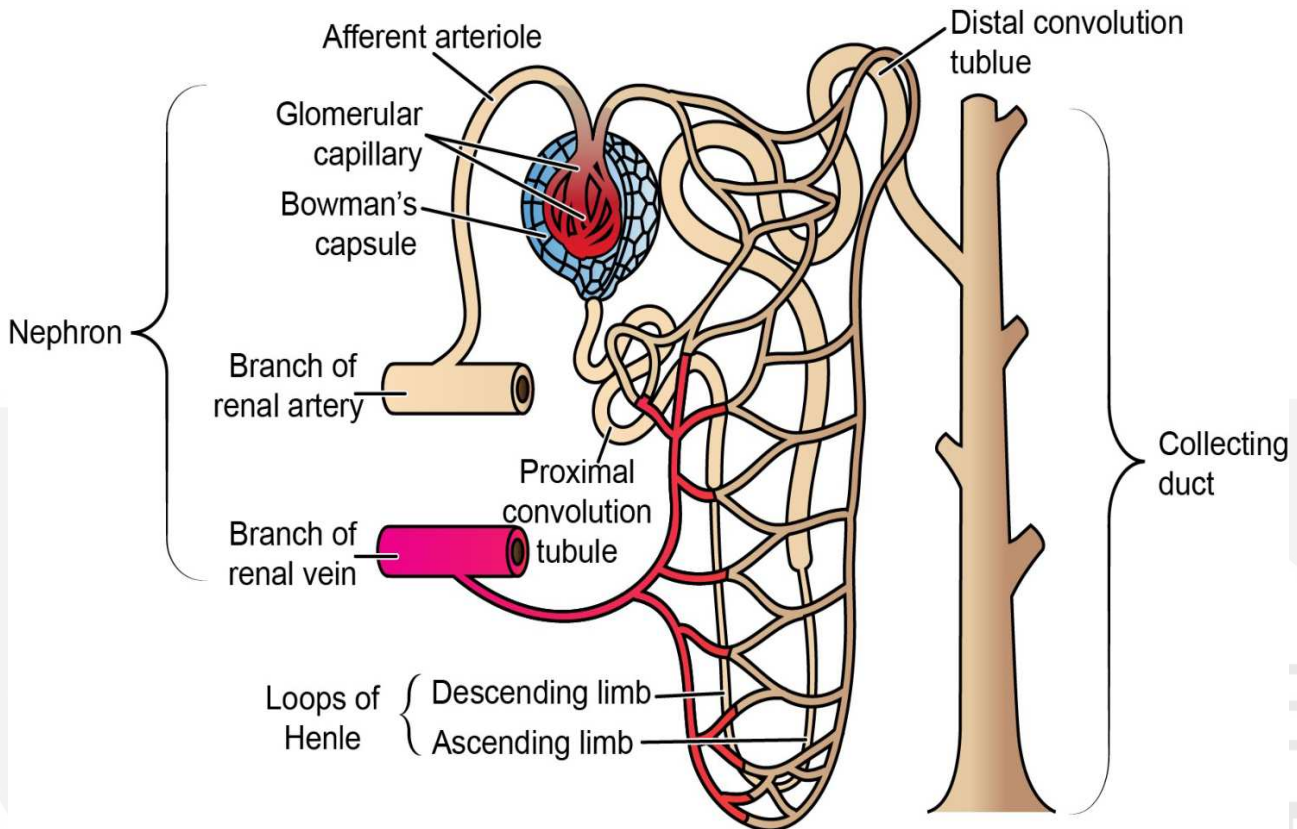


Fig. 6.6: Uriniferous tubule – the basic excretory unit.

I. Nephron

Each nephron has: a dilated portion – renal (Malpighian) corpuscle and the secretory tubule portion.

a) Renal Corpuscle or Malpighian Corpuscle

The renal corpuscle (Fig. 6.7) is the proximal portion of each nephron and is made of (i) a double walled squamous epithelial capsule called **Bowman's** or **renal capsule**. Between the layers of Bowman's capsule is a urinary space for receiving the fluid filtered through capillary wall and visceral layer; (ii) a spherical tuft of **inter-arterial** capillaries called **glomerulus** is surrounded by the Bowman's capsule. Each glomerulus is formed by the subsequent branching of the renal artery (one of the major branches from the dorsal aorta) into a capillarity bed. The inner layer of the Bowman's capsule is in contact with blood vessels of glomerulus. The point of entry of the blood vessels forms the **vascular pole** and the entry point of the nephric filtrate from the Bowman's capsule into the proximal convoluted tubule is called the **urinary pole** (Fig. 6.7).

The number of uriniferous tubules vary from only a few hundred in the kidneys of cyclostomes to over a million per kidney in mammals, in whom the tubules of both kidneys combined constitute over 120 km of tubing.

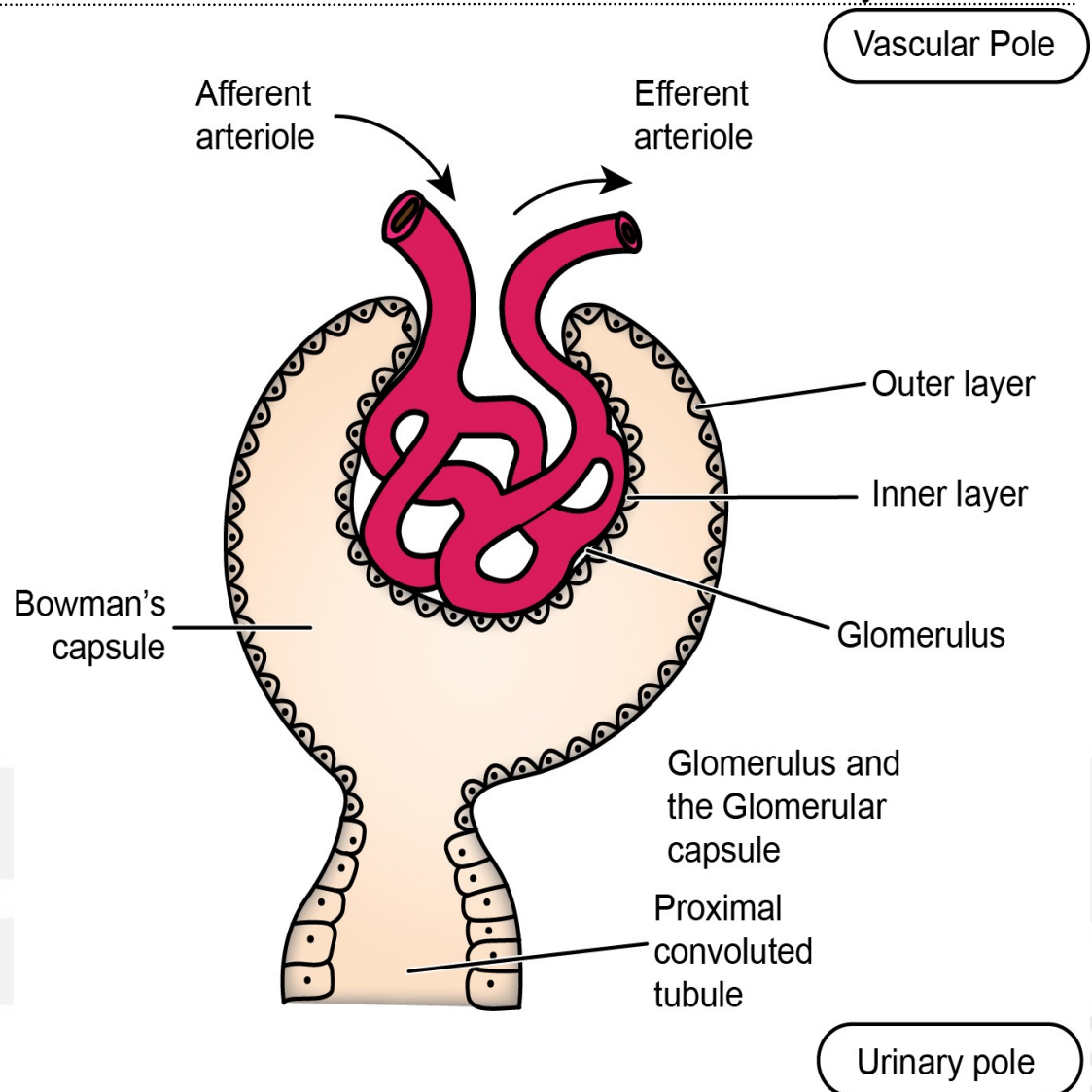


Fig. 6.7: Renal Corpuscle showing Bowman's capsule and glomerulus. Note that the afferent arteriole is wider than the efferent arteriole.

b) Tubular portion

The tubule portion is subdivided into (i) the proximal convoluted tubule (PCT) (ii) the loop of Henle with thick and thin limbs and (iii) the distal convoluted tubule (DCT). The PCT begins at the urinary pole of renal corpuscle (Fig. 6.8) and is lined by simple epithelial cells which have microvilli forming a brush border and lots of mitochondria and the enzyme $\text{Na}^+ \text{K}^+ \text{ATPase}$. PCT has a wide lumen and is surrounded by peritubular capillaries.

Loop of Henle or Henle's loop is U-shaped with thin descending and thick ascending limbs. Initially thick (the thick part is the straight part or **pars recta** of the proximal tubule) the loop of Henle thins near the turns then thickens again as it becomes part of the distal convoluted tubule. Henle's loop has a large lumen lined by squamous epithelium but no brush border.

The distal convoluted tubule (DCT) is continued from the ascending limb of Henle's loop and forms the last segment of the nephron. It is lined by cuboidal epithelium which lacks brush border. At the vascular pole, DCT establishes contact with renal corpuscle of the parent nephron. This part is known as macula densa (see Fig. 6.8).

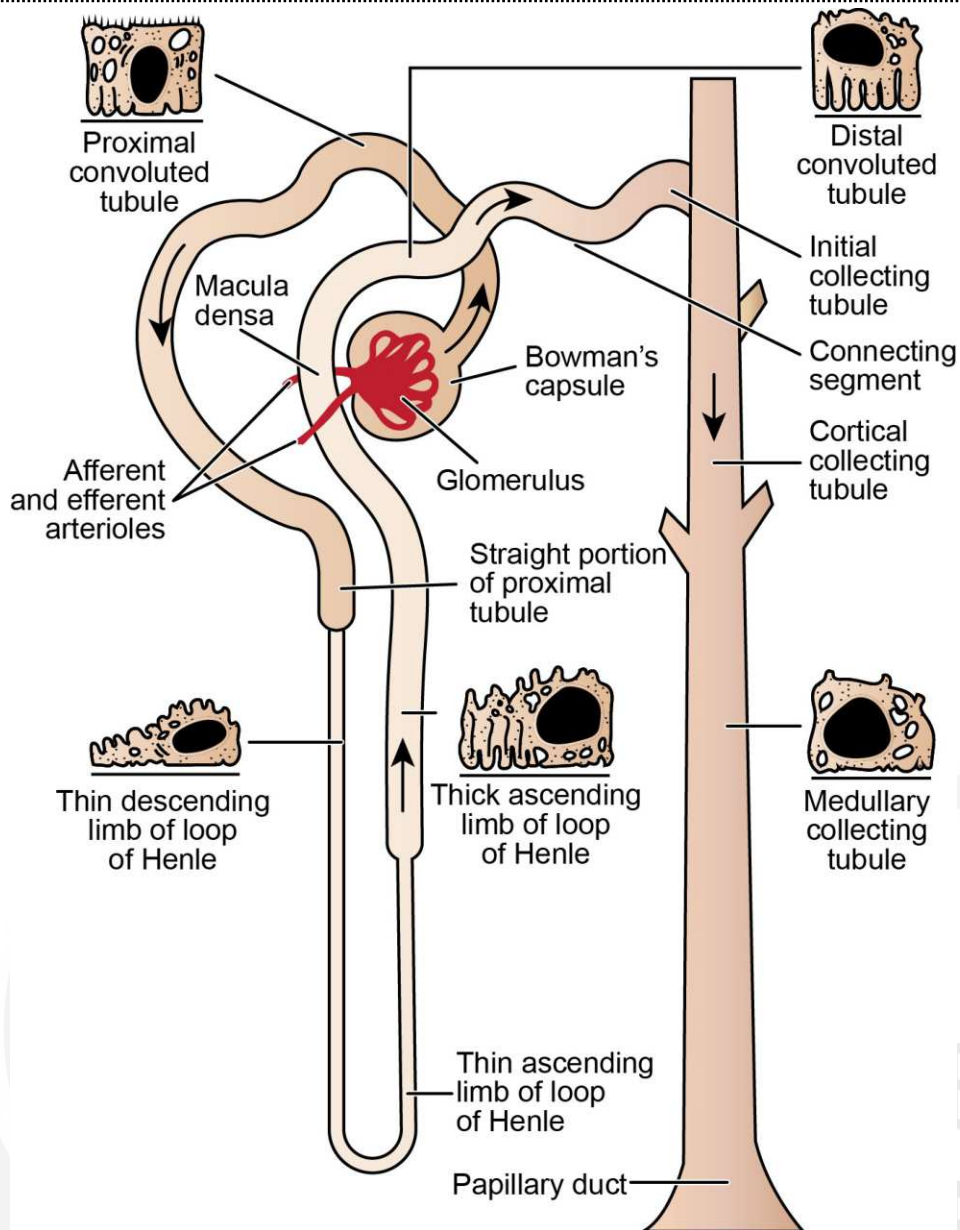


Fig. 6.8: Tubular portion of renal corpuscle and collecting duct showing the various types of cells in each part of the tubule. Also note the macula densa, a modified portion of the distal convoluted tubule, and its relation to the parent renal corpuscle.

II. The Collecting Tubule and Collecting Duct

Urine passes from the distal convoluted tubule to the collecting tubule. The collecting tubules of nephrons, join together to form, collecting ducts or papillary ducts of Bellini. These ducts widen near tips of the renal or medullary pyramids of the kidney.

Juxtaglomerular Apparatus

The wall of afferent arteriole near the renal corpuscle is made up of modified smooth muscle cells called **juxtaglomerular cells** which contain lots of Golgi bodies. The secretion of these cells is **renin** which helps to regulate blood volume. The wall of the distal tubule at this region is modified and looks dark under the microscope, hence it is called **macula densa** (Fig. 6.8). The afferent arteriole, juxtaglomerular cells and macula densa form the **juxtaglomerular apparatus**.

Mammalian kidneys have two types of nephrons which are named basically on the location of their glomerulus within the kidney as: (1) the cortical nephron and the (2) juxta medullary nephron (Fig. 6.9). The cortical nephron, has its glomerulus in the outer kidney cortex with a tubule that extends only in the peripheral region of the medulla. Cortical nephrons predominate in the human kidney (90%) and have short loops of Henle. The juxta medullary nephron has its glomerulus in the deep cortex region close (juxta meaning close) to the edge of the kidney medulla. The juxta medullary nephrons have long loops of Henle that dip deeply into the medulla. The ratio of cortical and juxta medullary nephron varies depending upon the vertebrate species. Juxta medullary nephrons are predominant (100%) in mammals of dry habitats.

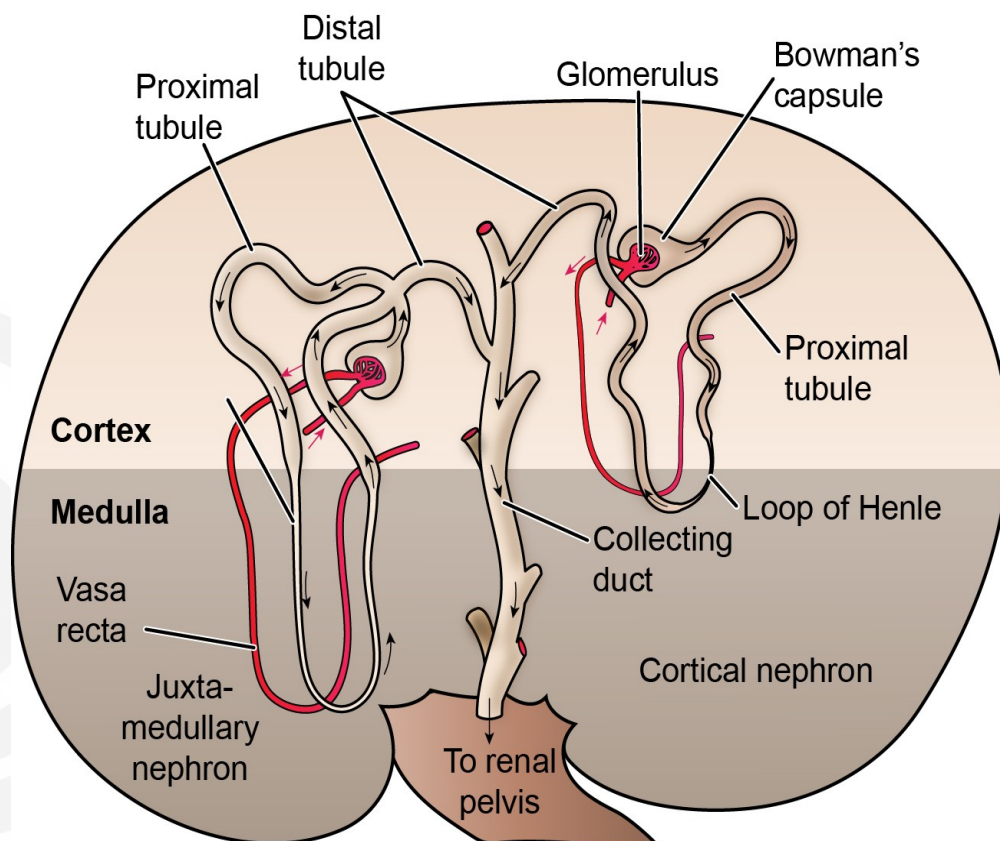


Fig. 6.9: A diagrammatic representation of section of mammalian kidney showing a cortical nephron and juxta medullary nephron.

6.3.3 Blood Circulation in Kidney

Kidneys are highly vascular. The blood supply to the kidney is through the renal artery and the venous (deoxygenated) drainage (removal) is through the renal vein. Fig. 6.10 shows the supply of blood to the kidney. The renal artery after entering the kidney divides into two segmental arteries – one going to anterior part of kidney and other to the posterior part. Each of these segmental arteries further divide and sub-divide into interlobular arteries which are located in the renal medullary pyramids. At corticomedullary junction i.e. place where renal cortex and renal medulla meet, they form the arcuate artery. Afferent arterioles arise from the interlobular arteries which finally terminate in the form of the highly coiled mass known as the glomerulus. The glomerulus forms the filtering unit of a nephron. The glomerulus of each nephron receives

an afferent artery which divides to form the ball shaped capillary network of the glomerulus. The glomerular capillaries then reunite to form the efferent arterioles that drain the blood out of the glomerulus. Efferent arterioles branch to form peritubular capillary network which nourish PCT and DCT. They also carry away absorbed ions and molecules.

The efferent arterioles associated with juxtamedullary nephrons form long thin capillary vessels which run straight into the medulla and loop back towards the corticomedullary boundary. These are called **vasa recta** or straight vessels. They provide nourishment and oxygen to medulla since they contain filtered blood.

Renal veins take the same course as renal arteries. Blood from interlobular vein form arcuate vessels. The interlobar vessels then converge to form renal vein through which blood leaves the kidney (Fig. 6.10).

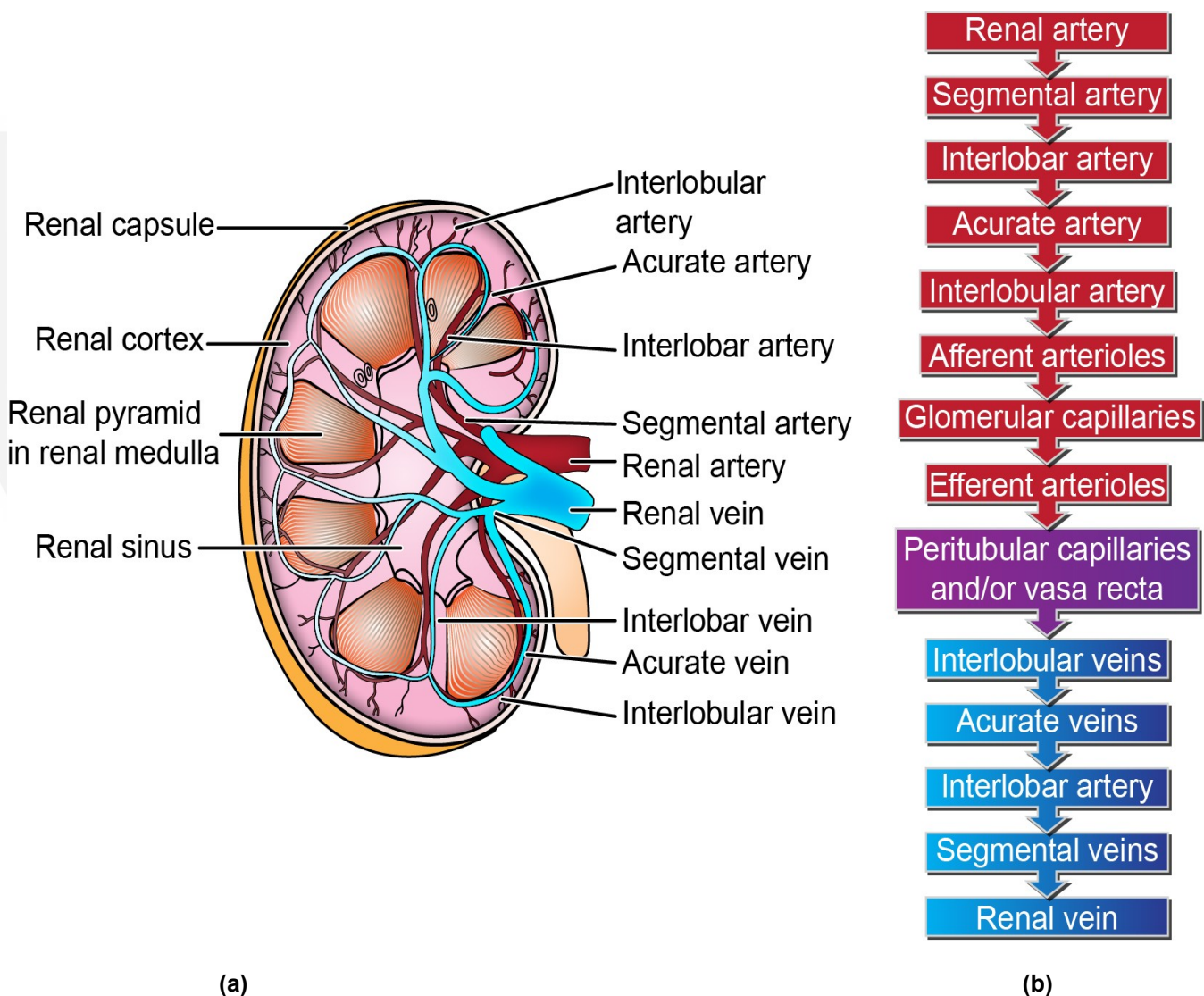


Fig. 6.10: (a) Section of kidney showing blood circulation; (b) flowchart to show the passage of blood in the kidneys.

Renal Interstitium: In both cortex and medulla, the spaces between the urinary tubules, contain cells called **interstitial cells**, which secrete **prostaglandin**.

SAQ 3

- i) Name the
 - a) Functional unit of the kidney.
 - b) Tuft of capillaries surrounded by renal capsule.
 - c) U-shaped loop between PCT and DCT.
 - d) Collecting ducts.
- ii) State the parts of the uriniferous tubule in proper sequence.
- iii) Match the following in column A with terms in column B.

Column A

- a) capillaries of efferent arterioles
- b) Renal interstitium
- c) macula densa
- d) renin

Column B

- i Prostaglandin
- ii Juxtaglomerular apparatus
- iii regulate blood pressure
- iv vasa recta
- v Sperms

6.4 URINARY BLADDER

The continuous filtration and output of water by the kidneys has made it necessary to make arrangement in the body to store the water temporarily before it can be excreted. The urinary bladder or sac evolved to fulfill this requirement. However, all vertebrates do not have a urinary bladder. Fishes have a tubal urinary bladder or sac which is formed by the widening of the urinary ducts. The bladder is found in dipnoans, amphibians and bladder possessing reptiles like the chelonians and *Sphenodon* and monotremes as an out pocket of the cloaca with no direct connection to the urinary duct. Except for ostrich all birds lack a urinary bladder, they excrete uric acid instead of urine and the urethra empties directly into the cloaca from where it is excreted. However, all placental mammals have a urinary bladder derived from the allantois of the embryo. It is a muscular sac abundantly supplied by blood vessels and nerves, lined with a mucous membrane and covered on the outside by the peritoneal membrane (Fig. 6.11). The bladder narrows down and is connected to the outside by the urethra. The lower ends of the ureters except in monotremes open directly into the bladder on its dorsal surface. In monotremes they open into the urethra through small papillae near the base of the bladder. At the junction of bladder and urethra there is an abundance of elastic tissue. Much of the bladder musculature is in the form of bundles continues down to the urethra. Urine flow is controlled by the internal sphincter and external urethral sphincter. The internal urethral sphincter is made up of smooth muscle therefore, under involuntary control and prevents urine leakage. The external urethral sphincter is made up of skeletal muscle

therefore under voluntary control of urination. In males the urethra passes through the penis to open at its tip through the external urethral orifice or urethral meatus. In females the position is different and varies. In some, as in female rat and mouse the urethra opens independently to the outside, passing through the clitoris; in others it enters a urinogenital sinus or vestibule, which is the terminal part of the genital and urinary tract.

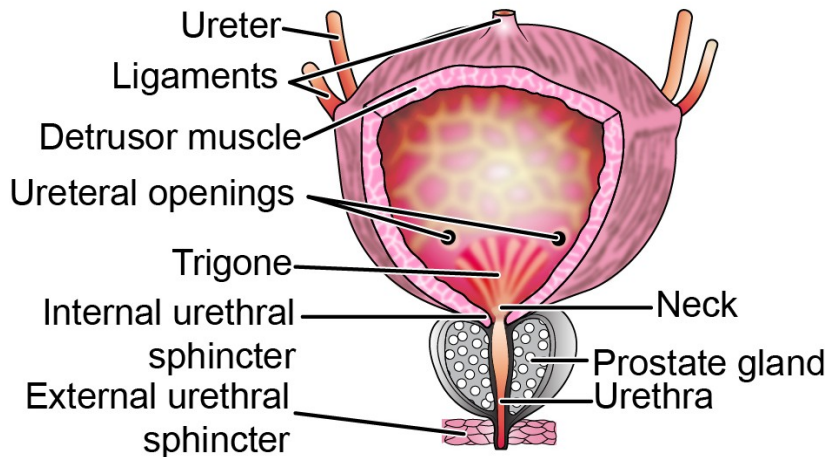


Fig. 6.11: A diagrammatic representation of section of urinary bladder.

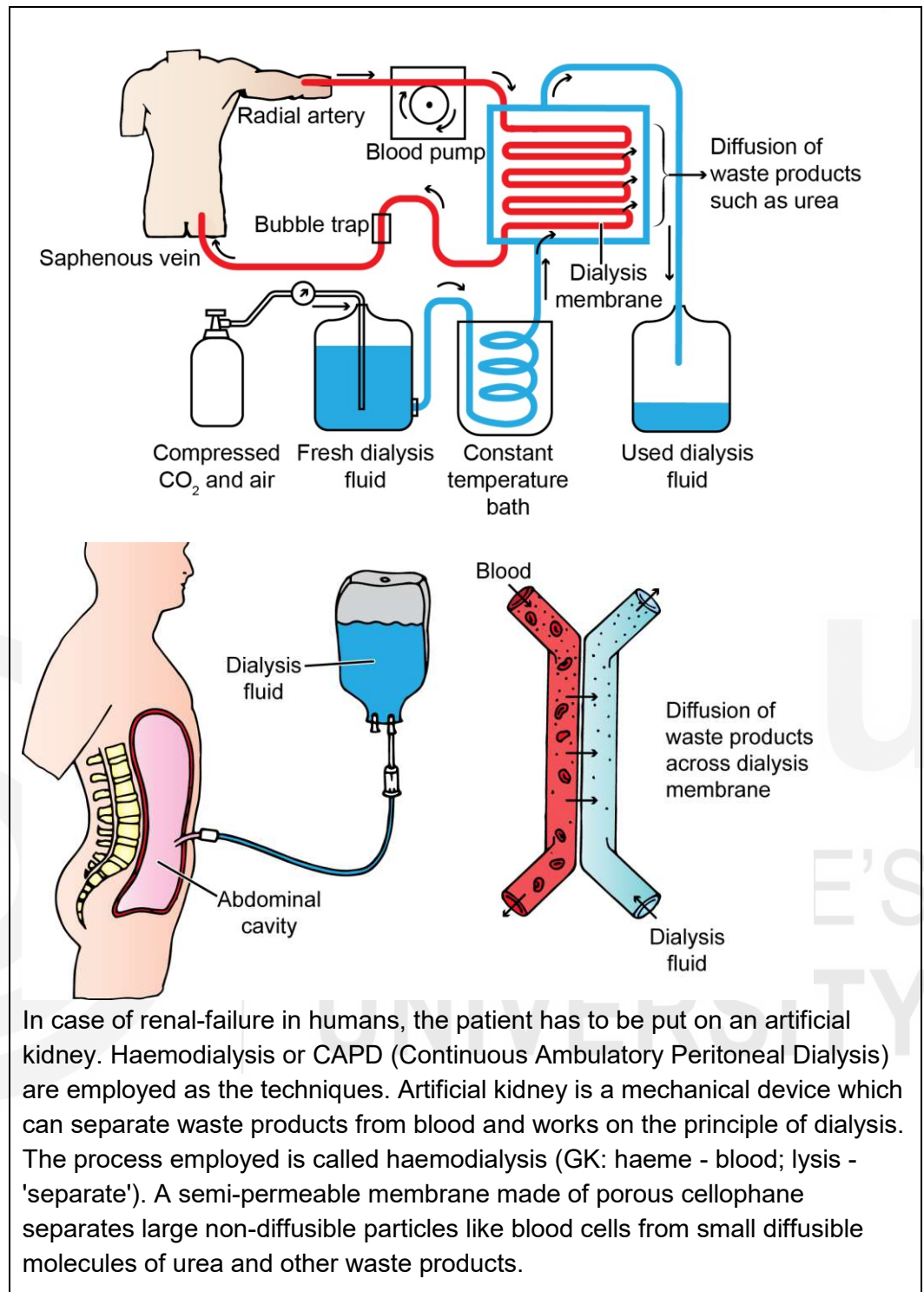
6.5 FUNCTIONS OF THE URINARY SYSTEM

The urinary system has several functions:

1. The kidneys produce and excrete urine which contains metabolic waste products such as ammonia or urea or uric acid etc. depending on the animal group. Urine passes from the kidneys via the ureters to the bladder. It is temporarily stored in the bladder and is then released to the outside via the urethra or through the urinary or urinogenital opening of the particular vertebrate species. Urine is formed by filtration, reabsorption and secretion.
2. Kidneys regulate fluid and electrolyte balance and hence serve in osmoregulation and water balance.
3. Kidneys produce an enzyme **renin** which functions in regulating blood pressure.
4. The cortical cells of kidneys secrete a hormone called **erythropoietin** which is associated with the production of blood cells. In case of loss of blood or hypoxia (low level of oxygen), erythropoietin formation is stimulated and acts on the bone marrow to promote formation of erythrocytes.
5. In certain male vertebrates, apart from carrying urine, the ducts from kidneys also carry sperms and are thus called the urinogenital ducts. In female vertebrates, ureters act only as a passage for urine.

Kidney function is vital for our survival, when the kidneys fail in a human being, the person can be put on an artificial kidney temporarily (See Box 6.1) till a compatible kidney can be transplanted.

Box 6.1

**SAQ 4**

Tick the appropriate functions of the kidney.

- a) Removal of metabolic waste.
- b) Osmoregulation.
- c) Transmission of gametes.
- d) Secretion of renin and erythropoietin.

6.6 THE GENITAL SYSTEM

The genital system or the reproductive system and is made up of the **gonads**, **gonoducts** and **genital openings**. The gonads as you have read are mesodermal in origin. They are called testes (sing. testis) in males and ovaries (sing. ovary) in female. Both the testes and the ovaries produce gametes and secrete hormones and are termed as **primary sex organs**. The early development of the genital organs is the same in both sexes, this is the sexually indifferent stage. For some time the sex organs of the embryo remain in an **indifferent stage**, during which the development of the gonads and their ducts proceed considerably far without any indication of whether the embryo would develop into a male or female. Finally the embryo develops its specific sex features, presumably due to hormonal activity.

Unpaired gonads are present in cyclostomes (jawless fish), certain fish as well as female birds of most species. This is the result of either fusion of paired gonads or the unilateral degeneration of one gonad. Evidence of metamerism (repetition of organs in segments) of gonads is only found in the primitive chordate amphioxus and in no other vertebrate.

In vertebrates the gonads called the ovaries in females and the testes in males are attached to the dorsal body wall by mesentery like bands of tissue, called the **mesorchium** in the males and **mesovarium** in the females (Fig.6.12). In most vertebrates the gametes ova in females and spermatozoa or sperms in males are produced by the ovaries and testes (sing: testis) respectively. In males the spermatozoa are transported outside the body by means of vas deferens while in females they are transported by oviducts. In a few forms of primitive vertebrates, like cyclostomes the ducts are absent in both sexes. In them the gametes escape from the body cavity through genital pores. The vas deferens of the male genital system of the anamniote vertebrates are usually the mesonephric or the Wolffian ducts which also serve to transport urinary wastes from the opisthonephric or mesonephric kidneys which function in these animals either during embryonic or adult life (in male). In amniotes in which the metanephros is the functional kidney and in

You will recall that anamniotes include cartilaginous and bony fishes and amphibians while amniotes include the reptiles, birds and mammals.

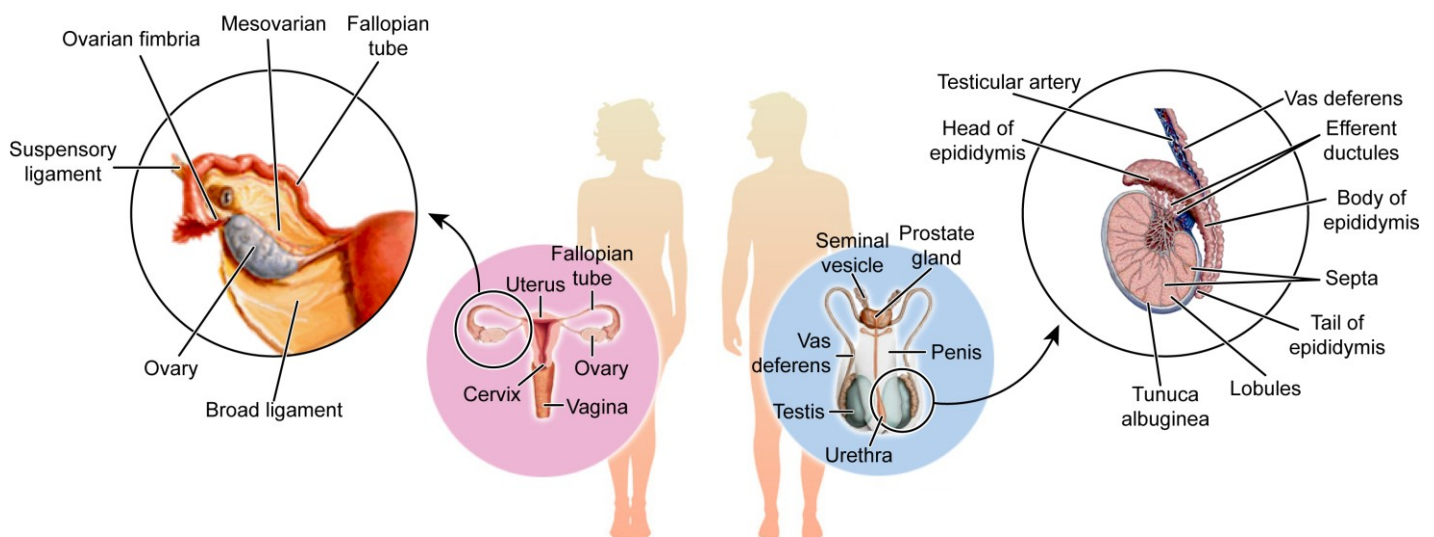


Fig. 6.12: Male and Female reproductive systems in humans.

which the mesonephros degenerates, the Wolffian duct of the male on each side of the testes persists to become the male genital duct and is referred to as vas deferens or ductus deferens.

In vertebrates, such as amphibians, birds reptiles and egg laying mammals a distinct cloaca (derived, from the Latin meaning “sewer”), is present into which the reproductive ducts open posteriorly. The cloaca is a common chamber into which intestinal, reproductive, and excretory canals empty. In all the placental mammals however, the cloaca is absent; instead the urinogenital system has its own opening separate from the anal opening and the cloacal region becomes modified so that in females the reproductive ducts called the **oviducts** open separately to the outside or as in the males, the reproductive ducts called the **vas deferens** join the excretory ducts to emerge as a common opening termed as the urinogenital opening.

In many aquatic vertebrates, fertilisation is external while in all terrestrial vertebrates except for anuran amphibians and even in many aquatic species it is internal. In some animals transport of spermatozoa from male to female is brought about by apposition of the cloaca (cloaca: sing) of the two sexes in most animals. However, several males have copulatory organs which are used in an intromittent manner to deposit the spermatozoa into the reproductive tract of the female. Various types of copulatory organs are found in the vertebrate groups.

In both sexes all the structures or organs which help to convey the germ cells or products of the primary sex organs like the reproductive ducts are termed as **accessory sex organs**. The other accessory sex organs include the, glands associated with the primary sex organs and the intromittent sex organs. **Secondary sex characters** are indirectly concerned with sex but play a part in the reproductive scheme. Sexual differences in secondary sex characters such as plumage, body size and strength, as well as vocal apparatus are only indirectly related to reproduction.

Functions of the Genital System

- The primary function of the genital system is production of gametes, the sperms and the eggs respectively by the male and female gonads respectively under the influence of hypothalamo – pituitary hormones.
- Gonoducts or genital ducts of the genital system transmit gametes to the place most suitable for fertilisation. It may be water in which eggs are laid by the female and sperms are dropped on them by the male (external fertilisation) or sperms may be discharged just as far into the female tract where egg and sperm can meet (internal fertilisation).
- Transport of sperms into female body is specially performed by accessory reproductive organs or intromittent organs, to ensure fertilisation.
- The female genital system is different from that of the male. It is specialised for retention of: (i) **egg** (in case of egg laying or **oviparous** organisms), e.g. fish, amphibia, reptiles and birds (ii) the fertilised egg with the developing embryo (in case of **ovoviviparous** organisms which lay the egg after embryo has developed to a certain stage) e.g. certain snakes or (iii) the developing embryo (in case of **viviparous** organisms which deliver full fledged young ones) e.g. mammals.

- Gonads secrete sex hormones which are steroid in chemical nature. The male hormone secreted by the testis is **testosterone**. The female hormones are mainly **estrogen and progesterone**. The sex hormones control the production of secondary sex characters, difference in structure, physiology and behaviour by which male and female can be distinguished. The secondary sex characters are especially prominent during breeding season.

SAQ 5

- Fill in the blanks with appropriate words.
 - The primary sex organs are the and
 - duct becomes the ductus deferens in male amniotes.
 - The are attached to the dorsal body wall by the mesovarium.
 - The tissue that suspends the testis from the dorsal body wall is called
 - Copulatory organ is an organ.
- Choose the correct alternatives from the parenthesis.
 - Reproductive organs develop from the embryonic (**mesoderm/ectoderm**) germ layer.
 - Organism that lay eggs in which the embryo develops are called (**viviparous/ oviparous**).
 - Mammals are (**ovoviviparous/viviparous**).
 - Estrogen is a (**male/female**) hormone.

6.7 MALE GENITAL SYSTEM OF VERTEBRATES

The genital system of male vertebrate composed of

1. Paired gonads – testes (singular - testis)
2. Paired urinogenital ducts
3. Single urinogenital opening

Let us begin our study of the male genital system starting with a description of the testis. We will describe the mammalian testes as an example.

6.7.1 Testes

The testes of all vertebrates have similar structure. The typical testis is a compact organ whose shape varies in members of different vertebrate classes. In some forms, (i) like in anuran amphibians and amniotes (reptiles, birds and mammals) the testis is composed of elongated tubules called the

seminiferous tubules in which the primordial germ cells develop into mature sperm and are conveyed to the outside by means of the vas deferens ducts. In others, such as cyclostomes, fish and urodele amphibians (ii) the testes consists of rounded cavities called **seminiferous ampullae** or spermatric ampullae or spermatric cysts. Both the elongated tubules, and rounded ampullae and at the embryonic stage consist of solid masses of cells which later develop the cavities or lumina.

Seminiferous Tubules

The testes in anurans, reptiles, birds and mammals and even some teleosts (bony fishes), are composed largely of seminiferous tubules which are coiled tubes and whose walls contain cells that produce the sperms (Fig. 6.13 a).

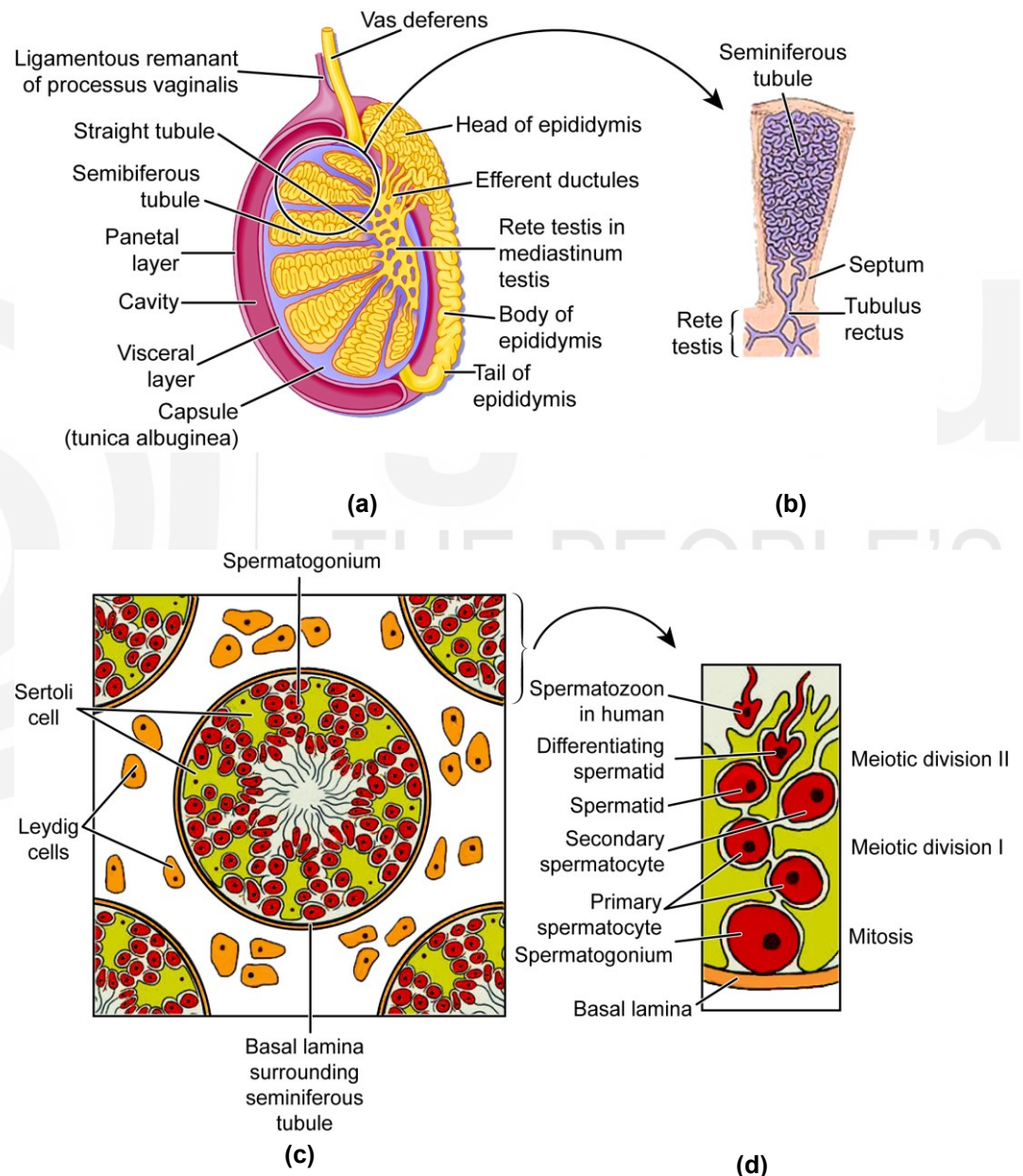


Fig. 6.13: Mammalian testis (a) Longitudinal section through testis showing the epididymis which is the passage through which the sperms travel to the penis (b) an enlargement of the boxed area in (a) showing the details of seminiferous tubules and rete testis (c) section of testes showing seminiferous tubules and a group of Leydig cells between the tubules (d) enlargement of the boxed area in (c) showing developing sperms and sertoli cell.

Each paired testis is surrounded by a capsule, the **tunica albuginae** (Fig.6.13 a) which grows inwards in many mammals including humans, to separate the inner cavity into compartments that contain the seminiferous tubules. This arrangement allows the packing in of an extensive quantity of germinal epithelium into a small space (Fig. 6.13 a). The seminiferous tubules are surrounded by interstitial **cells of Leydig**, which secrete testosterone. The seminiferous tubules are lined with multilayered germinal epithelium which contain the germinal cells called the spermatogonia cells and supportive cells called the **Sertoli cells** which are nutritive in function and in which the heads of the maturing sperms are embedded (Fig. 6.13 b & c). Sertoli cells also produce, most of the fluid in which the sperms are suspended, while leaving the testis. The seminiferous tubules are inconspicuous and the germinal epithelium is inactive in immature males and between breeding season in the adult males of those species which have specific breeding seasons. In some species however, spermatogenesis (Fig. 6.13 d) or production of sperms in adult males proceed at a variable pace throughout the year. An active germinal epithelium may exhibit all stages of developing sperms. The lumen or tubule cavity contains the tails of many sperms whose heads are embedded in the Sertoli cells, free sperms and fluid (Fig. 6.13c). In mammals in any single zone along a tubule, all sperm are at the same stage of maturation; adjacent zones contain different generation of sperms and a period of sperm formation and discharge is followed by interval of inactivity. Mature sperms move from the lumen of the seminiferous tubules into the straight tubules known as **tubuli recti** and from there to a fine network of tubules called **rete testes** and finally through 15-20 efferent ductules into the anterior head of the epididymus (see Fig. 6.13 a again). The process by which the spermatogonial cells in the seminiferous tubules develop into mature sperms is known as **spermatogenesis**, You will learn more about this process in Block 3, Volume 2 of this course

6.7.2 Male Genital Duct

The male genital ducts which in most vertebrates serve to transport spermatozoa to the outside of the body are as mentioned earlier, are the Wolffian ducts, and have been formed in the developing mesonephros kidneys. You will recall that the name Wolffian duct is used for the kidney duct in anamniotes. Although the male genital ducts are similar to the female genital ducts, the male genital ducts have a more complex history and organisation.

The original function of the genital ducts as you will recall, is the elimination of urinary wastes. In a number of fishes and amphibians certain tubules of the kidney become modified into genital ducts and are employed in carrying spermatozoa from the testis to the Wolffian ducts. They are referred to as efferent ductules or efferent ducts. The Wolffian ducts as genital ducts are named as the ductus deferens or vas deferens.

In all amniotes, the mature sperms from the testes are collected by the rete testes which are then drained by a number of small ducts called the efferent ducts or **vasa efferentia**. The vasa efferentia are modified kidney tubules and are usually less than 10 in number. The kidney tubules or vasa efferentia drain

into the Wolffian or mesonephric duct called the deferent duct or vas deferens which empties into the urinogenital sinus. The deferent ducts are collectively termed as **epididymis** or ductus epididymidis and are used primarily for sperm transport (Refer Fig. 6.13 a).

The teleost fish are the only vertebrates in which the genital ducts are derived from the testis itself and not from the kidney. The genital ducts are absent in amphioxus and modern jawless fish, the cyclostomes. In modern jawless fish the testicular ampullae rupture to release sperm into the coelom. In most vertebrates the sperms mature as they pass through the genital ducts but in teleosts they seem to be fully mature at the time they leave the testis. The genital ducts terminate at the urinogenital sinus which often empties into the cloaca. Each of the pair of the urinogenital duct, carries both sperms from testis and urine from the kidney to outside the body. In mammals, the parts of the epididymis consists first a head, then body and a tail that wrap around the testis and then gradually straightens out to become the spermatic duct. The epididymis secretes substances that prolong the life of the stored sperm and increase their capacity for motility.

6.7.3 Male Accessory Sex Glands

In mammals a number of relatively large and complex accessory glands occur. The testis and epididymis secrete fluids that form part of the semen. Other glands are the prostate gland, vesicular glands, bulbourethral glands, urethral glands (or Littre's gland) and coagulating glands. All of these open into the urethral part of the urinogenital sinus. Not all the glands are present in every species. However, the major mammalian accessory sex glands are the **prostate glands**, the **bulbourethral glands**, **ampullary glands** and the **seminal vesicles**. All these mammalian, accessory, sex glands are the outgrowths of the spermatic duct or of the urethra and all four occur in elephants and horses and in most moles, bats, rodents, rabbits, cattle and primates.

The prostate gland is the most widely distributed mammalian accessory sex gland. It empties into the urethra by multiple ducts. Many rodents, insectivores and lagomorphs (meaning "hare-shaped") have three separate prostatic lobes. In a few mammals which include some carnivores and primates, the prostate is a single mass with lobules and encircles the urethra at the base of the bladder. In many rodents as well as in some other mammals, the semen coagulates quickly after ejaculation due to secretion from a male coagulating gland which is usually considered part of the prostatic mass. **Coagulated** semen forms a vaginal plug that temporarily prevents copulation.

Bulbourethral or Cowper's glands arise from the urethra near the penis and are surrounded by the muscle of the urethra or penis. Usually there is one pair of Cowper's gland in the mammals, except for in some marsupials where as many as 3 pairs have been found.

Seminal vesicles are paired, typically elongated and coiled fibromuscular sacs that empty into either the spermatic duct or the urethra. These vesicles contribute the sugar fructose and citric acid to the semen but do not serve as a sperm reservoir.

6.7.4 External Male Genitalia: Intromittent Organs

In most aquatic forms external fertilisation takes place and water provides the medium by which the spermatozoa reach the eggs. In terrestrial forms, however, a liquid environment is needed to transport the spermatozoa so internal fertilization is the rule. The necessary fluids are produced by both male and female vertebrates. In a number of terrestrial vertebrates spermatozoa are transferred from male to female by cloacal apposition but in most terrestrial forms, and even in many aquatic species where fertilisation is internal the males develop sexual organs called **intromittent** or **copulatory organs** which are used by the males during internal fertilization to introduce the sperms suspended in seminal fluid into the female tract. In fishes the copulatory organs usually consist of modified fins. In snakes and lizards paired hemipenis are present; but in turtles, crocodilians, certain birds and all mammals, a single penis is used for this purpose. In all mammals except monotremes. The urethra arises from the urinary bladder and passes through the penis. It thus serves as a passage for both urinary and seminal fluids.

SAQ 6

1. Fill in the blanks
 - a) Testosterone is secreted by cells of.....
 - b) Sertoli cells secrete.....
 - c) The male accessory sex glands are, ... and
 - d) In aquatic species where fertilisation is internal the males develop organs called organs.

An ovarian follicle consists of an oocyte or immature egg enclosed in a epithelium. The cells of epithelium are referred to variously as follicular cell or nurse cell or granulosa cells. In cyclostomes, teleosts and amphibians the epithelium is one layer thick. In the hagfish and in those vertebrates like elasmobranchs, reptiles, birds and monotremes in which the oocytes have heavy yolk deposit, the epithelium appears to be two cells thick. In mammals above the level of monotremes, the follicular epithelium appears to be many cell thick.

6.8 FEMALE GENITAL SYSTEM OF VERTEBRATES

The genital system in vertebrate female (Fig. 6.14 a) consist of:

1. Paired gonads – ovaries (sometimes one due to degeneration)
2. Paired oviducts
3. Single female genital opening

6.8.1 Ovary

Ovaries lie within the body cavity and are suspended by the dorsal mesentry, the mesovarium, through which blood and lymph vessels and nerves pass. Primitive vertebrate ovaries are found in hagfish, in which a mesentry-like fold of gonadal tissue stretches across nearly the entire length of the body cavity. In the hagfish, the unique feature is that the functional ovarian tissue occupies only the anterior half of the gonadal mass while the rear part contains the rudimentary testicular tissue. In most fishes except in very primitive forms, the

ovaries are similarly elongated and large in comparison to body size. In tetrapods except for mammals the ovaries are usually confined to the middle third or half of the body cavity, particularly during the non breeding seasons. The ovaries of mammals undergo moderate caudal displacement in order to be located between the kidney and the pelvis and are much smaller in comparison to body size.

The shape of an ovary depends on many factors like whether one egg or thousands are discharged (ovulated), whether the eggs are immature or ripe; whether mature eggs are small or large, or whether pigments occur in the egg cytoplasm, such as those responsible for yellow yolk. The appearance of the ovary is also affected by other factors such as the season of the year in seasonal breeders, as ovary enlarges during the breeding seasons and diminishes in size between seasons, the age of the animal (whether juvenile or reproductively active or senile especially in birds and mammals) and the fate of the ovulated egg, follicles or sacs. Morphologically the ovary is of two types—compact or saccular. Most vertebrates have a compact ovary. Mammalian ovary is a typical example of the compact type. We will study the genital system and ovary of the female human being as an example of the genital system. In Fig. 6.14a you can see the female genital system of human female in which the paired ovaries are of compact type. In Fig. 6.14 b the internal structures of the female human ovary are seen in its longitudinal section. Each ovary is a compact structure which is covered by a **germinal epithelium** that is continuous with the peritoneum lining of the body cavity. Beneath the epithelium, is a layer of condensed tissue composed of short connective-tissue fibers with fusiform cells between them which forms the capsule of the ovary known as the tunica albuginea. The tunica albuginea of the ovary which is considerably thinner than that surrounding the testis. Internal to tunica albuginea is located an external cortex. The internal medulla is located underneath the external cortex

Müllerian duct: either of a pair of embryonic ducts parallel to the Wolffian ducts and giving rise in the female to the fallopian tubes, uterus, cervix, and upper portion of the vagina—called also paramesonephric duct.

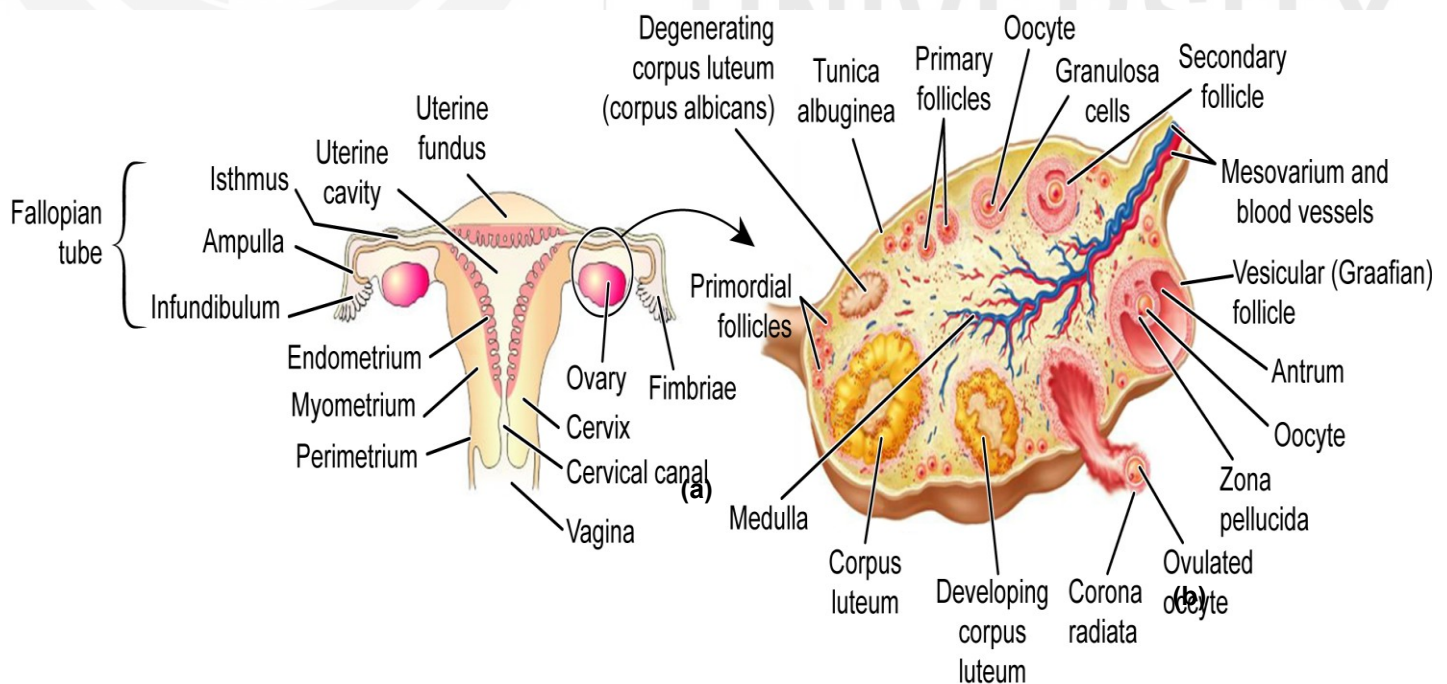


Fig. 6.14: Mammalian female reproductive system. (a) showing oviduct, ovary, uterus and vagina; (b) cut away of ovary showing internal structures.

The cortex which is the thick outer layer, lies immediately internal to tunica albuginea and contains many follicles, thousands of future eggs or **oocytes**. Some of the oocytes become mature **ova** during oogenesis (you will learn about the process of oogenesis later in this course). The cortex also contains remnants of ovulated follicles and clusters of interstitial cells that in some species are glandular. The cortical components are embedded in a supportive frame work of connective, vascular and neural tissue that forms the **stroma**. Internal to the cortex, the vascular, mesodermal, **medulla** consists of blood and lymph vessels, nerves and connective tissue. The medulla lacks germinal elements and exhibits no significant cyclical activity and is usually inconspicuous. and is continuous with the dorsal mesentry. In mammals the medulla is almost completely surrounded by the cortex and converges on the mesovarium at a narrow hilus, at which nerves and vessels enter the ovary. In the medulla of the mammalian ovary, near the hilus are present small masses of blind tubules or solid cords called the rete ovarii. The '**rete ovarii**' are homologous (of the same embryonic origin) with rete testis in the male. The rudimentary right ovary of the birds usually consists of only medullary tissue.

Amphibians possess true saccular type of ovaries. Their germinal epithelium and cortex is somewhat similar to the compact ovary. However, the medulla in the saccular type of ovaries has a large lymph space.

6.8.2 Female Genital Ducts

The female reproductive ducts are more independent of the excretory system than males. In most vertebrates, eggs are released into the coelomic cavity. Once in the coelom, the mature eggs enter the female genital duct called **oviduct** which parallels the archinephric duct in its embryonic course. The oviduct usually joins the urinogenital sinus near the cloaca. Oviducts except in teleosts and some fishes are modifications of the of the müllerian ducts and develop in every male or female embryo (except in cyclostomes) as a pair of longitudinal ducts. In males, the müllerian duct disappears or becomes rudimentary. In females, it grows larger to become the genital tract or gonoduct. Its smooth muscles and lining of ciliated cells, propels the eggs forward along the genital tract.

In higher mammals the oviduct differentiates into three regions (i) fallopian tube (ii) uterus and (iii) vagina. The oviduct of most vertebrates is open at the anterior end by means of an **infundibulum** which is also called **preampulla** and is located near ovary. The **preampulla** is ringed with mobile, finger like ciliated projections called **fimbriae** that actively envelops the ovary near the time of ovulation (see Fig. 6.14 a). The posterior end of the oviduct leads to at the urinogenital sinus which may open into the cloaca.

Oviducts may be long or short and may have glandular portions that are modified to be secretory in function. As a result along the course, the oviducts may differentiate into (i) a region that secretes protective and nutrient material on the eggs, like albumin and shell in case of egg laying vertebrates like birds, reptiles and egg laying mammals. (ii) uterus (pl: uteri) to lodge and nourish the developing embryo in case of viviparous animals. (iii) the terminal segment of the female genital duct (vagina) which is modified to receive the intromittent male organ.

Uterus

Uterus is the muscular middle part of the oviduct (refer to Fig. 6.14 a). Its muscular portion is formed of the **myometrium**. The inner lining of the uterus is called the **endometrium**. The endometrium becomes highly vascularised before the blastocyst stage when the developing embryo gets attached to the uterus.

In all mammals the uterus narrows to form the posterior **cervix** (Fig. 6.14a). Lips of the cervix enclose the uteri opening or '**os uteri**' through which sperms rise upto the upper part of oviduct for fertilisation. The cervix dilates during delivery of the baby.

Uterus shows a number of variations in mammals. In primitive mammals like monotremes (egg laying mammals) and marsupials there are two uteri (**duplex uterus**). In most mammals however, the distal parts of the two uteri are fused together to give a **bipartite** or **bicornuate** uterus. In higher primates there is a complete fusion of the two uteri to form a single **simplex uterus** as seen in humans (Fig. 6.15).

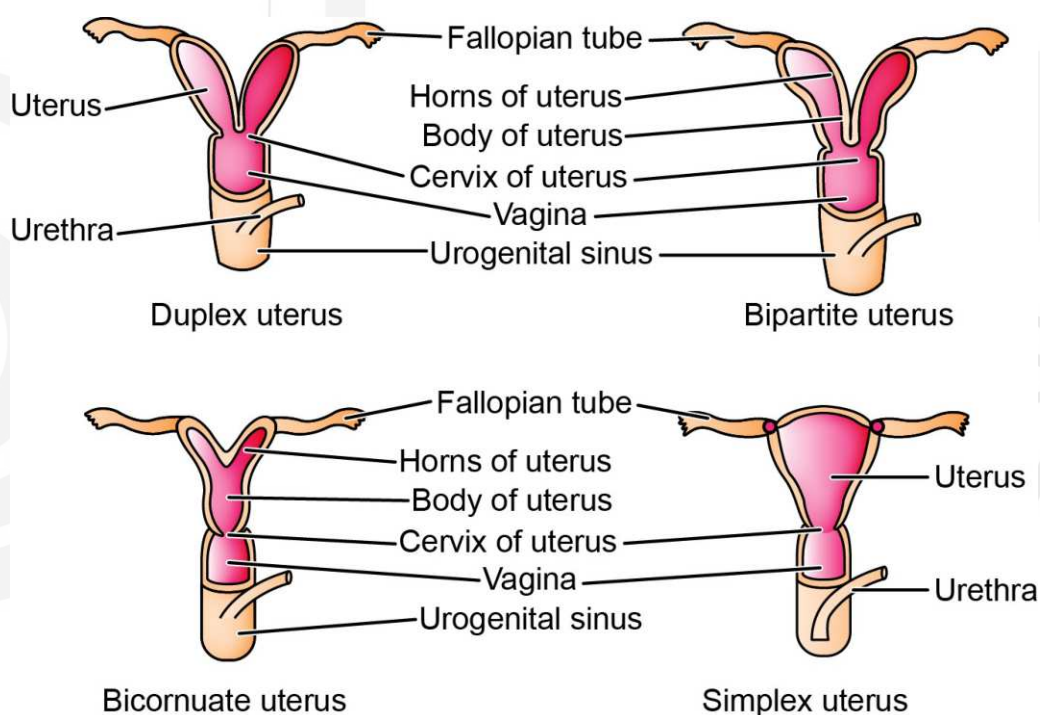


Fig. 6.15: Diagram showing the fusion of posterior ends of paired uteri in females of placental mammals. (The uterus and part of the vagina have been cut open.)

Vagina

The uterus leads through the narrow cervix into the **vagina**. Vagina is the fused terminal part of the Müllerian duct. It opens into urinogenital sinus or is extended to open directly to the outside. It is a muscular distensible tube which receives the penis during mating. It has convolutions on it which are called **vaginal rugae**. Vagina opens to the exterior by the female genital opening.

Vagina is absent in egg laying mammals. Marsupials, have paired vagina that open into urinogenital sinus. To match the two vagina, male penis is forked at the tip and one tip enters one lateral vaginal canal to discharge the semen.

6.8.3 Female Accessory Glands

You have already read in subsection 6.7.3 about the various accessory glands associated with the male genital system. You will similarly find that accessory glands are also associated with the female genital system of many vertebrates. Oviducts of many female vertebrates have glands called the albumin gland that coat the egg with albumin. Other glands associated with the oviduct are the shell glands that cover the egg with shell material; mucous cell or oviducal tubular glands that secrete a jelly like material. Amniotes that lay large eggs may have in the oviduct mucous secreting glands called vaginal mucous gland that coat the egg prior to expulsion, possibly to lubricate it. Some fishes have adhesive glands that coat the eggs with a sticky secretion so that the eggs can adhere together or to appropriate objects. In some vertebrates that retain the developing embryos within the body, special glands of the oviduct evolve in order to nourish the young. These glands secrete into the oviduct so that young present there absorb or ingest the secretion. This secretion is called **uterine milk** or **embryotrophe**.

6.8.4 External Female Genitalia

In females the external genitalia in comparison to males is feebly developed. Maximum development of female genitalia is in the Order Primates of mammals. In human females it is well developed and is described below:

External Genitalia of Human Female

The external genital organs of the female are termed as **vulva**. The external genitalia of the human female consists of an outermost structure called **labia majora** which is a pair of skin folds and contains adipose tissue. Within the cleft formed by these folds are the **labia minora**, which are a smaller pair of skin folds that are highly vascularised but have no fatty tissue. At the anterior end of the vulva, these two interior skin folds, partly enclose the **clitoris**, which is a small organ for sexual stimulation. The opening of the urethra is about midway between the clitoris and vaginal opening. The **vaginal opening** also called the **vestibule** of the **vagina** is located behind the urinary meatus and is much larger than the urinary opening. It is covered by a thin mucous membrane the hymen.

Bartholin's glands (or bulbovestibular glands) or greater vestibular glands are two bean shaped glands, one on either side of the vaginal opening also called **vestibule** into which they secrete a lubricating fluid. Bartholin glands are homologous to the male **bulbourethral glands**. A group of tiny mucous glands, the **lesser vestibular glands** also called the **Skenes glands** open into the vestibule as well.

6.8.5 Mammary Apparatus

Mammals are named so because of the characteristic presence of the mammary apparatus, which includes (i) **mammary glands**, (ii) **elevated nipples** which are the outlets for secretion of these glands and (iii) **breasts or mammae** which are the integumentary swellings due to localised presence of these glands (Fig. 6.16).

You will recall from Unit 1 Integument of this course that mammary glands are modified sweat glands. They are present in both male and female mammals but they become well developed only in females as their development is controlled during puberty by the ovarian hormones estrogen and progesterone.

Each mammary gland is divided into a number of lobes and each lobe has several **lobules**. Lobules are formed of connective tissue in which secretory cells called alveoli are embedded. **Alveoli** are arranged in grape like clusters around minute ducts. Progesterone stimulates the growth of alveoli and estrogen stimulates the growth of ducts.

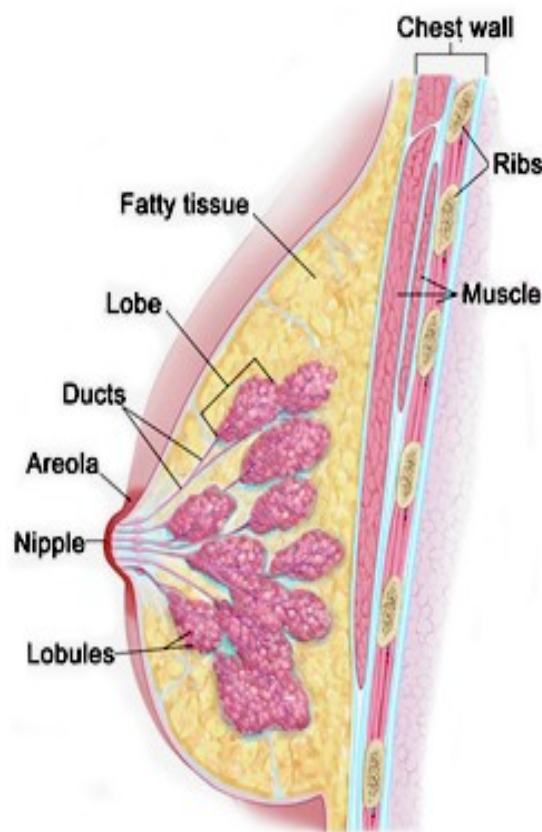


Fig. 6.16: Human female breast showing mammary apparatus.

Ducts from lobules unite to form a single lactiferous or milk carrying duct per lobe. Each duct opens by a pore at the nipple. The nipple is bordered by a pigmented area called the **areola** which contains several **sebaceous** glands that appear as small nodules under the skin. The nipples vary in number and location in different mammals. The number depends on the number of offsprings born in a litter. The position of mammae depends on their availability to the suckling offspring. In monkeys and other primates which are arboreal, the mammae are pectoral. Humans, who have descended from arboreal ancestors also have pectoral nipples. In ruminants which suckle their young, while standing, the mammae are elongated and project downwards. In pigs they are arranged on the sides and so the mother lies down to suckle the young. The number of nipples vary, horse, bats, whales and humans have a pair of nipple.

SAQ 7

1. Fill in the blanks and compare your answers with those given at the end of this unit.
 - a) The four types of mammalian uteri are,
..... and
.....
 - b) The muscle layer of the uterus is called
 - c) The sequence of organs of mammalian female genital system are:
two ovaries → → →
..... → genital opening.
 - d) In female birds only the gonad develops into the ovary.

6.9 SUMMARY

Let us sum up what we have learnt in this unit:

- Both the urinary and reproductive organs arise embryologically from the same or adjacent tissue and maintain close anatomical and sometimes functional association, throughout the animal's life.
- The excretory organs of the vertebrates consist of paired kidneys and their associated ducts.
- The various types of kidneys that are found in the vertebrates have been derived from a primitive structure termed as archinephros or holonephros.
- The archinephros (holonephros) consisted of paired archinephric ducts which extended the length of the coelom and were joined by segmentally arranged tubules, one pair to each segment. The free end of each tubule opened into the coelom by means of a ciliated, funnel shaped nephrostome. Each tubule was intimately associated with a small knot of inter arterial capillaries known as glomerulus. The larval stages of the hagfish exhibit an archinephric condition.
- Kidneys of living vertebrates have developed from this primitive plan of the archinephros type of kidney. The various types of vertebrate kidneys may be regarded as successive stages that have evolved in a craniocaudal direction from the original archinephros. They may be clearly observed during the embryonic development of the amniote vertebrate where there is a succession of three developmental stages of kidney – pronephros, mesonephros and metanephros. Some but not all these stages are also seen in other vertebrate groups.
- In a few lower vertebrates the pronephros persists in the adult stage and is called the head kidney. A head kidney is found in the adult hagfish and

in certain teleosts. The part of the anamniote kidney that persists and forms the adult kidney is called the opisthonephros, in which, there is a general tendency for concentration of kidney tubules towards the posterior end. The anterior end loses its importance as an excretory organ and in males archinephric duct becomes known as ductus deferens.

- In amniotes, of the three types of kidneys which appear during embryonic development, only the metanephros persists to form the adult kidney. The archinephric duct in amniotes is termed as Wolffian duct.
- In male amniotes, the Wolffian duct gives rise to the epididymis, ductus deferens and certain other parts of the reproductive system.
- The urinary system of most vertebrates includes a pair of kidneys and a pair of ureters. A urinary bladder and urethra occur in all mammals and some vertebrates.
- Ducts from the kidney lead to cloaca in most forms. In teleost fishes they open directly to the outside.
- In mammals, ducts of the kidney enter the urinary bladder (except in monotremes). Urinary bladder, may be present as ventral out pocketings of the wall of the cloaca. In mammals the bladder opens to the outside through a urethra which in males of all forms except for monotremes is also used by the reproductive system.
- Each mammalian kidney as well as that of most vertebrates is composed of a renal capsule, enclosing a cortex and an internal medulla. Numerous individual tubules called uriniferous tubules are the basic excretory unit of the kidney which produce urine. Each uriniferous tubule consists of i) nephron an excretory unit ii) collecting tubule.
- Each nephron consists of a cup shaped Bowman's or renal capsule, proximal convoluted tubule (PCT), loop of Henle and distal convoluted tubule (DCT). Blood vessels associated with the nephron are an afferent arteriole, glomerular capillaries, an efferent arteriole, and peritubular capillaries.
- The various functions of the urinary system are (i) excretion of metabolic waste products (ii) regulation of fluid, electrolyte balance and blood pressure (iii) secretion of hormone erythropoietin which is associated with production of blood cells in case of loss of blood or hypoxia.

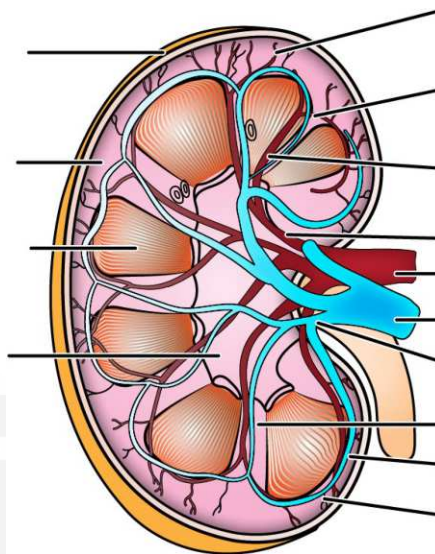
GENITAL SYSTEM

- The reproductive system of vertebrates consists of primary sex organs, the gonads which produce gametes and accessory reproductive structures.
- The primary sex organs or gonads are testes in males and ovaries in female. The testes produce the spermatozoa and the ovaries the ova.

- The accessory sex organs are ducts and glands which provide passage for transport of gametes (eggs or spermatozoa to the outside of the body). The archinephric duct in anamniotes or the Wolffian duct in amniotes becomes the reproductive duct or ductus deferens in the male. In females the Müllerian duct forms the oviduct. Ducts are absent in cyclostomes.
- In males, spermatozoa are formed within seminiferous ampullae or seminiferous tubules in the testes.
- Each ductus deferens establishes connections with the testes usually by means of epididymis and persistent kidney tubules called efferent ductules. In anamniotes the epididymis and ductus deferens consist of parts of the archinephric duct which may serve in some cases as an excretory duct as well as for passage of the spermatozoa. In amniotes however the epididymis and ductus deferens are formed from the persistent Wolffian duct, which is entirely dissociated from the ureter of the adult metanephric kidney.
- The testes in vertebrates are located in the abdominal cavity, except in a number of mammals. In most mammals they are either temporarily or permanently located in a scrotum outside the body proper.
- In male vertebrates especially mammals, accessory glands are associated with primary sex organs. These secrete seminal fluid in which spermatozoa are suspended and which are essential for the viability of the spermatozoa and for transport through the reproductive tract of both male and female.
- Fertilisation in vertebrates may be external or internal. Most vertebrates with internal fertilisation have copulatory organs which are used in transferring the spermatozoa from the male to the female.
- Eggs develop within ovaries and when fully developed they break out of the ovaries into the coelom. The oviducts of teleosts are derived in a different manner and may not be homologous with those of other vertebrates.
- In vertebrates other than mammals the paired oviducts are separate and usually open independently into a cloaca. In most higher mammals a cloaca is absent in the adult and each oviduct differentiates into three regions (i) fallopian tube (ii) uterus (iii) vagina. Various degrees of fusion of the paired uterus occur in mammals, resulting in different types of uteri.
- The external genitalia of females is called vulva and is feebly developed in comparison to males. Maximum development of female genitalia is in the primates.
- Accessory glands are also associated with the female reproductive organs and secrete mucous and milk in mammals to provide nourishment to their young.

6.10 TERMINAL QUESTIONS

1. Why are the urinary and reproductive systems usually studied under a common urinogenital system?
2. Draw a well labelled diagram of the uriniferous tubule of mammal.
3. Label the given diagram of human kidney.



4. Write short notes on (a) kidney blood circulation (b) types of mammalian uteri.
 a)
 b)
5. What are intromittent organs?
6. Draw a well labeled diagram of internal structures of ovary and describe the structures.

6.11 ANSWERS

Self-Assessment Questions

1. i) Refer Section 6.2.
 ii) Refer Subsection 6.2.2.
2. a) cortex, medulla; b) renal column of Bertini; c) hilum or hilus
3. i) a) nephron; b) glomerulus; c) loop of Henle; d) duct of Bellini.
 ii) renal corpuscle/glomerulus and Bowman's capsule, proximal convoluted tubule, descending limb, Henle's loop, ascending limb, distal convoluted tubule, collecting tubule.
 iii) a) iv; b) i; c) ii; d) iii.
4. a); b); d).

5. i) a) testis, ovary; b) Wolffian/Mesonephric; c) ovaries;
d) mesorchium; e) intromittent.
- ii) a) mesoderm; b) oviparous; c) viviparous; d) female.
6. a) leydig cells; b) fluid; c) prostate, bulbourethral, coagulating and vesicular; d) intromittent organs.
7. a) Duplex; bipartite; bicornuate; simplex;
- b) Myometrium;
- c) Two oviducts (fallopian tubes) → uterus → vagina;
- d) left.

Terminal Questions

1. Though the urinary and reproductive system have nothing in common functionally; they are usually studied under a common urinogenital system because both develop from the some segmental blocks of trunk mesoderm or adjacent tissues and share many of the ducts.
2. Draw figure on basis of Fig. 6.6 of this unit.
3. Label figure on basis of Fig. 6.10.
4. Refer a) subsection 6.3.3; b) subsection 6.8.2 – uterus.
5. Refer subsection 6.7.4.
6. Refer subsection 6.8.1.

NERVOUS SYSTEM|

Structure

7.1 Introduction	7.4 Peripheral Nervous System
Objectives	Spinal Nerves
7.2 Nervous Tissue in Vertebrates	Cranial Nerves
7.3 Central Nervous System	Autonomic Nerves
Cavities of the Brain and Spinal Cord	7.5 Brain – A Comparative Account
The Spinal Cord	Jawless Vertebrates
The Brain	Jawed Vertebrates
	7.6 Summary
	7.7 Terminal Questions
	7.8 Answers

7.1 INTRODUCTION

Each of us would have at some point in our life observed animals, how they move, catch prey or feed and respond to external and internal stimuli. All these activities take place because individual cells in the animal's body respond to certain stimuli and their responses are integrated in a meaningful co-ordinated manner. This co-ordination occurs in two forms, electrical through the nervous system and in chemical form through the endocrine system. In this unit you will learn about the coordination through electrical functions of the neuron and the anatomical organisation of the vertebrate nervous tissue into a well knit nervous system.

You would recall from what you have studied in class 11 that the function of the nervous system is to receive stimuli or sensory information and to send impulses from one part of the body to another. In this manner it regulates an animal's activities by integrating incoming sensory information with stored information, the result of past experience and then translating past and present information into action through muscles and glands (also known as effectors).

In this unit you will learn briefly about the structure of the vertebrate nerve cell or the neuron which is the functional and structural unit of the nervous

system; these neurons operate on the same principles throughout the animal kingdom. You must understand that the basic organisation of the nervous system is the same in all vertebrates and it can be divided into the central nervous system made up of the brain and spinal cord and the peripheral nervous system which consists of all nervous tissue outside the central nervous system. We will discuss the organisation of the vertebrate nervous system and the brain in relation to function in different vertebrate groups.

In the next unit you will study how the inputs from the external environment are received and collected by the sense organs and the further transmitted via the nerves to the central nervous system to elicit a suitable response.

Objectives

After studying this unit you should be able to:

- ❖ describe the structure of a typical nerve cell;
- ❖ discuss the organisation of central, peripheral and autonomic nervous system of vertebrates;
- ❖ Differentiate between the somatic and autonomic nervous system;
- ❖ Compare the parasympathetic and sympathetic divisions of the autonomic nervous system;
- ❖ give a comparative account of brain in vertebrates; and
- ❖ correlate the evolution of brain structures with their function in vertebrates.

7.2 NERVOUS TISSUE IN VERTEBRATES

The nervous system includes millions of nerve cells that originate from the ectodermal cells in the embryo. In vertebrates during embryonic development the flattened layer of ectoderm along the mid dorsal side of gastrula becomes thickened and is known as neural or medullary plate which gives rise to the neural tube and neural crest. The neural tube is the forerunner of the brain and spinal cord, and some of the neural crest cells migrate away from the neural tube to give rise to the bodies of nerve cells that lie outside the brain and spinal cord.

The basic unit of the nervous system is nerve cell or neurons. You must be knowing the structure of neuron but still lets recapitulate.

Fig. 7.1 is a typical diagram of a neuron. The primary components of neuron are

- Soma (cell body)
- Axon (long projection that conducts electrical impulse away from cell body).
- Dendrites (tree like structures that receive messages from neurons).

Some axons are covered with myelin a fatty material that acts as insulator and conductor to speed up the process of communication. The myelin sheath is not continuous but leaves small sections uncovered these are known as **Nodes of Ranvier**. The axon may be myelinated (shwann cells) or unmyelinated. The axon terminal does not actually make contact with other neuron and there is a tiny gap between the dendrites or cell surface of another neuron. This close gap is known as **synapse**. Synapse are of two types: i) chemical and ii) electrical synapse. In chemical synapse neurotransmitters are released from the axon terminals that conduct (carry) the information in the form of impulses across the synapse to the other neuron. This is normally unidirectional. A single neuron may have such communication with several other neurons that transmit information along their axons and receive information over dendrites. In electrical synapse axon terminals are separated with adjoining neurons by gap functions and ions transmit the impulse across the synapse.

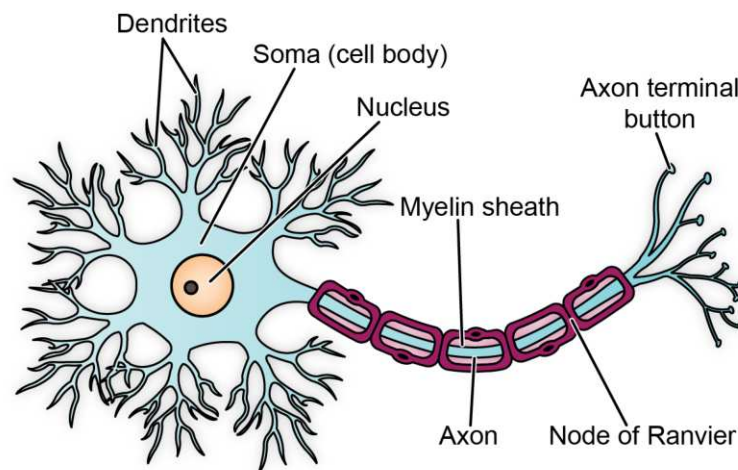


Fig. 7.1: Structure of a typical neuron.

Neurons can be classified according to the placement of the cell body in relation to its processes. The primary classification is based on the number of branches that originate from the cell body as: (i) multipolar (multiple branches) (Fig. 7.2 a); these are the most common and their structure resemble the typical neuron most closely. The many dendrites in these neurons allow for integration of information from many other neurons. The axons are usually long, thus taking information to distant parts of the nervous system; (ii) Bipolar neurons (two branches) (Fig. 7.2 b) have dendrite and axon emerging from the opposite side of the cell body. These are found in the sensory organs like eyes and nose; their dendrites receive signals from the sense organs, carry them to the cell body and from there via the axons take the signals to the brain and spinal cord. (iii) unipolar (single branch) (Fig. 7.2 c) that sense touch, pressure and pain. There is a single branch which splits close to the cell body into a single axon and many dendrite. The axon is usually long and ends in the spinal cord and the dendrites go to the skin, joints or the muscle.

Functionally neurons are of three types: sensory neurons, interneurons and motor neurons. Sensory (afferent or receptor) neurons either act as receptors of stimuli themselves or are activated by receptors. Sensory neurons are

stimulated by changes in the external or internal environment and respond by sending signals to the major integrating centers where the information is processed. Interneurons receive signals from the sensory neurons and transmit them to the motor neurons. Motor (effector) neurons send the processed information to the body's effectors like muscles and glands.

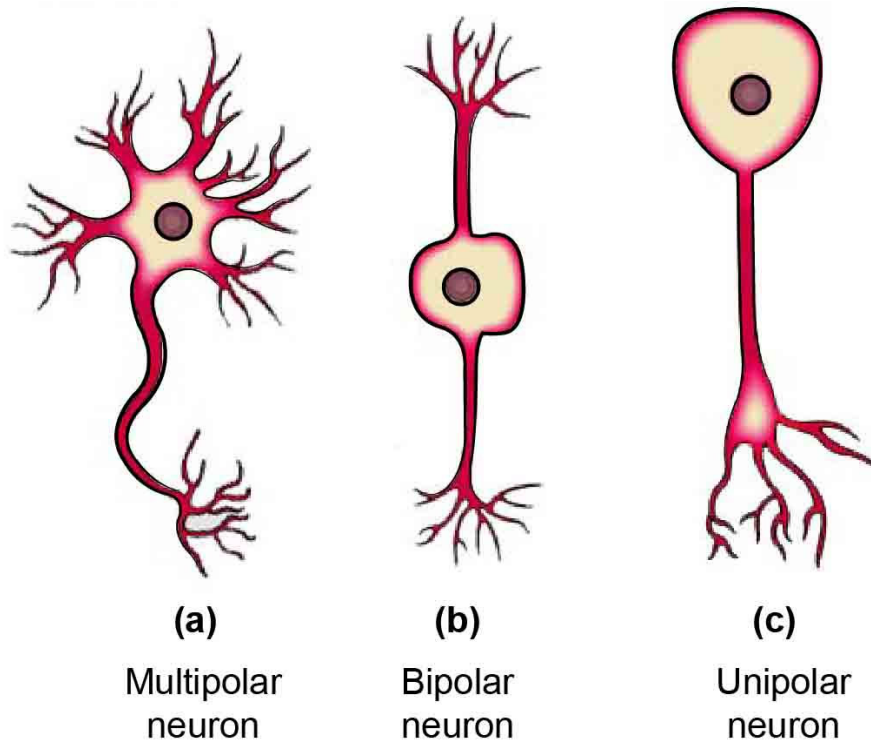


Fig. 7.2: Typical neurons in vertebrates. a) multipolar neuron b) bipolar neuron c) unipolar neuron.

Though the basic component of the nervous system is the neuron, another kind of tissue the **neuroglia** (meaning nerve glue in greek) are interspersed among the nervous elements and provide support and some degree of protection. These do not conduct signals nor secrete neurotransmitters.

The three main categories of glial cells in the brain and spinal cord are:

- 1) **macroglia** of ectodermal origin
- 2) **microglia** of mesodermal origin
- 3) **ependymal** glia

These have many sub categories. The macroglial cells found in the central nervous system are called **oligodendrocytes** and in the peripheral nervous system are called **Schwann** cells (Fig.7.3). The **oligodendrocytes** extend processes that wrap around axons. This wrapping or sheath is composed of **myelin** a substance rich in fats and proteins. Myelin sheaths are generally present in axons of only vertebrates. Amongst the vertebrates, myelin sheaths are absent in cyclostomes. Axons of neurons outside the brain and spinal cord are also coated by ribbon like cells. These are **Schwann** cells and are similar to oligodendrocytes in that they also produce myelin that serves as insulating material (which is similar to the coating on an electric wire), and prevents loss

Blood brain barrier about a century ago scientists found that a barrier exist which prevents material from blood to enter brain. Scientists injected blue dye into the blood stream of an animal and found that it reached tissues of the whole body EXCEPT brain.

of energy of the nerve impulse during its passage along the axon. Presence of myelin sheath also helps in fast conduction of nerve impulse as the fibres with thick covering of myelin conduct at the greatest speed. As mentioned earlier, this myelin sheath is interrupted at regular intervals by circular constrictions forming the **nodes of Ranvier**.

Types of Neuroglia

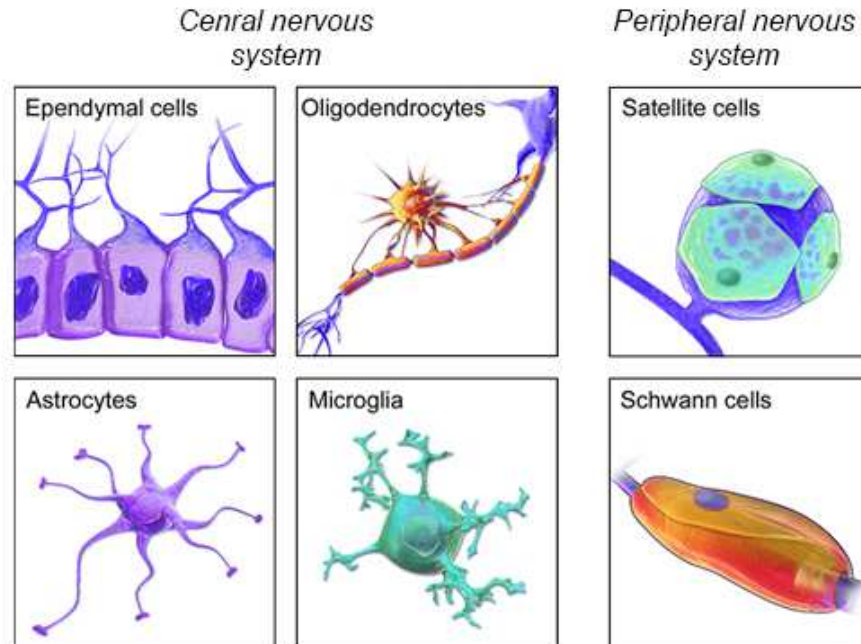


Fig. 7.3: Neuroglial cells in the nervous system Major types of glial cells in the nervous system. (Image: [Blausen.com staff](#) / CC BY 3.0 via Commons.)

Another kind of macroglial cells are the **astrocytes** which are the largest and the most abundant. They make contact with other nervous tissue and maintain normal nervous tissue physiology. They also play a role in brain development, repair and healing and also in maintaining the blood-brain barrier. **Ependymal** glia are cells that line the cavities of the brain and spinal cord and are involved in the production of neurospinal fluid cerebrospinal fluid. **Satellite cells** are small that surround the neurons in the peripheral nervous system and help to maintain the chemical environment around them. They are interconnected and highly sensitive to injury and inflammation.

Microglial cells are specialised populations of macrophages that are found in the central nervous system (CNS). They remove damaged neurons and infections and are important in maintaining the health of the central nervous system.

A collection of nerve cell bodies is known as a **ganglion**. Groups of nerve cell bodies and their dendrites and the proximal unmyelinated portion of the axons have a greyish appearance, they form the grey matter. The brain and spinal cord are chiefly composed of grey matter. On the other hand, white matter is composed of bundles of myelinated fibres. Such bundles are known as **nerve tracts** in the brain and spinal cord and **nerve** in the rest of the body. White and grey matter are sometimes intermingled. Such an arrangement is known as **reticular formation**.

The vertebrate nervous system has two main division.

- 1) **Central nervous system** (CNS) which consists of the brain and spinal cord.
- 2) **Peripheral nervous system** (PNS) consisting of the cranial nerves arising from the brain and the nerves and ganglia arising from the spinal cord. Part of the peripheral nervous system is composed of autonomic nerves which are distributed to those parts of the body that are under involuntary control.

Let us now consider the central nervous system. But before you move on to the next section try the SAQ given below.

SAQ 1

Correct the following statements suitably:

- a) Spinal cord and brain are formed of white matter.
- b) Myelin sheaths are secreted by astrocytes.
- c) Myelin sheaths are found only in the axons of the brain.
- d) Bundles of axon in the brain form the reticular formation.
- e) Microglia forms the blood brain barrier.

7.3 CENTRAL NERVOUS SYSTEM

We had mentioned in the earlier section that the central nervous system is composed of the brain, which lies within the cranial cavity of the skull and the spinal cord lies within the vertebral column in the neural canal formed by the neural arches of the vertebrae. The neural tube of the embryo differentiates into the brain and spinal cord, its original cavity becomes modified to form the fluid filled **ventricles** that are connected spaces located within the centre of the brain and the narrow central canal of the spinal cord. The anterior end of the neural canal thickens variably and can be recognised into three embryonic regions, **prosencephalon**, **mesencephalon** and **rhombencephalon** (Fig 7.4a). Prosencephalon includes telencephalon which contains cerebral hemisphere and under it the diencephalon containing the thalamus and hypothalamus. Mesencephalon is the portion of brainstem which connect the forebrain with the hind brain and forms the **midbrain**. Rhombencephalon which include metencephalon and myelencephalon which contains medulla, pons and cerebellum in the adult forms the **hindbrain** (Fig. 7.4b).

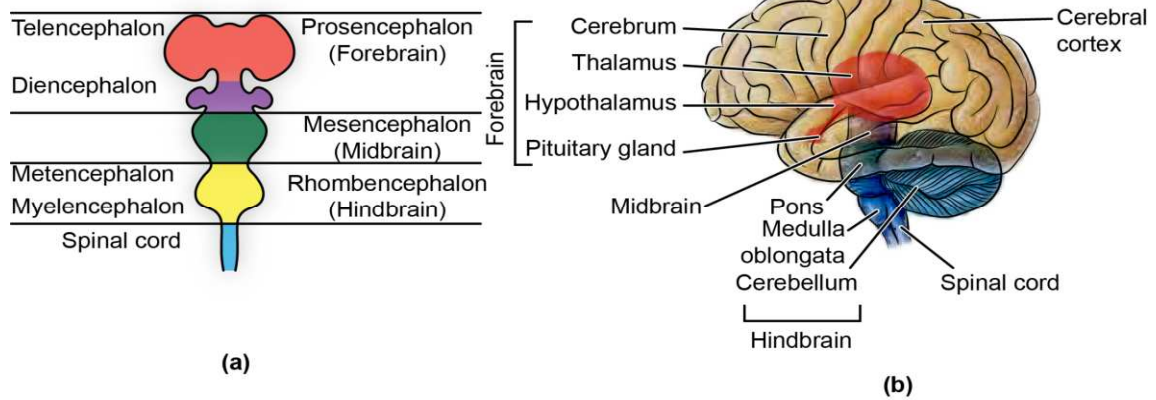


Fig. 7.4: a) Diagrammatic view of the major subdivisions of the primitive vertebrate brain; b) Diagrammatic view of the major subdivisions of adult vertebrate brain.

7.3.1 Cavities of the Brain and Spinal Cord

The embryonic neural cavity (Fig. 7.5 a) develops into a brain ventricular system. The neural cavities extending into the cerebral hemisphere become **lateral ventricles** or ventricle I and II (see Fig. 7.5 b). The remainder of the prosencephalon forms the **diencephalon** and its cavity is known as the **third ventricle**. Ventricles I, II communicate with the third ventricle by means of interventricular foramen or **foramen of Monro** (7.5 b). In higher vertebrates the third ventricle communicates with mesencephalon by **cerebral aqueduct** a narrow canal and posteriorly the cerebral aqueduct leads into the **fourth ventricle** in the rhombencephalon. The third and fourth ventricles of the vertebrate **brain** are connected by a passage known as **lter**. The portion of the fourth ventricle within medulla oblongata is referred to as **myelocoel** which is continuous with the canal of the spinal cord. The cavities of the brain and spinal cord are filled with lymph like **cerebrospinal fluid**.

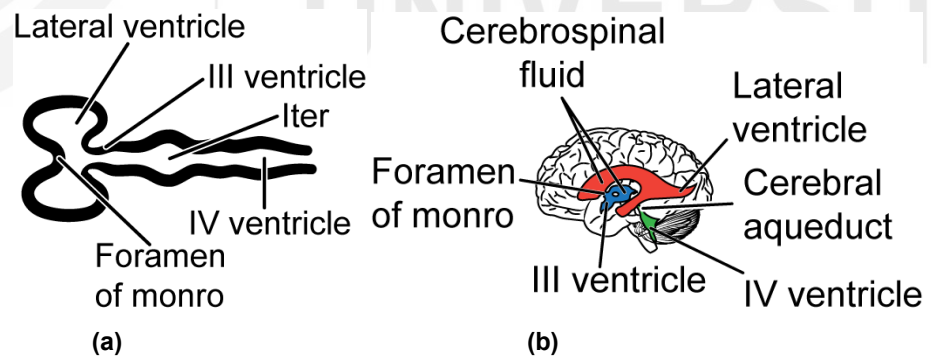


Fig. 7.5: (a) Embryonic neural cavity; b) Ventricles of the brain.

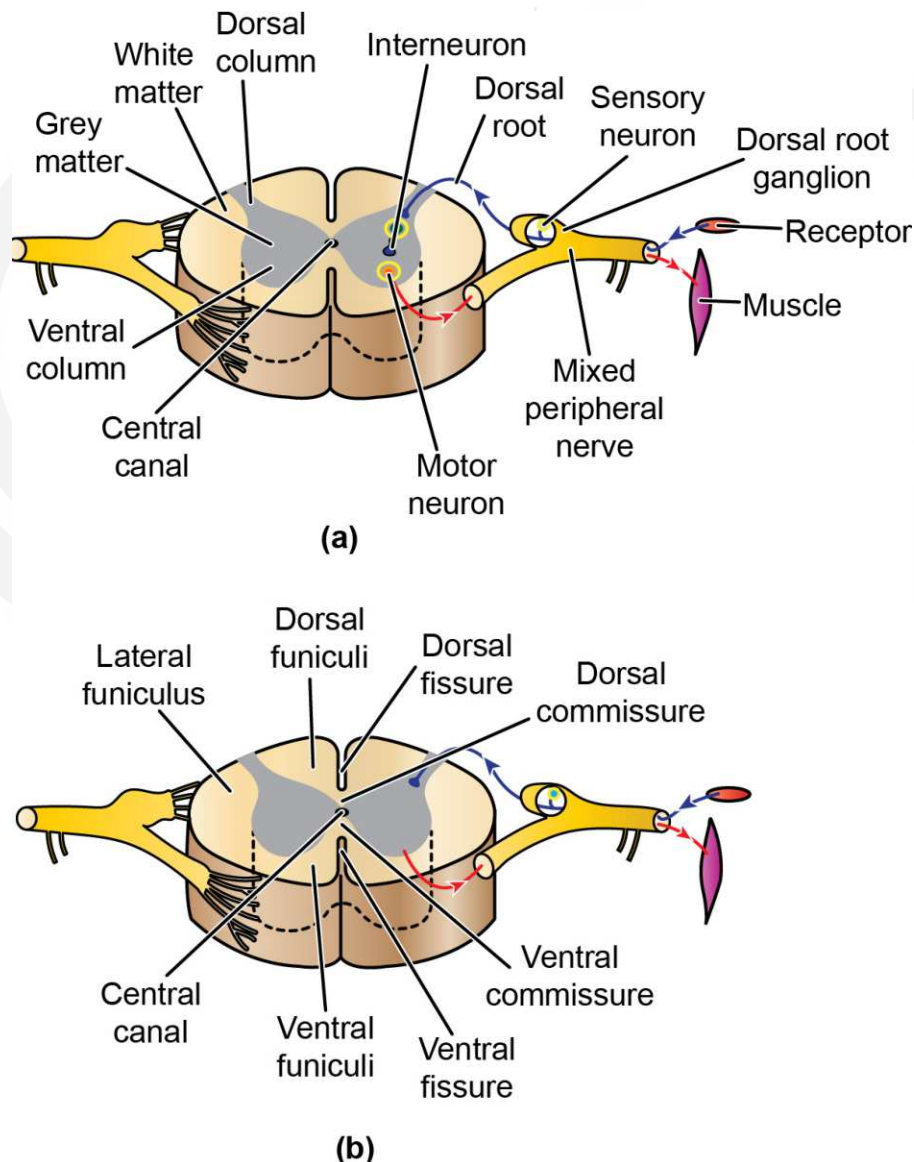
7.3.2 The Spinal Cord

The portion of the neural tube which forms the spinal cord undergoes considerably less modification than that forming the brain. It generally assumes the shape of a more or less cylindrical, but slightly flattened tube. It widens at the anterior end, where it is continuous with the brain stem or medulla oblongata. The posterior end usually tapers down to a fine thread the **filum terminale**.

In cyclostomes and fishes the spinal cord is fairly uniform in diameter but in most tetrapods two prominent swellings or enlargements are seen where the nerves going to the limbs arise. In the anterior part the cervical enlargement is the region where the large nerves supplying the forelimbs arise and the nerves supplying the hind limbs originate from the lumbar enlargement, near the posterior end of the cord. In limbless forms such as snakes neither enlargement is seen.

Grey and white matter of the cord

As you can see in Fig. 7.6 a, the spinal cord is seen to be composed of grey and white matter. The grey matter is almost completely surrounded by the white matter. In amniotes the grey matter is arranged in the shape of the letter 'H'. The portions corresponding to the upper bars of the 'H' extend dorsally and are known as **dorsal columns** and the lower bars, the **ventral columns**. The connecting bar in which the central canal lies forms the **dorsal and ventral grey commissures**, above and below respectively (Fig. 7.6 b).



All functions in the body can be termed as either somatic or visceral. Somatic functions are those carried out by the skin and its derivatives, voluntary muscles and skeletal structures. Visceral functions are performed by other organ system of the body i.e. digestive, respiratory etc.

Fig. 7.6: a) Cross section of spinal cord. See the relative positions of the four columns of grey matter; b) various regions of the spinal cord.

The cell bodies in the dorsal columns are, for the most part, those of interneurons. Their dendrites form synapses with the axons of sensory or afferent nerve fibres which enter the spinal cord via the dorsal roots of spinal nerves.

The axons of the interneurons form synapses with the dendrites of motor or efferent neurons, the cell bodies of which are located in the ventral columns. The somatic sensory fibres carry impulses from somatic tissue to central nervous system. They form synapses with cells in the upper portion of dorsal columns. The visceral sensory fibres form synapses with cells in lower portion of the dorsal column. The cell bodies of somatic motor neurons and fibres are located in the lower portions of the ventral column whereas, the cell bodies of visceral motor neurons and fibres have their origin in the upper and lateral portions of the ventral columns.

The white matter of the cord is arranged in longitudinal columns called **funiculi** which lie outside the grey matter. The funiculi are divided into fibre tracts, composed of medullated fibres, carrying impulses up and down the cord and to and from the brain. Lateral funiculi lie between dorsal and ventral columns, the dorsal funiculus lies between the dorsal septum and dorsal column and a ventral funiculus is located between the ventral fissure and ventral column of grey matter. The two ventral funiculi are connected through the ventral commissure (Fig. 7.6 b). The dorsal funiculi carry the sensory nerve impulses up the cord and to the brain, while those in the ventral funiculi are primarily motor, carrying impulses down the cord and from the brain. The lateral funiculi carry both sensory and motor fibres.

Lower vertebrates do not have such an elaborate arrangement of columns and funiculi. In cyclostomes there is no sharp delineation between grey and white matter as yet in the spinal cord.

SAQ 2

a) Match the following :

- | | |
|-----------------------|-----------------------|
| i) Telencephalon | a) Myelocoel |
| ii) Diencephalon | b) Fourth ventricle |
| iii) Rhombencephalon | c) Lateral ventricles |
| iv) Medulla oblongata | d) Third ventricle |

b) Fill in the blanks with appropriate words from the text.

- i) The dorsal column of the spinal cord has cell bodies of neurons.
 - ii) Sensory nerve fibres enter the spinal cord via the roots.
 - iii) Ventral columns of the spinal cord contain the cell bodies of neurons.
 - iv) carry messages up to the brain while carry messages down the cord from the brain.
-

7.3.3 The Brain

The chordate brain is basically an enlargement of the anterior end of the neural tube. In primitive condition the cell bodies of the neurons comprising the central nervous system are aggregated around the central canal of the neural tube. Although this arrangement persists in the spinal cord, in the brain region, migration of cells to the peripheral areas occurs.

In amphioxus the brain is seen in its simplest form, as a cerebral vesicle. As the vertebrates evolved, their brain grew larger and more complex, and the various parts of the brain developed to suit the specialised demands of their particular environment. For example, cavefish, that live in permanently dark subterranean environments have reduced eyes and the part of the brain which normally receives visual input is correspondingly reduced as well. In salmon, on the other hand the same portion is enlarged as visual information constitutes a large part of the sensory input to the brain.

As mentioned in sub-section 7.3.1, the three primary divisions of the brain are prosencephalon (forebrain), mesencephalon (midbrain) and rhombencephalon (hindbrain). Of these midbrain and hindbrain are often referred to as the brain stem. Each of these divisions may have evolved in association with the major senses (Fig. 7.3a). Forebrain or prosencephalon is related to the sense of smell; midbrain or mesencephalon to sight; and the sense of pressure changes, equilibrium can be related to the hindbrain or rhombencephalon. Cerebral hemispheres, roof of midbrain and cerebellum appeared later as outgrowths of the brain stem and nerve cells migrated into them so that grey matter appears on the periphery in these parts.

Flexures

Primitively, the vertebrate brain was merely a modestly developed anterior region of the neural tube. In the course of evolution, certain flexures or bending of the brain is seen during embryonic development. The anterior end folds downwards giving rise to a **cephalic flexure** (CF) (Fig. 7.5).

Since the brain lengthens more rapidly than other head structures, the bending is influenced by space limitations. In all vertebrates a cephalic flexure occurs in the region of the mesencephalon in such a manner that the derivatives of the forebrain are bent downward at right angles to the rest. The second flexure is **cervical** which occurs near the junction of medulla oblongata and spinal cord. The third **pontine flexure** is found in the region of the metencephalon and is opposite in direction to the other two.

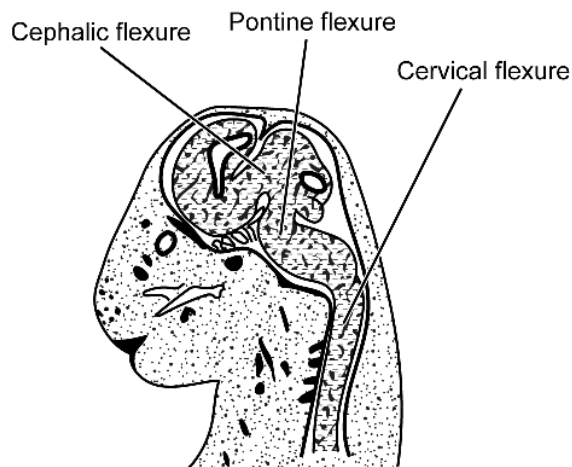


Fig. 7.7: Flexures of the brain as seen in sagittal section of 18 day old rat embryo.

Meninges

Both brain and the spinal cord are surrounded by membranes. These membranes protect and give support to the central nervous system and their complexity increases with vertebrate evolution.

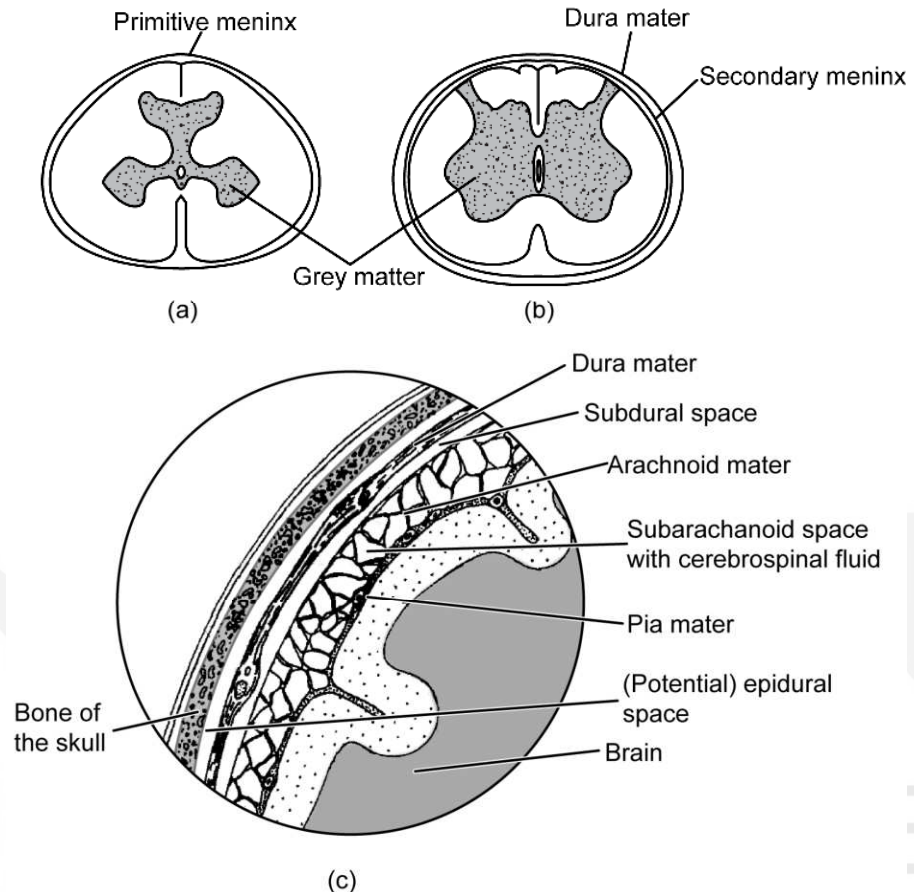


Fig. 7.8: Meninges. a) Meninges of fish consist of only a single thin layer of primitive meninx. b) In all tetrapods except mammals the meninges is double layered. c) Cross section of a triple layered meninges in mammals.

In cyclostomes and fishes (Fig. 7.8 a) a single membrane, meninx primitiva forms a close union with brain and spinal cord. With the adoption of terrestrial life the meninges doubled. In amphibians, reptiles and birds (Fig. 7.8 b), instead of a single meninx, an inner pia-arachnoid layer closely associated with the brain and spinal cord surface and outer dura mater (closest to the bone) is present. The cavity between these two layers is filled with cerebrospinal fluid that protects the brain and spinal cord from shocks during terrestrial locomotion. In mammals (Fig. 7.8 c) the tough dura mater persists and pia-arachnoid membrane differentiates into two layers, an inner pia mater (near the brain) and an outer arachnoid membrane. The pia mater contains blood vessels that supply the underlying nervous tissue. A subarachnoid space filled with cerebrospinal fluid makes its appearance between the pia mater and arachnoid membrane. In the brain region the cranial dura mater fuses with the endorachis and the epidural space and thus disappears. The cerebrospinal fluid, present in the ventricles of the brain, circulates slowly through the various cavities and spaces between the membranes.

The cerebrospinal fluid is derived from blood and returns to it while circulating over the nervous tissue and in the ventricle of the brain.

It is however, devoid of all red blood cells as well as other large formed elements. When a person is injured and trauma to the CNS is suspected, the cerebrospinal fluid sample is taken. If it contains red blood cells then the brain or spinal cord may be damaged.

Grey and white matter of the brain

The grey matter of the brain like the spinal cord consists of nerve cell bodies with their dendrites and proximal portions of their axons. Recall from the diagram of the spinal cord (Fig. 7.6) the grey matter lies in the centre and is surrounded by the white matter, in the brain the grey matter lies on the outside and the white matter forms the interior. In the white matter there are some collections of nerve cell bodies (grey matter) which are known as nuclei. The white matter of the brain consists of tracts of myelinated fibres connecting various parts of the brain and of ascending and descending fibres carrying impulses to and from the spinal cord.

Let us now consider the structure of the vertebrate brain as per its evolution from the primitive chordates to the advanced mammals. It would be better if you would read this description while referring to Figure 7.9 closely.

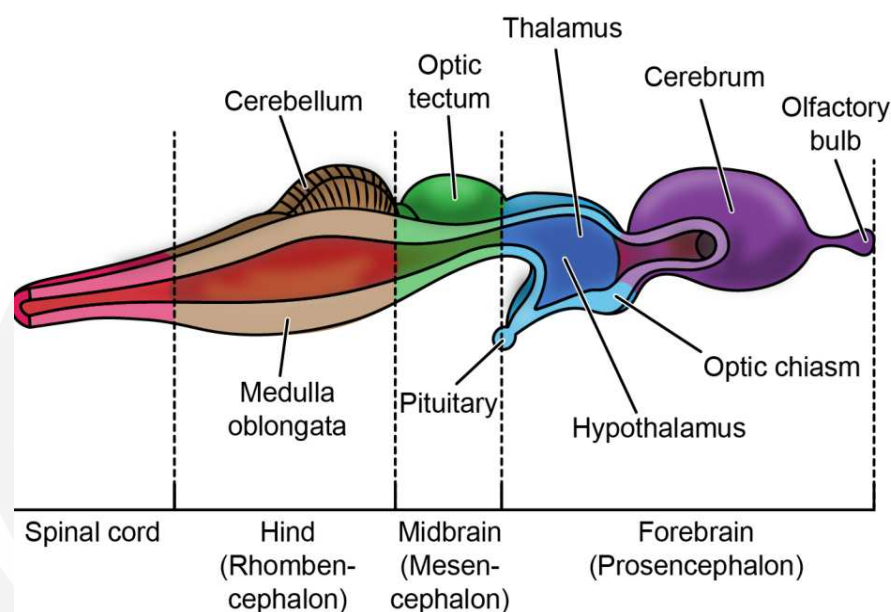


Fig. 7.9: Lateral view of generalised embryonic brain in vertebrates.

Rhombencephalon consists of **myelencephalon** that forms the **medulla** and **metencephalon** that forms the **cerebellum**; **mesencephalon** that forms the **optic tectum**; **prosencephalon** that consists of **diencephalon** that gives rise to **thalamus**, **epithalamus** and **pituitary**; and **telencephalon** that forms the **cerebrum** and **olfactory lobes**.

Hindbrain consists of the **myelencephalon** and **metencephalon** (Fig. 7.9 tan colour). **Myelencephalon** is the posterior most portion of the hindbrain and merges with the spinal cord. It forms the **medulla oblongata**. It is also referred to as the oldest part of the brain as it is well developed in all vertebrates even though other portions may be rudimentary. The general structure of medulla is like the spinal cord except that the central canal enlarges (as the 4th ventricle) and a thin highly vascular roof known as posterior choroid plexus forms dorsal to the central canal. The choroid plexi of the brain produce the cerebrospinal fluid and controls its composition.

The medulla contains important nerve centres or nuclei which control vital physiological functions that are involuntary like heartbeat, respiration and metabolism. It also houses the primary nuclei of cranial nerves. Damage to

the medulla can be life threatening. The dorsal anterior portion of the medulla contains nuclei associated with the nerves from lateral line system (a system of sense organs found in aquatic vertebrates used to detect movement, vibrations and pressure gradient in surrounding water) and inner ear. In terrestrial vertebrates these nuclei are associated with equilibrium and auditory functions of the ear. The medulla also serves as a route for descending and ascending pathways that run from and to the higher brain centres.

Metencephalon is the anterior part of the hindbrain, the dorsal part of which becomes elevated and thickened to form the **cerebellum**. The cerebellum is highly developed in animals that are active and whose balance and precise motor movements are well developed whether in water, air or on land.

The function of the cerebellum is to monitor and modify motor outputs but it does not initiate them. It operates at an involuntary level and maintains equilibrium. Information regarding touch, vision, hearing, proprioception (related to limb position, joint angle, state of muscle contraction) and motor input from higher centres of the brain are processed in the cerebellum. The cerebellum is involved in maintaining the positional equilibrium of an organism when it flies, jumps, swims in a three dimensional world in space in relation to gravity. Another function of cerebellum is refinement of motor action, a damaged cerebellum may still allow the organism to move but the movement would be uncoordinated. The size of the cerebellum is proportional to its role. In fishes and amphibians (salamanders) the cerebellum is small and simple, as their locomotion is simple and mainly co-ordinated by the spinal reflexes. In advanced tetrapods such as mammals and birds, there are so many cells in the cortex that it is folded. The increase in cells also increases the number of fibres and these fibres form bulging masses. The ventral side of metencephalon of mammals and some birds is composed of a prominent mass of transverse nerve fibres known as **pons**. Motor fibres from cerebral cortex pass via the pons to the cerebellum.

Midbrain (Figs. 7.9 green colour) or **mesencephalon** is marked off from the hindbrain very early in development by a conspicuous constriction, the isthmus. The floor and walls of the mesencephalon are thick and composed of fibre tracts called cerebral peduncles connecting forebrain and hindbrain. The roof consists of a thick layer of grey matter, the **optic tectum**. The central canal of the midbrain is of a relatively small diameter forming a canal the cerebral aqueduct between the hindbrain and midbrain. In lower vertebrates two optic lobes arise from the roof. The optic lobes in lower vertebrates serve as centres for the visual sense. In higher forms however the optic lobes are practically solid and the roof is known as **tectum**.

In fishes and amphibians the midbrain is often the most prominent region of the brain as all visual information is received here directly from the eyes. The anterior region of tectum in snakes and mammals is specialised into superior colliculi which serves to integrate visual inputs and posterior region is known as inferior colliculi, which integrates auditory inputs. Thus, visual information in all vertebrates reaches the forebrain via the tectum. In mammals however, due to development of cerebral hemispheres the superior colliculi are less important as visual centres.

Forebrain consists of the **diencephalon** and the **telencephalon**.

Diencephalon is the initial portion of the forebrain and regulates many bodily functions. It contains the expanded neural canal or third ventricle (Figs. 7.9 blue colour) with a thin dorsal roof, the **epithalamus**, the walls form the **thalamus** and the floor forms the hypothalamus (Fig. 7.10). Each is thickened by the presence of a proliferation of neurons. The epithalamus is made up of a **parietal body** or **parapineal body** and **pineal gland** in lower vertebrates. The parietal body is absent from higher vertebrates, only the pineal body or gland is present in all (Fig. 7.10). The pineal body affects skin pigmentation in lower vertebrates and probably affects photoperiod. In higher vertebrates it is important in controlling biological rhythms. The thalamus contains a number of cell clusters that are important in co-ordinating sensory impulses from all parts of the body, except olfactory impulses that go directly to the cerebral cortex. The thalamus is actually a relay centre for all sensory information going to the cerebral cortex. The anterior part of the roof of the diencephalon forms the anterior choroid plexus.

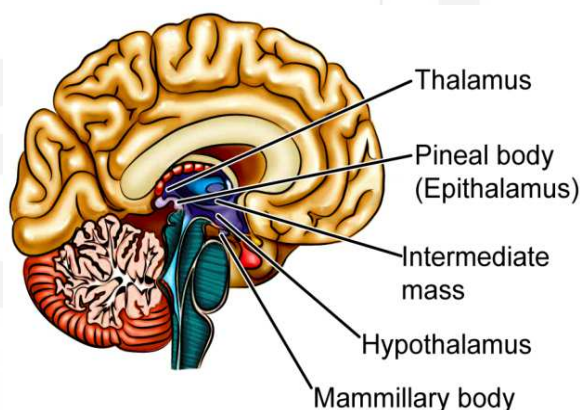


Fig. 7.10: Forebrain in mammal.

The hypothalamus is the most ventral portion of diencephalon. This includes the posterior **pituitary** (neurohypophysis). Hypothalamic nuclei are involved in maintaining the body's internal homeostasis. They regulate appetite, sexual activity, body temperature, water balance and alertness and some aspects of emotional behaviour. Hypothalamus stimulates the pituitary gland to regulate many homeostatic functions.

Telencephalon (Fig.7.9 purple colour) or **cerebrum** is the terminal portion of the forebrain. It shows the greatest difference in degree of development among vertebrates. In primitive vertebrates the forebrain is mainly concerned with integrating sensory inputs from nasal olfactory sensors which are important in complex aspects of behaviour.

In the course of development from both sides of telencephalon arise the each of the paired **cerebral hemisphere** with its associated **olfactory bulb** develops from the telencephalon. The neural canal extends into the lateral ventricles of the cerebral hemispheres. The seat of consciousness lies in the cerebral hemispheres. The nerve centres controlling the activities which characterise the highly developed psychic life of humans, such as intelligence, thought and sensation are located in this region.

In neurophysiology a nucleus is a small cluster or aggregate of nerve cell bodies within the central nervous system.

Decussation:

Commissures serve to connect similar regions in the left and right sides of the central nervous system, and make bilateral integration possible. There are also fibre tracts in the brain which in their course, cross over, or decussate to the opposite side. Injury to one side of the brain often results in paralysis of muscles of the opposite side.

At the anterior end of each cerebral hemisphere is an outgrowth called the **olfactory lobe**. The olfactory lobe may come in contact with the nasal apparatus. In the lowest living vertebrates, the hemispheres are divided into an anterior and posterior olfactory lobe, concerned mainly with receiving olfactory impulses. The size of the cerebral hemisphere increases as we go up the evolutionary ladder from primitive vertebrates to advanced vertebrates. In all vertebrates the floor of each hemisphere differentiates into a thickened **corpus striatum** which is best developed in reptiles and birds. This becomes the **corpus callosum** in mammals which becomes a relay center for involuntary response. The grey regions of corpus striatum are often referred to as **basal nuclei**. The remainder of the hemisphere consists of a pallium which forms a roof over the lateral ventricles. In fishes it is present only on its inner walls adjacent to the ventricle and the telencephalon serves mainly as an olfactory centre. As the vertebrates evolved further, there is an increasing tendency for nerve cells from the inner grey layer to migrate out into peripheral area. The first real change is seen in reptiles. The cerebral hemispheres enlarge in size and extend backwards to cover partially the diencephalon and increased grey matter migrates to the periphery. A new area the **neopallium** appears in the reptiles and this is what forms the large cerebral cortex in mammals. In crocodile for the first time nerve cells migrate to the outer surface in the neopallium and form the true cerebral cortex.

In mammals the neopallium enlarges enormously and the grey cell bodies form a layer of grey matter which even in humans is only a few centimetres thick. In all vertebrates below mammals, the cerebral hemispheres though large, are smooth. In many mammals the surface becomes convoluted or folded. The ridges are called **gyri** and depressions **sulci**. These convolutions increase the surface area and total amount of grey matter. Larger mammals have more convolutions though these are not necessarily connected to intelligence!

SAQ 3

a) Match the following correctly.

- | | |
|-------------------|---------------------------------------|
| i) Metencephalon | a) Medulla oblongata |
| ii) Mesencephalon | b) Cerebellum |
| iii) Diencephalon | c) Optic tectum |
| iv) Telencephalon | d) Epithalamus, hypothalamus thalamus |
| v) Myelencephalon | e) Cerebrum |

b) Fill in the blanks:

- i) In fishes the covers the brain and spinal cord.
- ii) Reptiles and birds have a double membrane made up of and to protect the brain.
- iii) In mammals the layers of the meninges are called and
- iv) In lower vertebrates the epithalamus forms and

7.4 PERIPHERAL NERVOUS SYSTEM

The nerves and ganglia which form connections with the central nervous system and which are distributed to all parts of the body, comprise the peripheral nervous system or PNS. It consists of two divisions:

- i) **Sensory-Somatic nervous system** composed of cranial and spinal nerves. Both contain nerve fibres connected to the sensory receptors, skin and internal organs that bring information to the CNS and motor neurons that take signals to the skeletal muscles from the CNS. The somatic system also provides us with automatic reflex actions that does not involve the attention of brain.
- ii) **Autonomic nervous system** made up of the PNS distributed to structures under involuntary control. Connection with the central nervous system is mediated via the paired spinal and cranial nerves (motor and sensory).

7.4.1 Spinal Nerves

Spinal nerves are mixed nerves which arise from the spinal cord. Each spinal nerve connects to the spinal cord by means of two roots, dorsal and ventral (Fig. 7.11).

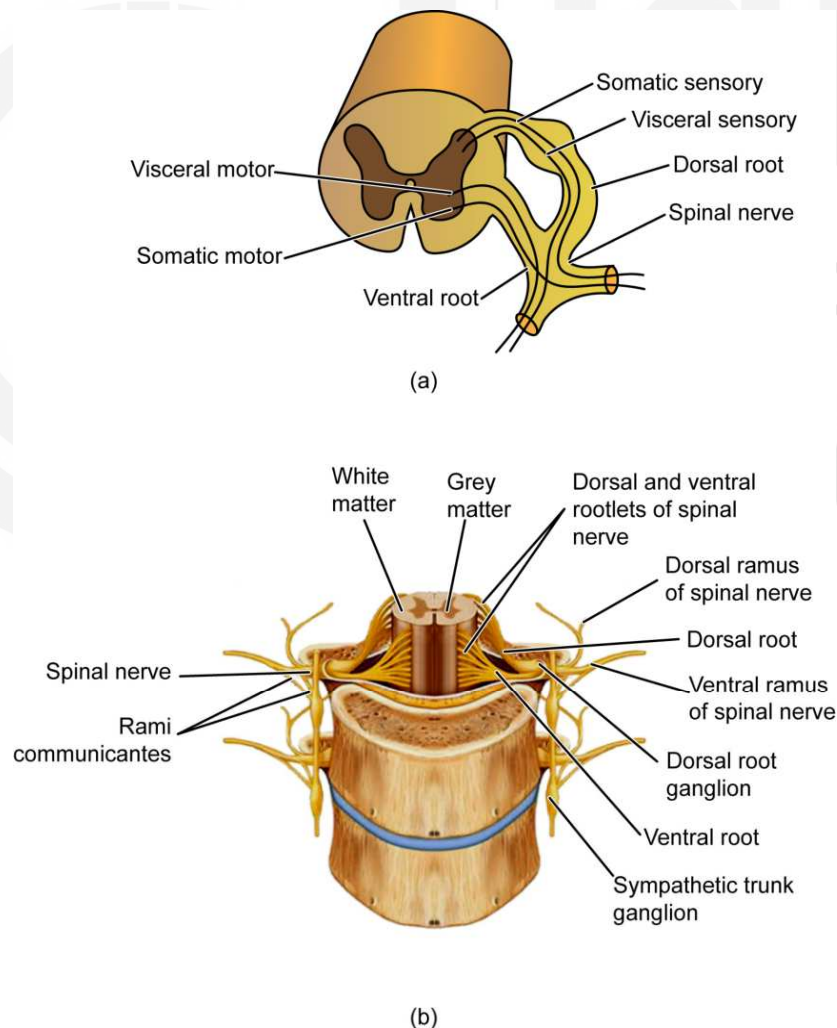


Fig. 7.11: Spinal cord and spinal nerve anatomy. a) Sensory and motor routes in the spinal nerve; b) Dorsal and ventral roots connect the spinal nerve to the spinal cord. Spinal nerve joins the autonomic chain ganglion through a communicating ramus.

The sensory nerve fibers of spinal nerve travel towards the spinal cord via the dorsal roots and are spoken of as **afferent fibres**. The sensory fibres are said to be either somatic or visceral. Somatic sensory fibres are those coming from the skin and its derivatives, voluntary muscles and skeletal structures. They form synapses with cells in the somatic sensory column of grey matter. Visceral sensory fibres from visceral structures (internal organs of the body) terminate in the visceral sensory column of the grey matter of the cord (see Fig. 7.11 b again).

Cell bodies of the neurons making up the ventral roots lie in the grey matter of ventral columns of the spinal cord. In motor fibres, impulses are conveyed away from the spinal cord; hence they are referred to as **efferent fibres**. Somatic motor fibres arise in the somatic motor column of grey matter in the spinal cord and are distributed to somatic structures. Visceral motor fibres pass to autonomic ganglia, where they form synapses with motor autonomic neurons (Fig. 7.11 b).

The dorsal roots are strictly sensory in the amniotes. In lamprey dorsal roots are composed of both sensory and motor fibres. In fishes and amphibians visceral efferent fibres pass through both dorsal and ventral roots.

Near the area where dorsal and ventral roots unite to form spinal nerves, three rami are usually given off. These include 1) a dorsal ramus supplying skin and muscles of dorsal part of the body, 2) a ventral ramus distributed to the ventral and lateral regions, and 3) a visceral ramus that forms connections with one of the chain ganglia of the peripheral autonomic nervous system (Fig. 7.11 b). Both dorsal and ventral rami are composed of somatic sensory and somatic motor fibres.

A typical visceral ramus consists of a white ramus and a grey ramus. The white ramus carries medullated visceral sensory and medullated preganglionic motor fibres. The grey visceral ramus carries only non-medullated postganglionic autonomic motor fibres. The fibres of grey ramus join the spinal nerve and travel out either via dorsal or ventral rami where they supply structures under involuntary control such as blood vessels, muscles and glands of the skin.

7.4.2 Cranial Nerves

The peripheral nerves which form connections with the brain are called cranial nerves. There are 10 pairs of cranial nerves in anamniotes and 12 in amniotes. All but the first four are joined to the medulla oblongata. Some are entirely sensory, composed of afferent fibres alone; others are purely motor. Still others are mixed nerves, consisting of both motor and sensory fibres. The nature and distribution of different cranial nerves is given Table 7.1.

Early human anatomists assigned cranial nerve numbers in an anteriorposterior sequence. This system has now proved to be artificial and superficial but continues because of convenience and familiarity. Later in 1894 a new cranial nerve was discovered which was numbered 0 to preserve the terminology of 1-10, or 1-12.

Table 7.1: Cranial nerves, their nature and distribution.

Number	Name of the Cranial nerve	Nature of the cranial nerve	Distribution of the cranial nerve to various organs
0	Terminal	Somatic Sensory	From olfactory mucous membrane to Jacobson's organ (Best developed in elasmobranch fishes).
I	Olfactory	Special somatic Sensory	From Olfactory epithelium, olfactory lobes, Jacobson's organ.
II	Optic	Special somatic Sensory	From retina to optic bulb in brain optic tectum. (actually a fibre tract of brain rather than nerve)
III	Oculomotor	Somatic Motor	To four of the six eye muscles.
IV	Trochlear	Somatic Motor	To superior oblique eye muscle.
V	Trigeminal	Mixed	From Skin, dorsal side of head and snout, conjunctiva, cornea, iris, ciliary body, lachrymal gland, nose and forehead skin, eyelid.
	Maxillary	Somatic Sensory	From upper jaw, upper lip, lower eyelid, teeth of upper jaw.
	Mandibular	Mixed	From lower lip, teeth of lower jaw, skin of temporal region, external ear, lower part of the face to muscles used in chewing.
VI	Abducens	Somatic Motor	To eye muscle, nictitating membrane.
VII	Facial	Mixed	To muscles of face, scalp, external ear, lacrimal gland, mucous membrane of nose
VIII	Auditory	Special somatic Sensory	From inner ear.
IX	Glossopharyngeal	Mixed	From posterior region of tongue and taste buds.
X	Vagus	Mixed	To lower jaw and throat, larynx and salivary glands.
XI	Spinal accessory	Visceral Motor	To pharynx, larynx, (Considered as posterior branch of vagus)
XII	Hypoglossal	Somatic Motor	Muscles of tongue and muscles below the tongue in the lower jaw

Even though autonomic system is not under voluntary control, conscious centres also can affect visceral activity controlled by the autonomic nervous system. For example, through practice of meditation or through deliberated effort it is possible to affect the heart beat or release of sweat. The ancient yogis mastered the art.

7.4.3 Autonomic Nerves

The autonomic portion of the peripheral nervous system is composed of both sensory and motor fibres. Autonomic sensory fibres monitor the internal environment of the organism, that is, blood pressure, partial pressure of oxygen and carbon dioxide (tension), core and skin temperature and activity of the viscera, while the autonomic motor fibres send impulses to smooth muscles and glands in various parts of the body. Autonomic nervous system regulates the functions of structures which are under involuntary control. The proper functioning of this part of the nervous system is necessary for regulating such activities as rate of heartbeat, respiratory movements, composition of body fluids, constancy of temperature, secretion of various glands, peristalsis, and other vital processes and it is controlled by hypothalamic centres.

The system is composed of preganglionic and postganglionic fibres and a number of ganglia which serve as relay centres (Fig. 7.12).

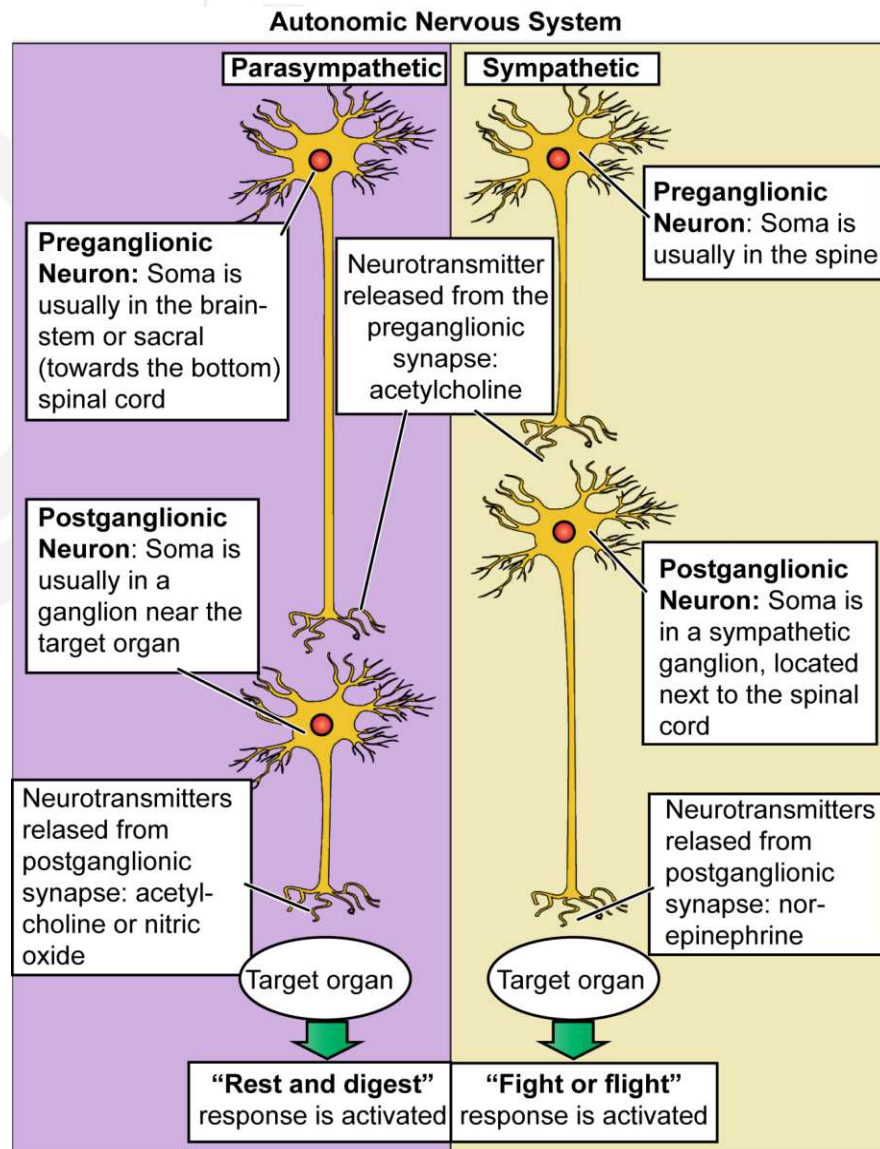


Fig. 7.12: Autonomic nervous system. *Left* parasympathetic division. *Right* sympathetic division.

The cell bodies of the preganglionic neurons are located in the visceral motor column of grey matter in the central nervous system. Their medullated fibres pass to outlying ganglia. Postganglionic neurons have grey nonmedullated axons. The cell bodies of these neurons, lie in outlying ganglia which are often located at some distance from the central nervous system. It is here, that the preganglionic fibres form synapses with the dendrites of postganglionic neurons.

The autonomic portion of the peripheral nervous system is divided into two main parts, the sympathetic and parasympathetic system. The essential features of both the systems are summarised in Figure 7.12.

Both these systems work antagonistically. The sympathetic system functions to strengthen the body reactions against adverse condition, it calls for expenditure of energy. The parasympathetic system is concerned with restoring and conserving energy. In mammals, almost every visceral organ has sympathetic and parasympathetic innervation except the adrenal gland, peripheral blood vessels and sweat glands; all of which receive only sympathetic innervation. Cessation of sympathetic stimulation allows these organs to return to resting state.

Post ganglionic axons of the sympathetic system except those going to uterus and sweat glands secrete norepinephrine or epinephrine (also known as noradrenaline or adrenaline). The postganglionic axons of the parasympathetic system release the neurotransmitter acetylcholine. Acetylcholine is also released between pre- and post ganglionic fibres in both these divisions of the autonomic system (Fig.7.12).

The sympathetic and parasympathetic functional components are clear in mammals; however, in other vertebrates their comparative anatomy is not well understood.

Functions of sympathetic system

- 1) Constriction of cutaneous blood vessels, causing pallor.
- 2) Contraction of pili muscles, causing "goose flesh" and causing the hair to stand erect.
- 3) Secretion of sweat glands.
- 4) Dilation of pupil.
- 5) Reduction in amount of saliva secreted.
- 6) Acceleration of heartbeat.
- 7) Dilation of the bronchi.
- 8) Relaxation or inhibition of the smooth muscles of the digestive tract.
- 9) Relaxation of bladder musculature.
- 10) Contraction of the sphincter muscles of the bladder.

- 11) Increase in blood sugar, red corpuscles in the blood stream.
- 12) Rise in blood pressure.
- 13) Decrease in clotting time of blood.

The above reactions together are usually associated with pain, anger, fear and gear up the body to react suitably to these situation.

Functions of the parasympathetic system:

- 1) Dilation of blood vessels (except the coronary vessels of the heart).
- 2) Constriction of the pupil.
- 3) Increase in salivary and gastric secretion.
- 4) Constriction of bronchi.
- 5) Contraction of walls of the digestive tracts.
- 6) Contraction of bladder musculature.
- 7) Relaxation of the sphincter muscles of the bladder.
- 8) Dilation of blood vessels of the external genital organs.

These reactions when taken together are associated with sensations of pleasure or comfort and conserve energy. The general scheme of arrangement of autonomic system is similar in all tetrapods except that it starts from the representation in a primitive form in lower vertebrates and increases in complexity as the evolutionary scale is ascended.

SAQ 4

- a) i) Which of the cranial nerves are purely sensory in nature?
ii) Which part of the peripheral nervous system controls visceral activity?
- b) A nerve carrying information about the condition of internal viscera to the central nervous system is a nerve.
- c) Which of the activities given below are controlled by sympathetic or parasympathetic part of the autonomic nervous system?
 - i) dilation of pupil,
 - ii) increase in heartbeat
 - iii) constriction of bronchi,
 - iv) contraction of bladder muscles,
 - v) increase in blood sugar, and
 - vi) decrease clotting time of blood.

7.5 BRAIN – A COMPARATIVE ACCOUNT

You learnt in earlier sections that all vertebrates share the major brain divisions, ten or more cranial nerves, spinal nerves and major spinal pathways to and from the brain. As we examine the vertebrates from cyclostomes to mammals we find that the structure of brain undergoes various modifications along with the evolution of major head sense organs (eyes, ears, nose, taste and lateral line system). The brain acquired major functions that were not found in primitive forms.

As we compare the brains of various vertebrate classes (see Fig. 7.13) we find that the hindbrain has become specialised for processing sensations from touch, taste and balance from the near environment while the mid- and forebrain have become specialised for processing sensations from the eyes, and nose from the distant environment.

7.5.1 Jawless Vertebrates

The brains of lamprey (Fig. 7.13) and hagfish have a well developed hindbrain that suggests that its functions are the most important. The cerebellum is small and the forebrain is mostly concerned with olfaction. This suggests limited locomotor abilities but highly developed sensory abilities, which is what is required in their environment.

7.5.2 Jawed Vertebrates

The medulla is well developed in all jawed vertebrates showing its connections with the visceral network and as a screen through which all the information enters or leaves the brain.

The cerebellum is distinct in cartilaginous fishes with one or more transverse fissures. In teleosts the cerebellum is large in actively swimming fishes and relatively small in inactive fishes.

Amphibians often have small or rudimentary cerebellum (Fig. 7.13) reflecting simple locomotory abilities. In advanced tetrapods, the lateral part of the cerebellum expands to control the muscles of the appendages which are specialised for locomotion.

Cerebellum is seen in alligators amongst reptiles, and becomes more prominent in birds and mammals, again reflecting their complex locomotor abilities.

In mammals the sides of the cerebellum expand into separate hemispheres (Fig. 7.13). In primates, as in no other vertebrates the most lateral part is associated with finger coordination.

The midbrain optic tectum in particular is large in vertebrates that depend on their visual abilities but in mammals it is relatively small as visual functions are taken over by the cerebral hemispheres. In primitive vertebrates the midbrain is relatively important as a principal centre of integration and its sensory link to the cerebrum through thalamus is extremely well developed in amniotes especially in mammals.

The cerebrum is relatively small in all fishes. Olfactory bulbs and a thin walled pallium is present in cartilaginous and bony fishes. In fishes the cerebrum is mainly associated with olfaction. In amphibians the pallium is thicker than fishes.

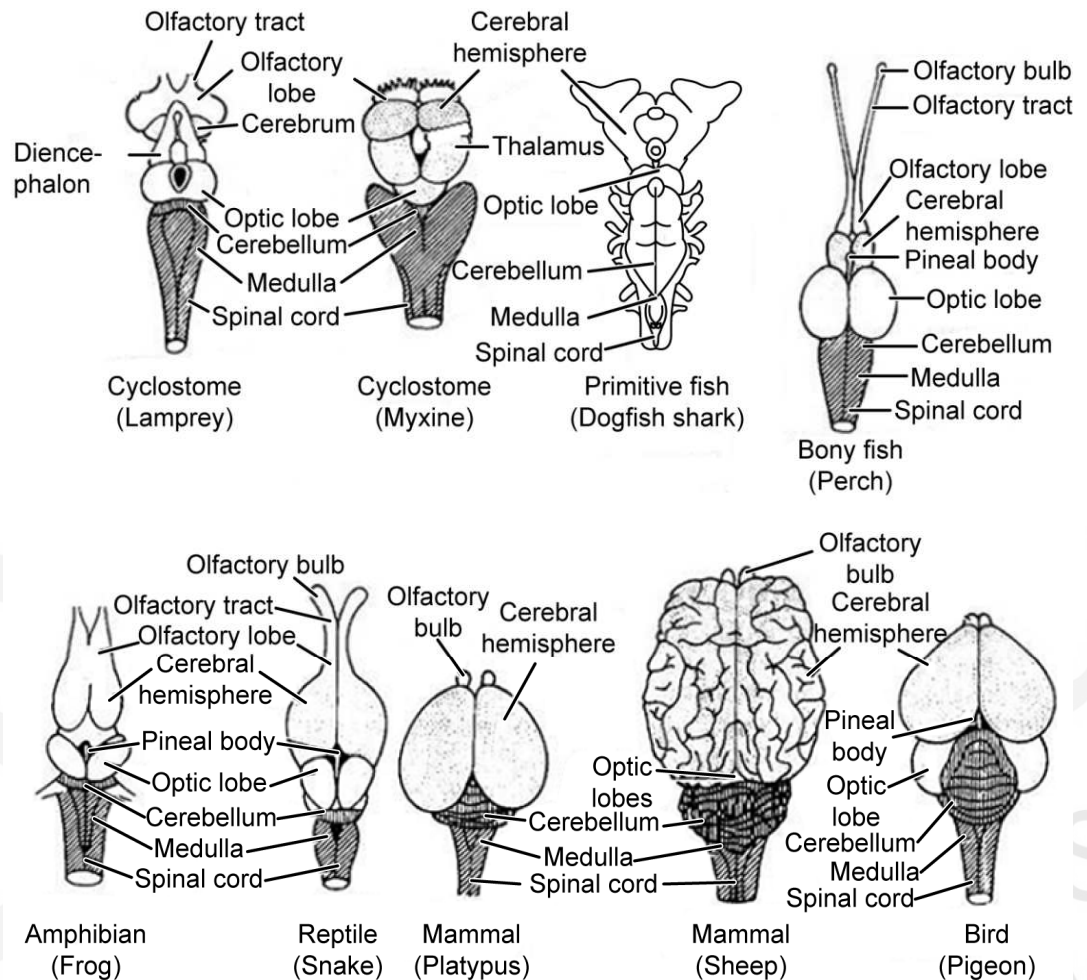


Fig. 7.13: Vertebrate brains (dorsal view) showing the relative size and position of the major parts of the brain. Note that the maximum changes and expansion is seen in the cerebrum and cerebellum.

The first change in the cerebral hemisphere is seen in reptiles with the migration of the inner nerve cells to the peripheral areas. The cerebral hemispheres enlarge greatly and grow backwards to cover partially the diencephalon. The olfactory lobes merge with the cerebral hemispheres. In crocodiles the first emergence of a true cerebral cortex or neopallium is seen. In birds the olfactory lobes are rudimentary. Neopallium, however, is absent in birds. The cerebral hemispheres are large because the corpus striatum of birds is unusually large.

In mammals, particularly in human beings the cerebral cortex is the most highly developed. The neopallium has taken over the greater part of the expanded and highly convoluted surface of the hemispheres and because of this expansion, the hemispheres tend to cover the other brain structures. Beginning with marsupials, a broad white mass the corpus callosum appears in mammals between the two hemispheres. It consists of medullated fibres and connects the neopallial cortex of the two sides.

SAQ 5

Choose the correct word from the parenthesis.

- a) Olfactory lobes are well developed in (**birds/mammals**).
- b) Neopallium is first seen in (**birds/reptiles**).
- c) Cerebellum is most well developed in (**reptiles/mammals**).
- d) Optic tectum is not an important visual centre in (**fishes/mammals**).
- e) (**Hind/ mid brain**) is the most primitive part of the brain.

7.6 SUMMARY

After studying this unit you have learnt that:

- The nervous system is derived from the neural tube and neural crests which appear very early in embryonic development.
- The basic unit of the nervous system the neuron is specialised to receive, integrate and transmit information. The neuron consists of a cell body with branching processes arising out of it known as dendrites, and a single process known as axon. Dendrites receive information. Axons carry information from the neuron to other neurons and target organs. These neurons can be classified into different types according to their structure and functions.
- The nervous system of vertebrates has two main divisions a) the central nervous system composed of brain and spinal cord that are covered by protective membranes known as meninges; b) the peripheral nervous system, made up of paired cranial and spinal nerves and the autonomic system, consisting of portions of certain cranial and spinal nerves, as well as outlying ganglia connected with those structures of the body under involuntary control.
- Nervous system pathways are composed of bundles of axons that are mostly medullated. In the central nervous system grey matter is formed of the nerve cell bodies and white matter is formed of the axons of the neurons. Aggregations of nerve cell bodies in the central nervous system are called as nuclei and those in the peripheral nervous system are known as ganglia.
- In lower forms, brain and spinal cord are disposed in a straight line. In higher forms, flexures or bends occur which make possible the accommodation of a larger mass of nervous tissue within relatively narrow confines of the cranium.
- The spinal chord serves two functions, it connects the brain to the rest of the body and it is involved in spinal reflexes that are responses to a stimulus without the involvement of the brain.

- The brain of all vertebrates can be divided in three portions known as forebrain, midbrain and hindbrain. The oldest part is the hindbrain, It is responsible for vital functions of the body including equilibrium. Midbrain is responsible for visual senses; forebrain regulates many functions of the body and is the center for coordinating all the sensory information received from the body.
- In the peripheral nervous system the spinal nerves are paired. Most spinal nerves give off three branches or rami and bring sensory information to the spinal cord which is conveyed to the brain and take back motor instructions to the muscles, organs and glands via motor nerve fibers.
- The paired cranial nerves, arising from the brain, number 10 in anamniotes and 12 in amniotes. Some cranial nerves are purely sensory (I, II and VIII, and other are purely motor (III, IV, VI, XI, XII). The remainder (V, VII, IX, X) are mixed (sensory and motor).
- The autonomic nervous system is made up of sympathetic and parasympathetic components. Each consists of preganglionic and postganglionic system. The sympathetic and parasympathetic nerves have antagonistic functions.
- When we compare the brain of all vertebrate groups we find they have the same basic divisions but as they evolved the structure and function has modified in different groups according to their requirements. In sharks and other fishes, the hindbrain is predominant, and the rest of the brain serves primarily to process sensory information. In amphibians and reptiles, the forebrain is far larger, and it contains a larger cerebrum devoted to associative activity. In birds, which evolved from reptiles, and in mammals the cerebrum is even larger. The dominance of the cerebrum is greatest in humans, where it envelops much of the rest of the brain.

7.7 TERMINAL QUESTIONS

1. Make a flow chart to show the primary divisions of the nervous system and their subdivisions.
2. Name the flexures and their position, that are present in vertebrate central nervous system.
3. List the cranial nerves of special senses and the nerves that innervate the eye muscles.
4. What are the components of the dorsal and ventral column in the spinal cord?
5. Which part of the brain is well developed in all vertebrates and why?
6. With which parts of the brain are the essential senses of smell sight and hearing associated?

7.8 ANSWERS

Self-Assessment Questions

1.
 - a) Brain is formed mostly of grey matter except the medullated tracts while spinal cord is formed of both grey and white matter.
 - b) Myelin sheaths are secreted by Schwann cells and oligodendrocytes.
 - c) Myelin sheaths are found both in brain and spinal cord.
 - d) White and grey matter intermingled in the brain forms the reticular formation.
 - e) Astrocytes form the blood brain barrier
2.
 - a) Telencephalon matches lateral ventricles
Diencephalon matches third ventricle
Rhombencephalon matches fourth ventricle
Medulla oblongata matches myelocoel
 - b)
 - i) sensory
 - ii) dorsal roots
 - iii) motor neurons
 - iv) dorsal funiculi, ventral funiculi
3.
 - a)

Metencephalon	-	cerebellum
Mesencephalon	-	optic tectum
Diencephalon	-	epithalamus, thalamus, hypothalamus
Telencephalon	-	cerebrum
Myelencephalon	-	medulla oblongata
 - b)
 - i) meninx primitiva
 - ii) dura mater and pia arachnoid
 - iii) dura mater, pia mater, arachnoid
 - iv) parpineal body/parietal body and pineal gland
4.
 - a)
 - i) O, (Terminal); I, (Olfactory); II (optic); VIII (auditory)
 - b) autonomic motor
 - c) Dilation of pupils – sympathetic
increase in heartbeat – sympathetic
constriction of bronchi – parasympathetic

contraction of bladder muscles – parasympathetic

increase in blood sugar – sympathetic

decrease in clotting time – sympathetic

5.
 - i) mammals
 - ii) reptiles
 - iii) mammals
 - iv) mammals
 - v) hindbrain

Terminal Questions

1. The primary subdivisions of the nervous system are:

- i) central nervous system and the
- ii) peripheral nervous system.

The subdivisions of the central nervous system are composed of brain and the spinal cord and the peripheral nervous system consists of spinal nerves, cranial nerves and autonomic nerves.

2. Three types of flexures are present in vertebrates:

- i) A cephalic flexure between forebrain and midbrain,
- ii) A cervical flexure near the junction of medulla oblongata and spinal cord.
- iii) A pontine flexure in the region of metencephalon.

3. Terminal nerve, olfactory nerve and the optic nerves are termed as the nerves of special sense.

Occulomotor, trochlear and abducense nerves innervate the eye muscles.

4. In the spinal cord, the dorsal column is composed of upper somatic sensory and lower visceral sensory regions. The ventral column in turn, is composed of upper visceral motor and lower somatic motor regions.
5. Myelencephalon or medulla is the oldest part of the brain and well developed in all vertebrates as it controls the vital functions of the body, including the involuntary functions and equilibrium.
6. Smell with the olfactory lobe in telencephalon: sight with the optic tectum in midbrain and hearing with the hind brain

SENSE ORGANS |

Structure

8.1	Introduction	8.5	Olfactory Organs of Vertebrates
	Objectives		Olfactory System in Humans
8.2	Sensory Receptors and Sense Organs		Comparative Olfactory System of Vertebrates
	Types of Sensory Receptors	8.6	Specialised Sensory Organs
	Sensory Organs		Lateral Line System in Fishes
8.3	Photoreceptor Organs of Vertebrates		Pit Organs in Snakes
	Parietal Eye		Echolocation in Aquatic (Dolphins) and Aerial Mammals (Bats)
	Vertebrate Eye	8.7	Summary
	Comparative Anatomy of the Vertebrate Eye	8.8	Terminal Questions
8.4	The Vertebrate Ear	8.9	Answers
	Auditory System of Mammals		
	Vestibular Apparatus		
	Comparative Anatomy of the Ear		

8.1 INTRODUCTION

In the previous unit 7 you had studied about the organisation of the nervous system of vertebrates, and learnt that the functional unit of the nervous systems is the 'neuron'. One kind of neuron that you studied is the sensory neuron that responds to the external and internal stimuli. The sensory neurons form the sensory receptors which may be wide spread in the body or may be in the form of specialised organs called the sense organs. Sensory receptors and sense organs receive external and/or internal environmental information and convert and transmit this information in the form of electrical impulses to the nervous system. In the present unit we will describe the three basic types of sense organs namely, the optic, auditory and olfactory organs which are used for seeing, hearing and smelling respectively in vertebrates.

Some vertebrate groups have specialised sense organs that have evolved to suit their special mode of life and these too will be discussed briefly in this unit so that you can understand how these organs help animals respond to sensory stimulus.

Objectives

After studying this unit you should be able to:

- ❖ describe and illustrate the structure of eye, internal ear and olfactory organs in vertebrates;
- ❖ explain the functions of sense organs in vertebrates; and
- ❖ describe specialised sensory organs of vertebrates and relate their role to their habitat.

8.2 SENSORY RECEPTORS AND SENSE ORGANS

In Unit 7, you learnt about the organisation of the nervous system of vertebrates. You will recall that the peripheral nervous network of the vertebrates receives information in the form of sensory signals from various 'sensory receptors. These sensory signals or **stimulus or energy** in the form of sensations or impulses are relayed to the central nervous system or brain which interprets them as sensation.

The sensory information that is sent to the sensory receptors and sense organs may be information about the; i) **quality of stimulus** (such as colour of light, static pressure, heat, cold, sweat, taste, pain, etc.) and/or ii) the **intensity of stimulus** (e.g. brightness, how strong) and /or iii) the **spatial patterns** (location, orientation, distribution).

The sensory neurons as you will recall from the previous unit are specialized nerve cells, and are also called sensory receptors. The sensory receptor functions as a transducer (a device that translates energy from one form into another). Most sensory receptors convert mechanical or light or chemical stimuli or energy into electrical impulses. These sensory receptors as you would recall can detect and transmit information about the external and internal environment to the peripheral or central nervous system.

The tip of the sensory nerve fiber is often, associated with tissues that amplify the stimulus and thus, enhance the sensitivity of the receptor.

8.2.1 Types of Sensory Receptors

The various sensory receptors in the vertebrate body can be broadly classified in different ways : i) on basis of their distribution, ii) on basis of their location, and iii) on basis of the kind of energy they are able to perceive. According to these receptors can be classified and described as follows:

1) Classification of sensory nerve receptors on the basis of their distribution in the body.

The receptors (Fig. 8.1) which are widely distributed throughout the body are termed as **general sensory receptors**. These receptors are involved with the sensations of touch, temperature and proprioception (perception or awareness of the position and movement of the body). General receptors may be of three anatomical categories – (a) free or (b) encapsulated or (c) associated with nerve endings as given in Table 8.1.

Table 8.1: Classification of the General sensory organs.

Sl. No.	Types of General Sensory receptors	Description
1.	Free sensory receptors	The terminus of the sensory neuron process lacks any specialized association, and so is termed as a free nerve ending or free sensory receptor . At its terminus, the free nerve ending may arborize (branch) in order to extensively increase the area to be monitored. Free sensory receptors are primarily concerned with sensations that are interpreted as painful, but can also be stimulated by extremes of heat or cold. Tissue damage can lead to swelling and to direct stimulation of the free sensory receptor.
2.	Encapsulated sensory receptors	In this type of receptor the terminus (terminal end) of the sensory process of the neuron is enclosed or wrapped in a specialized structure formed of mesodermal cells. Such a type of sensory receptor is called an encapsulated sensory receptor . Encapsulated sensory receptors are located in the dermis of the skin just beneath the epidermis (Fig. 8.1) and respond to touch and/or vibration and/or heat. For example: Ruffini sensory receptors in which the nerve endings are responsive to touch, pressure, vibration and heat are encapsulated mechanoreceptors and are located in the dermis.
3.	Associated Sensory receptors	When the terminus of the sensory process of the neuron is wrapped around another organ, then the terminus called an associated nerve ending, and sensory receptor is termed as the associated sensory receptor . For example, nerve endings that are associated with the base of a hair follicle (Fig. 8.1). When a hair is moved, the entwined nerve endings at the base of the hair are stimulated.

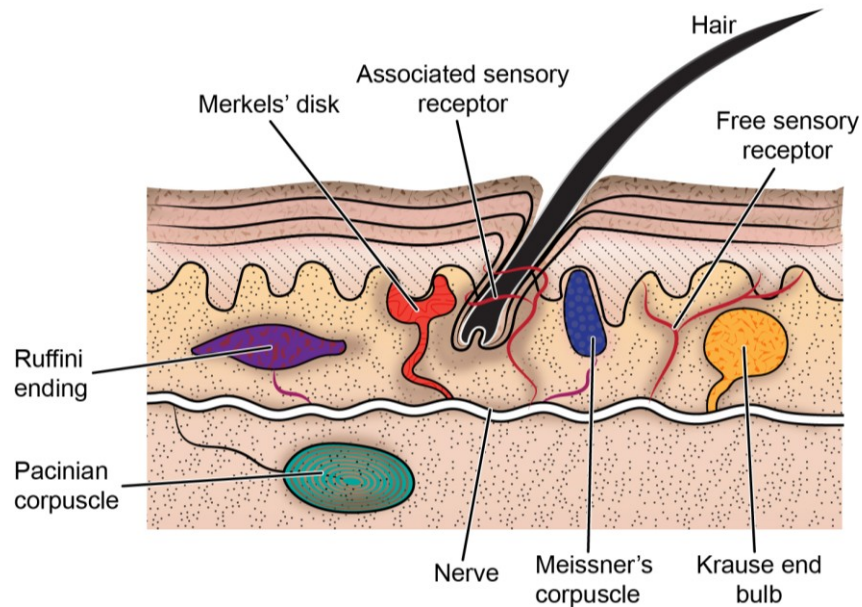


Fig 8.1: General sensory receptors found in the skin.

2) Classification of sensory nerve receptors on the basis of their location on/in the body.

- i) Sensory receptors (Fig 8.1) that are present on the skin and/or body surface and/or skeletal muscles are called **somatic receptors**.
- ii) **Visceral sensory receptors** are present in the viscera (abdominal organs).

3) Classification of sensory nerve receptors on the basis of the source from which they are stimulated

Broadly the various sensory receptors in the animal body can be classified according to the kind of energy they are able to perceive i.e. mechanical, chemical, light or thermal (Table 8.2)

Table 8.2: The sensory exteroceptors and sensory interoceptor of vertebrates.

1.	Exteroceptors (External senses) that receive and respond to sensations from the external environment	Name of the exteroceptors
i.	Sight Hearing Smell Taste Touch Pressure Temperature Pain Currents of water	Photoreceptors Phonoreceptors Olfactoreceptors Gustatoreceptors Tangoreceptors Mechanoreceptors Thermoreceptors Nociceptors Rheoreceptors

2.	Interoreceptors (internal senses) that receive and respond to sensations from the internal environment of the body.	Name of the Interoreceptor
i.	A special type of sensory organ that is located in the striated muscles, joints and tendons.	Proprioceptors

The information received by a single sensory receptor or the sensory receptors present in the sense organs provides the body of the vertebrate with continuous information of the constantly changing environment.

8.2.2 Sensory organs

During the course of evolution sensory systems consisting of independent receptors and sensory nerve fibers with their associated tissue became organised into **sensory organs** like eyes (Fig. 8.2), ears etc. These sensory organs are localised and specialized for a particular function. They are sensory due to the sensory receptors and neurons present in them.

Most vertebrates have sensory receptors for the five major senses, namely taste, touch, sight, smell and hearing. Let us first examine the specific sense organs associated with sight, hearing and smell. After studying these senses we will learn about the special sensory receptors that are found in some vertebrates.

8.3 PHOTORECEPTOR ORGANS OF VERTEBRATES

The ability to sense light is an important ability of all organisms especially vertebrates. The most developed photoreceptor of vertebrates are the eyes. These are highly specialised structures that originate, as out pocketing of the brain. Photoreceptors or eyes are of two types: (1) Median or parietal eye is a single structure located medially on the dorsal surface of the head and (2) paired, lateral eyes which are located on either side of the head.

8.3.1 Parietal Eye

The simplest and smallest vertebrate photo sensory organ is the **median or pineal eye** or **parietal eye** which develops from the diencephalon of the brain. The parietal eye is located near the middle of the top of the head (Fig. 8.2a). Today only a few fishes and lizards possess a median eye (Refer again to unit 15, of Block 4 of the first semester course BZYCT-131). The median eye of the lizard (Fig. 8.2 b) consists of several thousand sensory cells that transmit information to the brain. A transparent lens is present and lies over the sensory layer. The incoming light is concentrated by the lens on the sensory layer. The median eye is really a dosimeter (a device used to measure absorbed light) of light exposure. It functions in regulating circadian rhythms and in thermoregulation. However, the parietal eye does not produce images as the lateral eyes do.

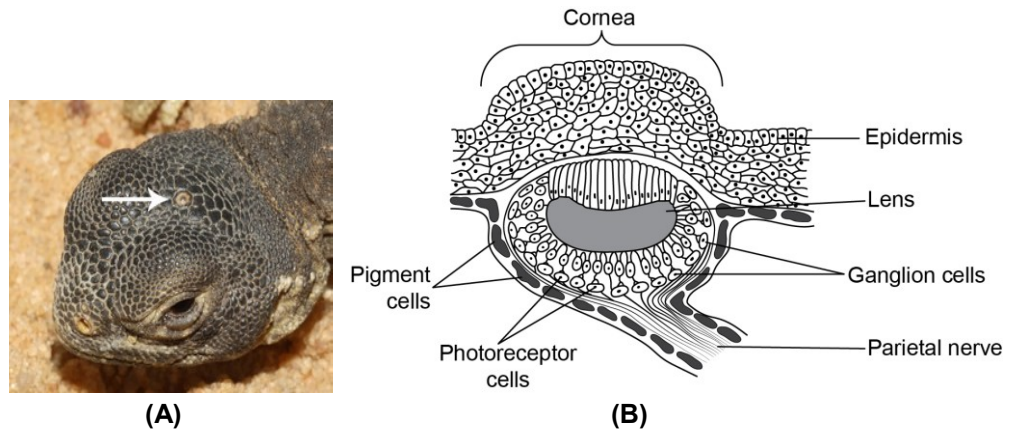


Fig. 8.2: a) Median eye in a reptile, b) A generalized, sagittal section of a median eye of a reptile.

8.3.2 Vertebrate Eye

All classes of vertebrates have paired eyes which are similar in the basic construction plan. The embryonic sources for the formation of the eye structure are: 1) the anterior brain or diencephalon for the retina and optic nerve, and 2) ectoderm for the lens and part of the cornea and 3) the nearby mesoderm for sclera, muscles and adjacent tissue.

We will first describe the human eye as a representative of the mammalian eye. Furthermore, the human eye is highly developed and is a good example of the vertebrate eye too.

Before we start describing the main structure of the human eye let us first study the auxiliary (additional), protective structures of the human eye.

Auxiliary or the accessory structures of the eye:

- i) **Bony eye orbit:** Each of the paired lateral eye is enclosed in a bony socket, called the eye orbit or simply orbit. The bony, eye orbits are present in the skull and function to protect the eyes from mechanical injury.
- ii) **Extraocular eye muscles:** Six extraocular muscles are attached to each eye and govern the eye movements (Fig. 8.3).
- iii) **Layer of orbital fat:** Each eyeball and its associated muscles are surrounded by a layer of orbital fat which act like a cushion and enable the smooth rotation of the eyeball around a virtually fixed point called the “centre of rotation”.

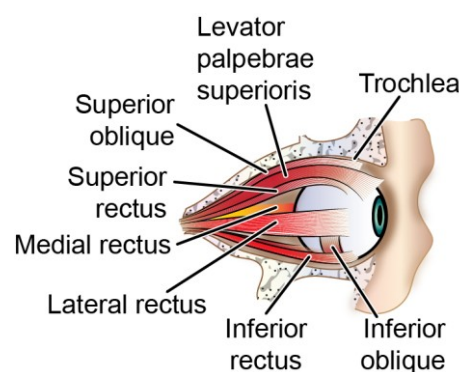


Fig. 8.3: Right eye of a human, showing its muscles and location in the eye socket of the skull.

- iv) **Eyebrows:** These are two arched, raised, part of the skin present above the eye. Numerous hairs project obliquely from the surface of the eyebrow part of the skin. The function of the eyebrows is to protect the eyeball from sweat, dust and other foreign bodies (Fig. 8.4 a).
- v) **Eyelids (palpebrae) and eyelashes:** The eyelids are two movable folds of skin situated above and below the eye. Thus each eye has an upper and lower eyelid which at their free edges is provided with eye lashes. The third eyelid is vestigial and is called **plica semilunaris** (nictitating membrane). A nictitating membrane is present in many vertebrates and helps to protect and moisten the surface of the eye. Both the eyelids and eyelashes can close over the eyes and so protect the eyes from injuries from foreign bodies. The blinking mechanism of the eyes also protects them from injuries. Furthermore the eyelids have lachrymal (lacrimal) glands also called tear glands which secrete the lachrymal fluid (tears) (Fig. 8.4 b). Tears keep the cornea moist and continuously flush out debris from it.

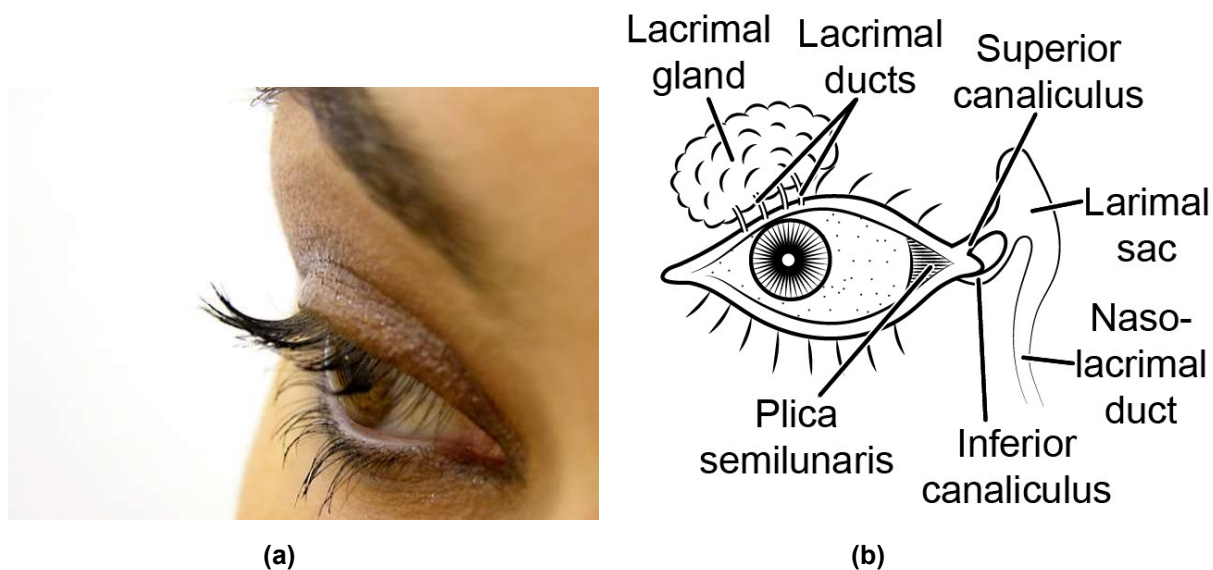


Fig. 8.4: (a) A human eye with upper and lower eyelids which are provided with eye lashes at their free ends; (b) Lachrymal glands that secrete tears are present in the eyelids.

- vi) **The Conjunctiva:** The innermost layer of the eye lid is covered by a clear, protective, mucous membrane called the conjunctiva (Fig. 8.5). The conjunctiva attaches the eyeball to the eye orbit and lids and forms an outer covering on the anterior part of the eye. The conjunctiva is lubricated by mucous, oils, and a watery solution. The lubrication of the eyes keeps them in good working order. The lubricants prevent the eyes from drying out and also protect the eyes from surface irritants.

Structure of the human eye

The human eye as in all vertebrates is made up of three coats, which internally enclose the optically clear aqueous humour, lens, and the vitreous body containing the vitreous humour (Fig. 8.5).

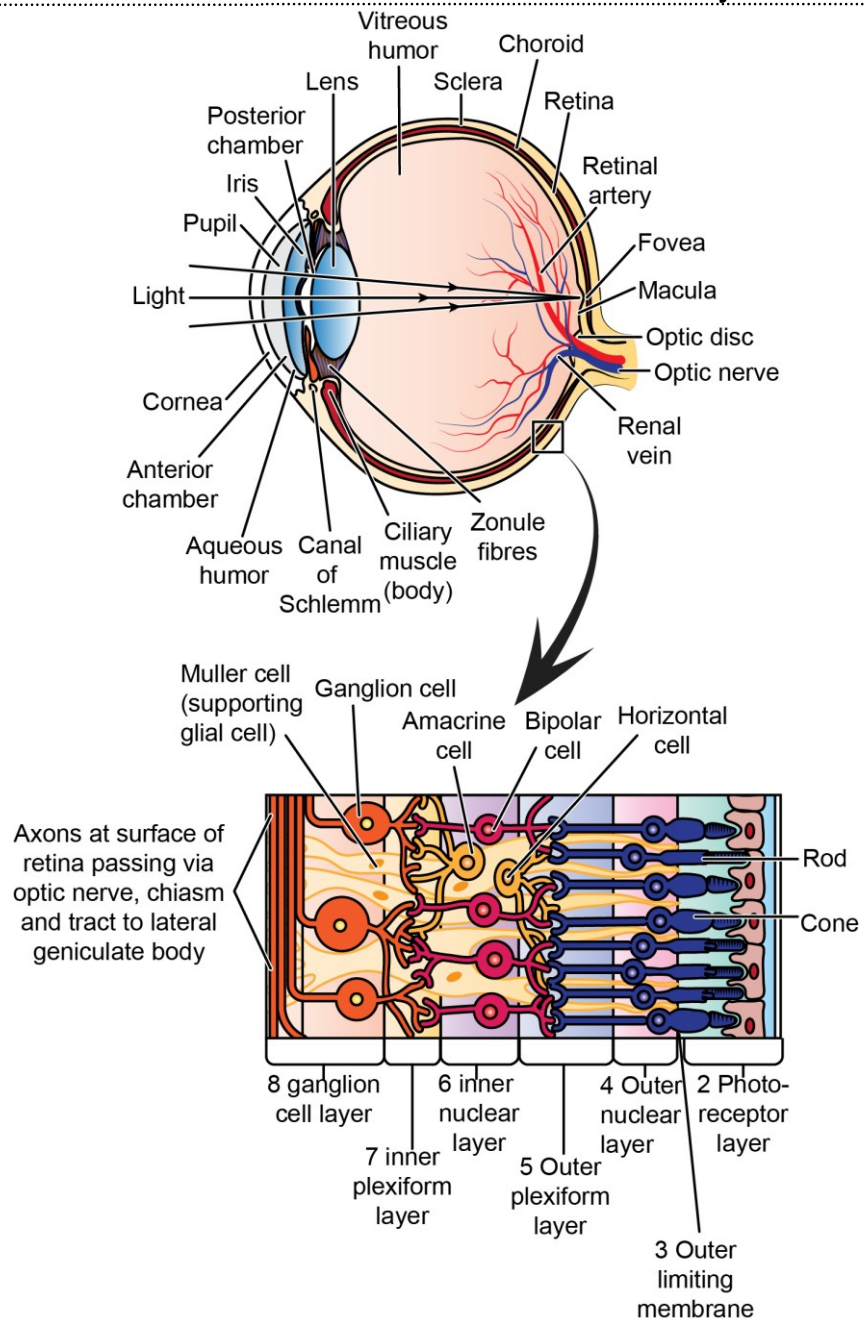


Fig. 8.5: (a) Cross section of the human eye showing an almost spherical eyeball with its various structures including the three layers- i) The outer tough sclera that provides support and protection, ii) The middle choroid coat containing blood vessels and nourishment, and iii) the light sensitive retina (b) Enlarged view of retinal area.

The vertebrate eye has the following structures (Fig. 8.5):

- **Sclera** – a tough outer most layer (the white of the eye) that forms the eyeball. It is the protective layer of connective tissue that helps maintain the shape of the eye and provides an attachment for the muscles that move the eye.
- **Conjunctiva** – membrane inside the eyelid attached to the sclera
- **Cornea** – the front of the sclera that is a transparent sheet of connective tissue. It covers the pupil and iris through which the light enters. It functions with the lens to focus the light on the retina.

- **Anterior Chamber** – a small chamber between the cornea and the pupil
- **Aqueous Humor** – clear fluid behind the cornea that fills that anterior chamber of the eye and helps to maintain the shape of the cornea providing most of the nutrients for the lens and the cornea and involved in waste management in the front of the eye.
- **Uvea** – middle coat of the eye between the sclera and inner retina; richly supplied with blood vessels; forms the choroid, ciliary body and iris.
- **Choroid layer** – pigmented layer the forms posterior part of uvea. It absorbs the excess light.
- **Ciliary body** – composed of ciliary muscles and ciliary process it is continuous with the choroid in the anterior part. It secretes the aqueous humour of the eye and is responsible for adjusting the focus (this process of changing the focus is called accommodation).
- **Iris** – anteriormost continuation of the uvea just behind the cornea. It is a circular muscular diaphragm that controls the diameter of the pupil (see Fig.8.6). It is the pigmented front portion of the choroid layer and contains the blood vessels. The eye colour is determined by the iris (an albino only has the blood vessels – not pigment so it appears red or pink because of the blood vessels).
- **Pupil** – the opening in the center of the iris- it changes size as the amount of light changes (the more light, the smaller the hole) and it allows light to reach the retina
- **Lens** – is present immediately behind the pupil. It is a transparent, crystalline complex structure with tightly packed fibrous cells. It is enclosed in an elastic collagenous capsule
- **Retina** – innermost thin layer of photoreceptors sensory cells (rods and cones) and neurons (bipolar and ganglion neurons) that converts light rays into electrical impulses that are relayed into the brain via the optic nerves.
- **Optic nerve** – made up of the axons of ganglion cells in the retina.

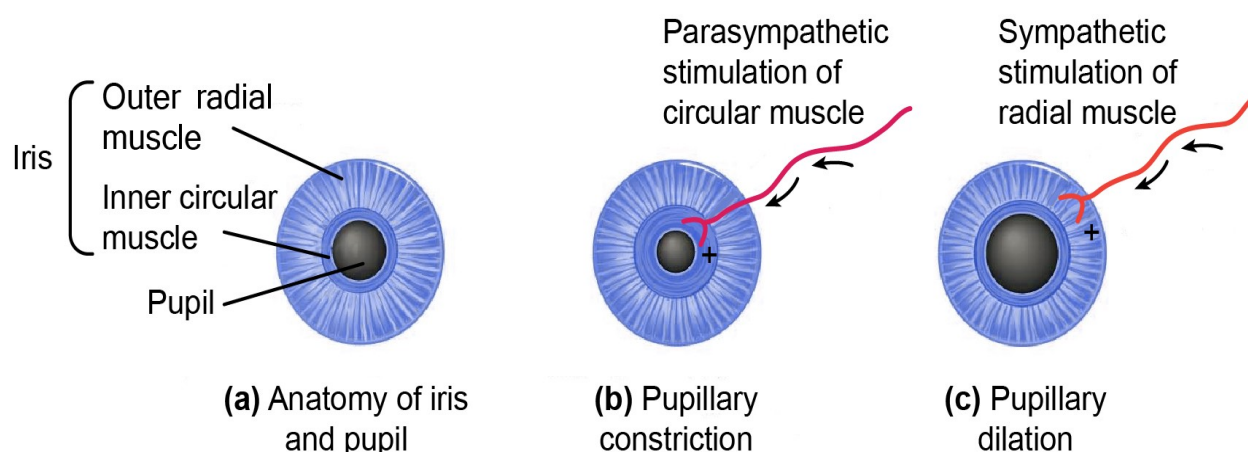


Fig. 8.6: The amount of light, entering the eye through the pupil is regulated by the radial and circular muscles of the iris.

You may have observed that the colour of eye in people differs, ranging from black to very pale blues and greens. This colour difference in eyes is due to the amount of pigment present in the iris.

Retina

The retina, forms the innermost layer of the eye and extends forward from the rear portion of the eye upto the ciliary body which as you will recall is present at the anterior part of the eye. The retina is a complex neural and sensory layer of the eye ball, and is an outgrowth of the forebrain. It is multilayered and includes both sensory and nonsensory cells. Its external surface is in contact with the choroid and its internal surface with the vitreous humour. The sensory part of the **retina** receives light that enters the eye through the cornea and passes through the pupil. The retina converts light energy into chemical energy. The chemical energy activates the nerves which conduct messages out of the back of the eye into the higher regions of the brain. The retina covers about 65% of the inner surface of the eyeball and contains the light sensitive cells also referred to as photosensory cells. These photosensory cells have the ability to determine the intensity of light (whether the light is dim or bright), and the colours of the objects that are viewed by the eye. A microscopic examination of the retina layer of the human eyes when studied from the external surface (choroid side), shows multilayers and includes sensory and nonsensory cells.

Figure 8.5 (b) provides a closer look of the retina. The sensory cells in the retina that respond to light are called photoreceptors and are of two types, the **rod cells** and **cone cells** (named for the shape of the cells). They form a layer at the back of the retina. Photoreceptors synapse with the intermediate layers of neurons that are connected with each other and with another set of neurons called **ganglion** cells. The axons of the ganglion cells come together along the inner surface of the retina and turn inwards in one place to form a nonsensory area the **blind spot** and continue to the brain as optic nerve. Fibres from left and right optic nerves cross at the optic chiasma and the nerve impulses travel from right to left field of vision of occipital cortex in the brain. This is an unusual arrangement as light has to pass through several layers of neurons before it reaches the photoreceptors, and the axons of the ganglion cells have to pass through the photoreceptor layer to exit as the optic nerve. At the margin of the retina near the ciliary body and iris there are no rods or cones.

Rods are very sensitive to dim light but not to colour. Cones in contrast are less sensitive to faint light but sensitive to different wavelengths or colours. Thus vertebrates that usually live in low light levels or are nocturnal have more rods than cones. Those that need to see more details have large retinas because resolution is controlled by the density of receptors. There are more rods than cones in the human retina, however there is one small spot in the retina where rods are absent and a concentration of cones is present. This is called **fovea** and when we focus on something the eye moves so that image falls on the fovea of each eye, therefore fovea is responsible for maximum resolution of the image.

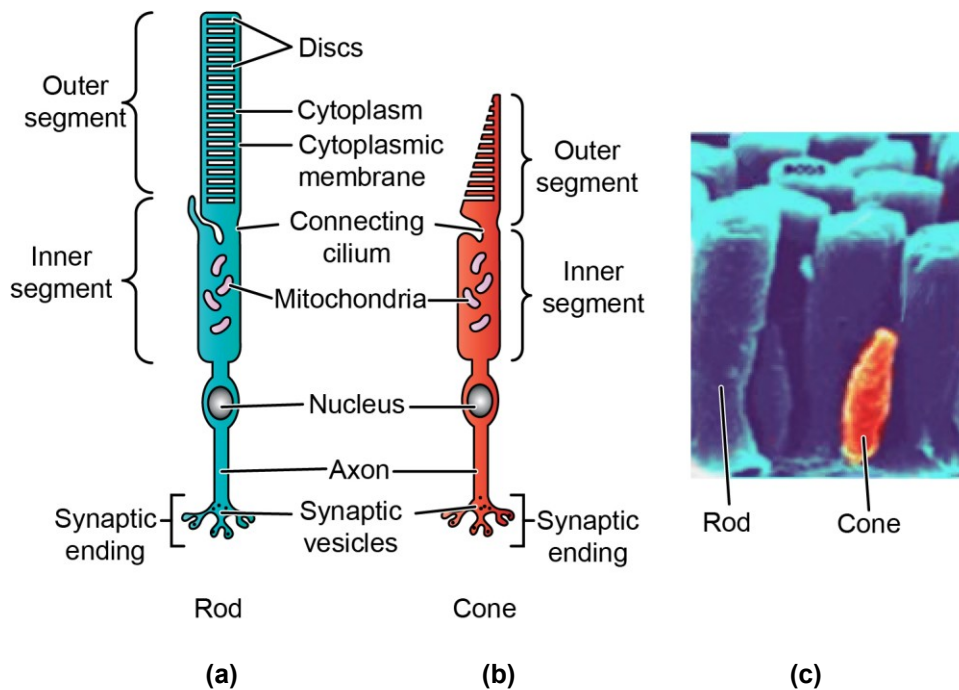


Fig. 8.7: Structure of the photosensory cells: (a) rod cell and (b) cone cells.

Notice that the photosensory cells have stacks of membranes called transmembranes that form discs. The discs contain the visual pigment retinal and the transmembrane protein opsin. c) Microscopic view of rod and cone cells seen packed together in the human retina.

Figure 8.7 shows the structure of a rod and a cone. You can see that they have a segment that is packed with membrane rich discs. The membranes contain large quantities of a transmembrane protein **opsin**, and each opsin is associated with a pigment known as **retinal**. In rods this complex is known as **rodopsin**. Retinal changes shape when light falls on it which results in change in shape of opsin which sends the signal to the neurons in the retina that convey the signal to the brain via the optic nerve. But how is colour perceived? Scientists discovered that there are only three types of colour sensitive cones that absorb short, long and intermediate wavelengths of light. Each of these has a slightly different opsin molecule that responds to either blue or green or red colour, although retinal is same in each of these cones. Based on various experiments scientists have concluded that the brain distinguishes different colours by combining signals initiated by the three different types of cones.

Several types of neurons in the retina convey information to the brain either directly or by interaction modify the input to the visual centres of the brain (see Fig.8.5b). Light energy is converted to electrical signals and transmitted by the **bipolar cells** to the **ganglion cells** which then transmit the signal to the brain. Other neurons like **amacrine** and **horizontal cells** interact for the transmission between photoreceptors and bipolar cells or between bipolar and ganglionic cells.

At the base of the retina is the pigmented choroid. It is either black or very shiny. Choroid pigment in day adapted animals is black and absorbs any stray light so that it does not get reflected to the sensory retina. Reflected light produces images that do not get correctly aligned to the primary image and thus reduce visual acuity. Nocturnal animals have a mirror like choroid known as **tapetum lucidum** that reflects back the light into the retina. Because little

light is lost through absorption by choroid their eyes are sensitive to dim light but at the cost of visual acuity because reflected image does not coincide exactly with primary image.

Lens

The light entering the eye through the cornea and the pupil passes into the lens. The lens in the eye is flatter on its anterior than on its posterior surface and is suspended within the eye by the zonule (little band) (Refer again to Fig. 8.5) fibres of Zinn, which is a ring like structure composed of fibrous strands. The zonule fibres connect the crystalline lens of the eye with the ciliary body. The zonule fibres are sometimes collectively referred to as the suspensory ligaments of the lens. The lens focuses the light on the retina by changing its shape by bending and in conjunction (together) with the cornea

Image formation in vertebrates is done by the cornea and crystalline lens. Cornea is almost flat in fishes but in terrestrial animals the cornea is curved and main image former and the crystalline lens is used for fine focusing. Many animals have a method to control the amount of light entering the eye. Like the aperture of the camera, their pupil which is an opening in the iris regulates the light intensity (Fig. 8.8). In most diurnal animal the pupil tends to be circular and relatively small. Nocturnal animals have round and relatively large pupils that permit maximum amount of light to enter the eye. Pupils of animals that are active both during day and night are able to expand greatly at night and become fine slits at day.

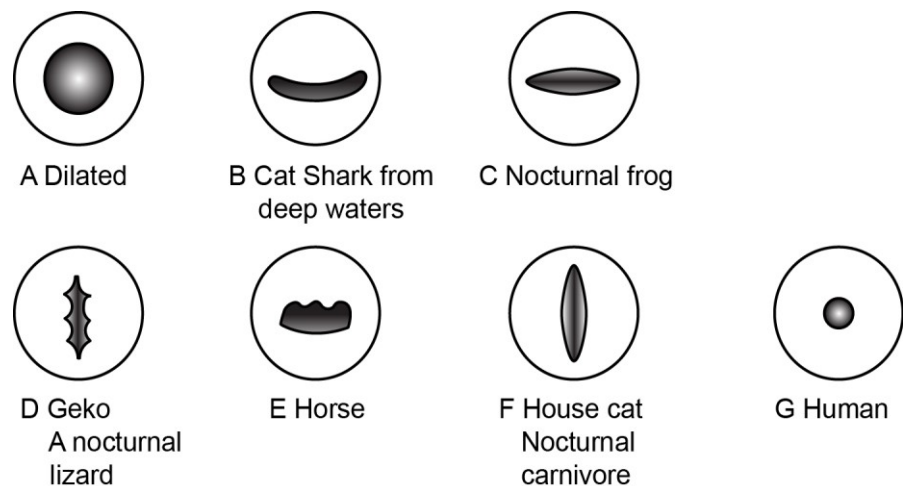


Fig. 8.8: The pupil is constricted in bright light and dilated in dim light (A) dilated pupils in vertebrate to allow light and (B-G) contracted pupils of vertebrates.

Three chambers of the eye

The three layers of the eye, internally enclose three chambers (Refer again to Fig. 8.5), two of which lie in front of the lens namely, 1) **the anterior chamber** between the iris and the cornea and 2) the **small posterior chamber** of the eye between the iris and the lens. 3) The third and the largest chamber is the **vitreal or vitreous chamber** which is located between the lens and the retina.

All the three chambers are filled with a transparent fluid that helps maintain the shape of the eyeball. The **anterior and posterior chambers** are filled with a watery solution called the aqueous humour that helps the cornea and pupil to focus the entering light entering to form an image by refracting light at a constant rate.

The **vitreous chamber** is filled with an avascular, thick, gelatinous fluid called vitreous humour or body. The vitreous humor contains phagocytes that remove blood and debris from the eye under normal circumstances. Vitreous humour similar to aqueous humour refracts light at a constant rate. Furthermore, the vitreous humour serves to keep the underlying retina pressed against the choroid and so the jelly-like thickness of the vitreous humour helps the eye to retain its round shape which is essential for vision.

Binocular Vision

Recall we had said earlier that the left optic nerve and the right optic nerve cross over at the optic chiasma. Humans have binocular vision due to this crossing over of the optic nerves which is termed as **deccussation**. Typically the nerves from the left side of the body **decussate** to the right side of the brain and the nerves from the right side of the body **decussate** to the left brain and so enable both the eyes to be focused simultaneously on a common object (Refer to Fig. 8.9 a).

Binocular vision is just the reverse of monocular vision (Refer to Fig. 8.9b) as seen in many animals like rabbit, in which each eye focuses its own object and both the eyes cannot focus on one object. The eyes of an animal with monocular vision are usually positioned laterally on opposite sides of the animal's head, giving it the ability to see two objects at once.

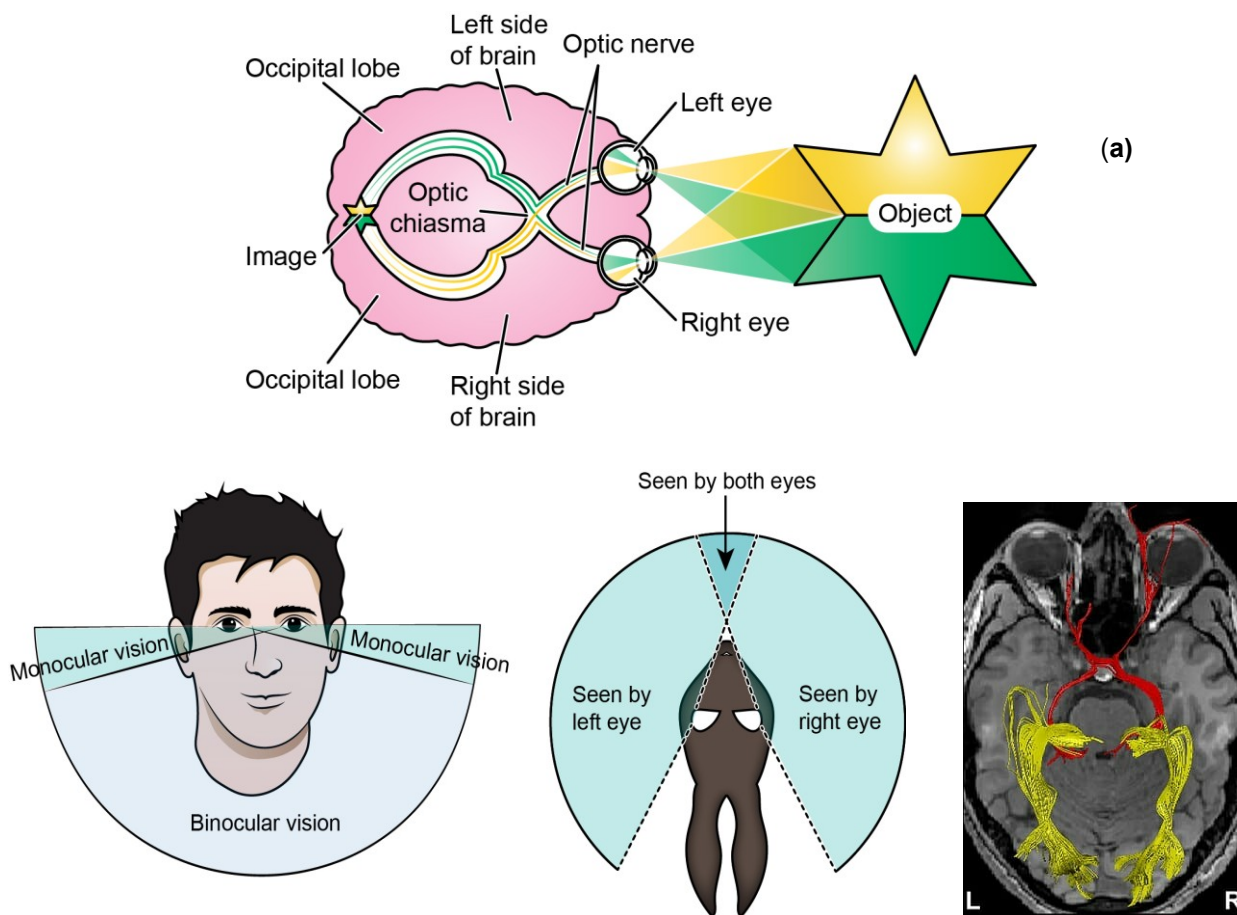


Fig. 8.9: (a) A schematic figure showing the crossing over of the optic nerves at the optic chiasma. The crossing over leads to binocular vision.(b) Comparison of binocular and monocular vision. (c) The optic chiasm as seen in a brain scan of human.

8.3.3 Comparative Anatomy of the Vertebrate Eye

The eyes of all vertebrates are built on the same general pattern. However, variation occurs in them due to the habitat they live in. In most vertebrates the eyes are well developed. However, in some forms the eyes are primitive, while in others they have become degenerated and functionless. The eyes in various groups of vertebrates also vary in their methods of accommodation, degree of retinal development and the pupil shape. The structural features of eyes among the various classes of vertebrate are described in this subsection.

Other Mammals

The human eye structure is more or less typical of that seen in mammals. Variations are seen among mammals that are aquatic, terrestrial and those that lead an aerial life. **Tapetum lucidum** is present in nocturnal forms. Round pupil is most common but variations do occur. The retina mostly contains rods and cones, though capacity of colour vision is mostly limited to higher primates. The optic nerve decussation leads to binocular vision giving a third-dimensional effect

Birds

Birds show adaptation for aerial vision. They usually have uniocular vision except for birds of prey such as owls and to a lesser degree, hawks and eagles which have binocular vision. Birds have a uniform eye structure. The eyeball of the aves is very large in proportion to body size and is correlated with their aerial mode of life (Fig.8.10a). An ossified sclerotic ring is present in the eye of birds and surrounds the ciliary region. The eyeball is partly concave and has a highly developed nictitating membrane which offers protection during flight. The ciliary bodies are well developed with extra muscles that change the shape of the cornea, thus providing a greater capacity for accommodation in birds in comparison to mammals. In birds of diurnal habit the cones predominate, while the rods predominate in nocturnal forms. A fovea is present in all birds. Some birds have two foveas. Colour vision is wide spread among aves. A special feature of birds is **pectin**, a serrated fan shaped structure which extends into the posterior chamber from the point at which the optic nerve emerges from the retina. It is well developed and is believed to aid in perception of movement and acts as a supplemental nutritive device for the retina.

Reptiles

Eyes (Fig.8.10 b) of reptiles are adapted to a terrestrial mode of life. Most reptiles except for snakes and a few others have movable eyelids. The eyes of most reptiles have a true nictitating membrane, Harderian gland and well developed lacrimal glands. However, lacrimal glands are poorly developed in snakes, chameleon and *Sphenodon*. In the reptilian eyes the number of cones are relatively increased. In most reptiles, a central area for acute vision is present in the retina. Colour vision is believed to exist in turtles and lizards but is of doubtful occurrence in crocodiles and snakes. In snakes, a fixed transparent skin called the spectacle is formed over the eyes as the eyelids are fused. A very important difference in the reptilian eye is the presence of a special ciliary apparatus, which alters the shape of the lens and cornea. Accommodation in the eyes of reptiles and most other amniotes is

The Harderian gland, or Harder's lacrimal gland, was described by Harder in 1694 in the red deer. It is located directly behind and around the eye in all vertebrates that have a nictitating membrane (reptiles, birds, and most mammals). In humans, the Harderian gland is poorly developed (rudimentary).

accomplished by changing the shape of the lens. The shape of the lens may be flattened for distant vision or rounded for near vision through the action of the muscles connected with the ciliary body.

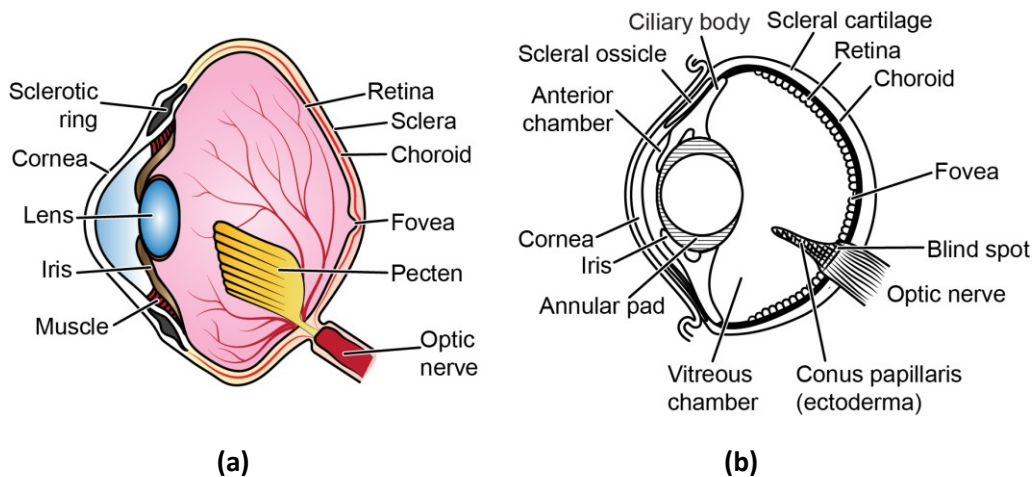


Fig. 8.10: Cross section of the vertebrate eye of: a) a bird; and b) a reptile.

Amphibians

The amphibian eye (Fig. 8.11) is basically like that of other vertebrates.

Amphibians close their eyes by retracting their entire eye within the orbit of the eye socket by means of their retractor bulbi muscles. The opening of their eye is accomplished by means of levator bulbi muscles which cause the eye to protrude out of the eye socket. Ciliary bodies and poorly developed lacrimal glands are present in the amphibian eyes. The eye is however, kept moist by glandular secretions. Moveable eyelids and glandular secretions that moisten the eyes make their appearance for the first time in amphibians. Tapetum lucidum is not present in the eyes of amphibians though the eyes appear to shine. Scientists believe that amphibians lack colour vision.

Amongst all the amphibians, the eyes in anurans are best developed. In caudate amphibians (group of amphibians containing the salamanders and all extinct species of salamander-like amphibians) the eyes are small. The caudate lens is exceptionally large and the ciliary body is less developed. Cave-dwelling salamanders have non functional, degenerated eyes.

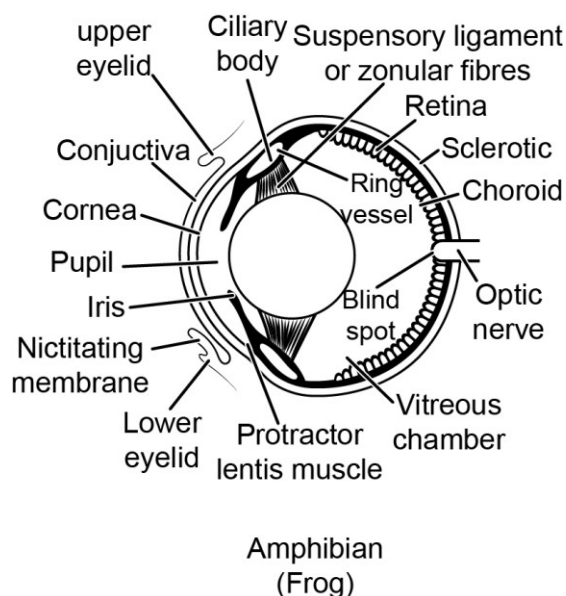


Fig. 8.11: Cross section of the vertebrate eye of an amphibian.

Fishes

The size of eyes is large in cartilaginous fishes. Each eye-ball is lodged in its eye orbit and is held in position by the six eye-muscles. A characteristic cartilaginous stalk called the optic pedicel arises from the posterior angle of the orbit (Fig. 8.12). In cartilaginous fishes the sclera is cartilaginous and the intrinsic muscles are absent in the ciliary body of the eye. Among all the groups of cartilaginous fishes the eyes in holocephalians are the largest in relation to body size. In elasmobranchs the surface of choroid coat contains light-reflecting crystals of guanine. In both cartilaginous fish species except in elasmobranchs (like sharks and rays) and bony fish species, the size of the diameter of the pupil is fixed. In elasmobranchs a muscular iris that allows the pupil diameter to be adjusted is present. Cones are absent in elasmobranchs.

In bony fishes colour vision appears to be wide spread. Ciliary muscles are however, absent in them. The sclera in the eyes of higher teleosts contains cartilage and sometimes bone. In most teleosts, the eyes (Fig. 8.12) are normally adjusted to near vision so the lens is moved back towards the retina when distant vision is required. Eyes of certain teleosts are adapted for vision in both air and water. Many deep-sea fishes have relatively enormous eyes for vision in regions of low-light intensity. Recognition of enemies, prey, members of the same species and opposite sex is thus possible. In adult flatfishes, both eyes are on the same side of the head. Other deep sea fishes and some cave inhabiting species have degenerated eyes and so have lost the power of sight.

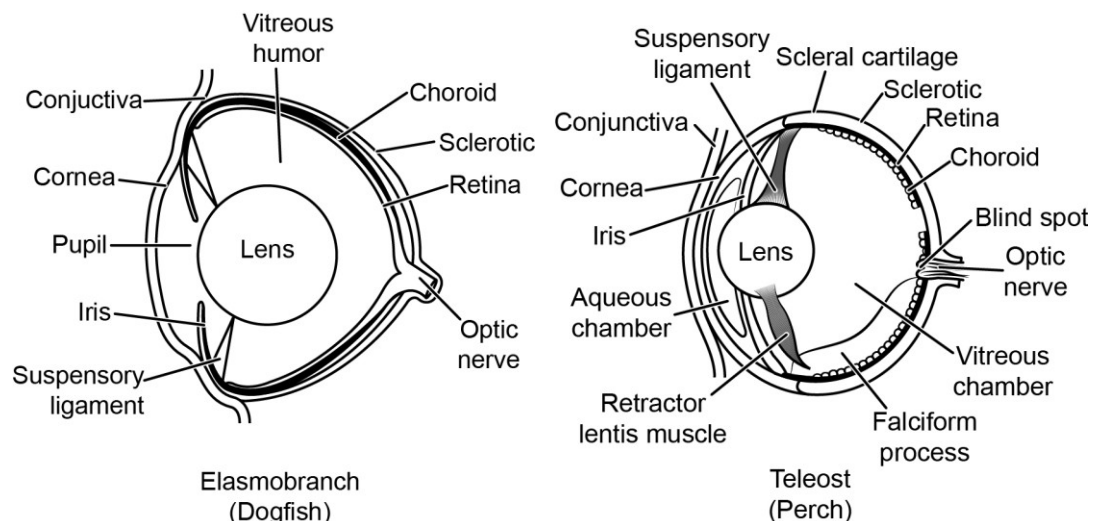


Fig. 8.12: Cross section of the vertebrate eye of a cartilaginous fish (*Scoliodon*) showing eye muscles and optic pedicle; and a bony fish (teleost).

1) Cyclostomes

In hagfishes the eyes lie beneath the skin, minute, degenerated and functionless. The cornea, sclera and the choroid are not differentiated. On the other hand, lamprey eye though primitive, is nevertheless a well-developed structure. The eyeball is flattened; sclera and the cornea are not fused to skin (Fig. 8.13). There is a lack of suspensory ligament and ciliary apparatus, the pupil is of fixed size and the eyelids are absent. Rods outnumber cones.

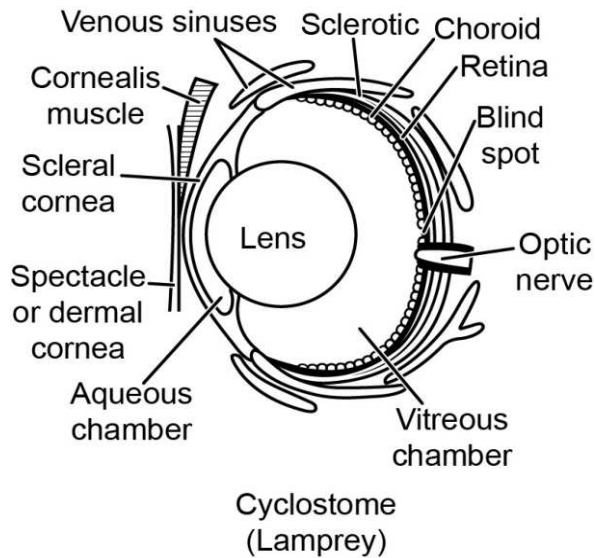


Fig. 8.13: Eye of lamprey.

SAQ 1

Give one or two word answers:

- i) Which photoreceptor is sensitive to dim light and detects changes in light intensity?
- ii) Which of the photoreceptors respond to high intensity of light and are responsible for colour vision?
- iii) Outer coat of tough elastic tissue in the eye is known as?
- iv) Light is focussed on the retina by what parts of the eye?
- v) What is the function of pupil?
- vi) Which muscles are responsible for changing the shape of the lens for near and far vision?

8.4 THE VERTEBRATE EAR

The vertebrate ear is a specialised receptor organ for detecting sound waves in the environment. It usually functions in a dual capacity, serving at least in higher forms, both as an organ of hearing and of equilibration. What we see as the ear in mammals is actually only the external ear. The actual function of hearing and equilibrium are performed by the internal ear which has a similar structure in all vertebrates and is enclosed in a bony skull that protects it from the external environment. During evolution the vertebrate internal ear originated as the **labyrinth** also known as **vestibular apparatus** which was primarily an organ for balance. We will explain the structures responsible for hearing first.

Hearing in vertebrates probably appeared as a mechanism to alert animals to nearby activity that could be dangerous. Later it also became important in the search for food, mate and in communication. In most vertebrates, part of the inner ear became modified to receive sound waves and certain hair cells in the inner ear became specialised to detect sound.

8.4.1 Auditory System of Mammals

We will begin as in the previous section with the study of human ear both as a representative of the mammalian ear and as the reference organ for the comparative study of vertebrate ear.

Human ear (Fig. 8.14) like that of other mammals, contains the auditory or hearing senseorgans and functions both 1) as the sensory or auditory organ of hearing as it detects and analyzes sound by transduction (converting) sound waves into electrochemical impulses and 2) for maintaining the postural equilibrium and coordination of head and eye movements of the human body.

The Human ear has anatomically, three distinguishable parts: i) the outer, ii) middle, and iii) inner ear (Fig. 8.14) which are described below:

- i) **The outer or external ear** consists of: a) paired, visible pinna also called auricle, which projects from the lateral side of each side of the head and b) the short external auditory canal called the external auditory meatus, which is closed at its internal end by a thin, semi-transparent tympanic membrane generally referred to as the eardrum or tympanic membrane. The external auditory canal is lined with fine hairs that are directed outwards and modified sweat glands. The modified sweat glands produce ear wax, or cerumen, which discourage insects from entering inside the ear.

The tympanic membrane, or eardrum, forms the boundary between the outer ear and the middle ear, and is stretched obliquely across the internal end of the external canal. The function of the outer ear is to collect sound waves and guide them to the tympanic membrane.

- ii) **The middle ear** is a narrow air-filled cavity in the temporal bone of the skull. The middle-ear space roughly resembles a rectangular room with four walls, a floor, and a ceiling. The outer, lateral wall of the middle-ear space is formed by the tympanic membrane. The eustachian tube which is also known as the auditory tube is a part of the middle ear and connects the outer, lateral wall of the middle ear to the nasopharynx. The eustachian tube helps ventilate the middle ear and maintains equal air pressure on both sides of the tympanic membrane.

The middle-ear contains three tiny bones or ossicles (Refer again to Fig. 8.14) that link the tympanic membrane with the oval window and the inner ear. The oval window is a membrane-covered opening that leads from the middle ear to the vestibule of the inner ear. The ossicles from the outer end to the inner end of the middle ears are named on the basis of their shapes as malleus (hammer), incus (anvil), and the stapes (stirrup). These bones or ossicles are suspended by ligaments, in such a manner so that they can vibrate freely and transmit sound from the tympanic membrane to the inner ear.

- iii) **The inner ear** all vertebrates have an inner ear (Refer again to Fig. 8.15). However, the inner ears of vertebrates show considerable variations in form and function. The actual function of hearing and equilibrium in the ear of the vertebrates are performed by the internal ear which has a similar structure in all vertebrates. During evolution the vertebrate internal ear originated primarily as an organ for balance, part of which then evolved to become an organ of hearing.

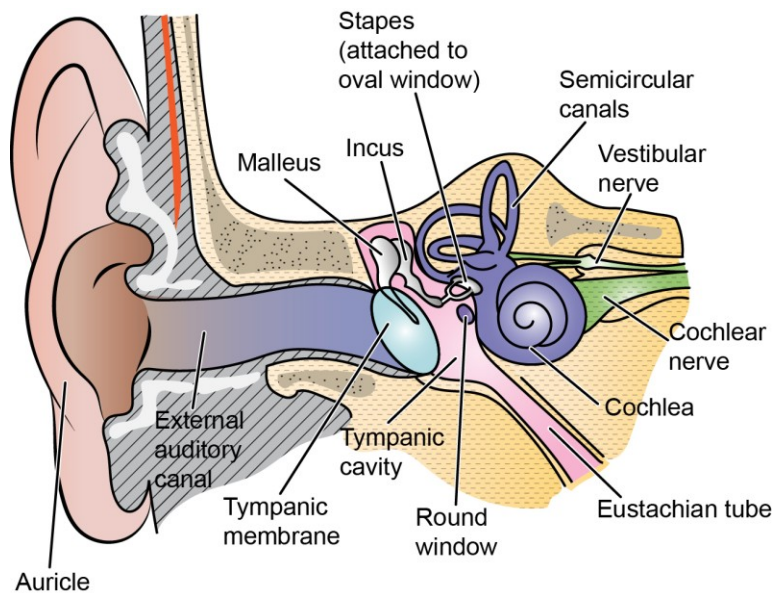


Fig. 8.14: Anatomy of the Human Ear (*Encyclopaedia Britannica, Inc.*).

The inner ear connects to the middle ear by means of the footplate (end part) of the stapes of the middle ear at the membranous oval window, which is the beginning of the inner ear. The inner ear in all vertebrates is innervated by the eighth cranial nerve.

The **inner ear** of mammals consists of a **bony or osseous labyrinth** which encloses the membranous labyrinth. The bony labyrinth (Fig 18.15) is divisible by region and functioning to:

- 1) **The bony vestibule and the bony semicircular canals** which enclose the membranous vestibule and membranous semicircular canals respectively; and
- 2) **The spirally coiled bony cochlea** enclosing the spiral membranous cochlea.

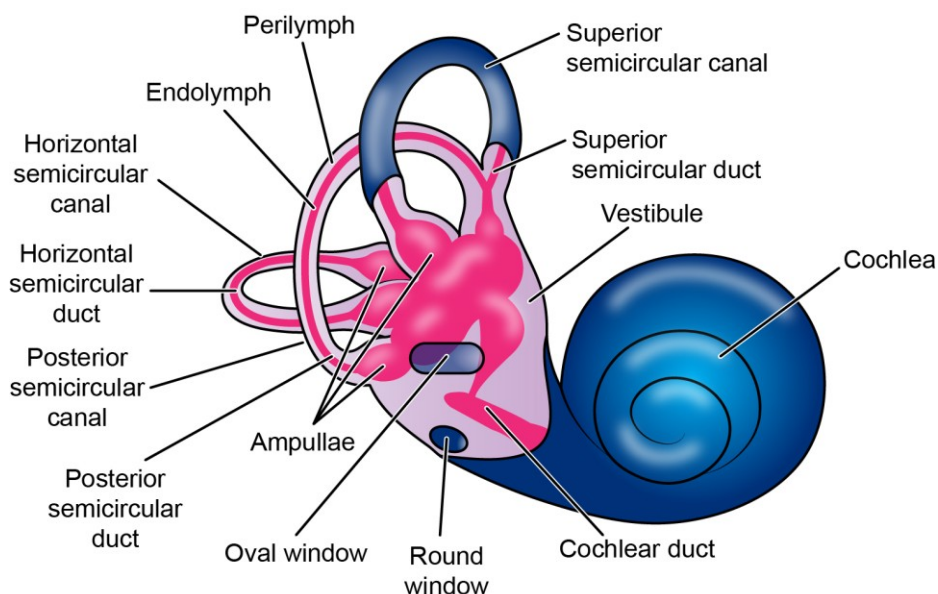


Fig. 8.15: Structure of the internal ear of a human showing both its bony and membranous structures. The bony labyrinth is partially cut away to show the membranous labyrinth within. (Modified from Encyclopaedia Britannica, Inc.)

The membranous labyrinth in mammals runs inside the entire length of the bony labyrinth and has the same structure as the bony labyrinth. It is filled with endolymph fluid which is rich in potassium ions (K^+). The membranous labyrinth similar to the bony labyrinth consists of three major membranous parts: 1) the membranous vestibule which is formed of the utricle and saccule, 2) three membranous semicircular canals and their ducts, which contain the sensory organs of postural equilibrium; and the 3) the snail shell like membranous cochlea with its cochlear duct. The membranous cochlea has originated from the lagena that was present in early vertebrates as an organ of balance but later in higher vertebrates evolved into the organ of hearing, called cochlea. The membranous cochlea contains the sensory organs of hearing which we describe next.

STRUCTURE OF COCHLEA

The cochlea is a fluid filled spirally coiled tube divided into three canals called **scala vestibuli** and **scala tympani** which run on either side of the central channel or **scala media** and contain perilymph (Fig. 8.16). The scala vestibuli and scala tympani are linked by a small opening at the apex of the cochlea called the helicotrema. Scala vestibuli communicates with the vestibule via the oval window. The scala tympani communicates with the tympanic cavity via the round window. The scala media is separated from scala vestibuli by a vestibular membrane also called the Reissner's membrane and from the scala tympani by the basilar membrane. The sensory, spiral organ of the cochlea is called the "**Organ of Corti**". It is a specialized sensory neuroepithelium and is located on the basilar membrane that runs the length of the cochlea. The cochlea is immersed in endolymph of scala media.

STRUCTURE OF ORGAN OF CORTI

The organ of Corti is the site of transduction (transforming) of mechanical signals to electrical signals and is designed like a sandwich. It consists of two **tectorial (covering or cover)**, acellular, gelatinous membranes of which the basilar membrane forms the bottom layer and the tectorial membrane forms the upper layer. The mechanosensory hair cells and the various types of supporting cells associated with them are located between the two membranes as seen in this close-up view of the organ of Corti in Fig 8.16b. Three rows of outer hair cells (OHCs) and one row of inner hair cells (IHCs) along with their supporting cells are present on the basilar membrane. The inner hair cells are the primary auditory receptors and exist in a single row. They are approximately 3,500 in number. They provide the main neural output of the cochlea. The outer sensory hair cells, mainly receive neural input from the brain. Tiny finger like projections called stereocilia, project from the apical (top) end of the hair cells. The stereocilia are arranged in a graduated manner in which the shortest stereocilia are present on the outer rows and the longest are present in the center. This gradation is thought to be the most important anatomic feature of the organ of Corti as this allows the sensory cells to have superior hearing capability. The exposed hair-like **stereocilia** are either embedded or are in contact with the upper tectorial membrane and can move in response to pressure variations in the fluid – tympanic and vestibular canals. Each sensory hair cell is connected with neurons of the auditory nerve at its basal end.

Pathway of the neural signal of sound from external ear to auditory cortex of the brain

The auditory receptors are mechanoreceptors, and when bent by vibrations they respond by opening a gated ion channel. As a result, the hair cell membrane is depolarized, and a signal is transmitted to the cochlear nerve. Intensity (volume) of sound is determined by how many hair cells are stimulated at a particular location.

The base of cochlea is more sensitive to high frequency vibrations while the apical portion can detect very faint vibrations. Sound waves from stapes enter scala vestibuli through the oval window, then travel to the entire length of cochlea and return back via scala tympani and escape to the middle ear cavity through the round window. *Simultaneously the sound waves cause the basilar membrane to move which in turn causes the movement in the hair cells. When hair cell bends in one direction, the hair cell depolarizes. In turn, when it bends in the other direction the cell hyperpolarizes. From the hair cell the electrical signal is sent to the brain.*

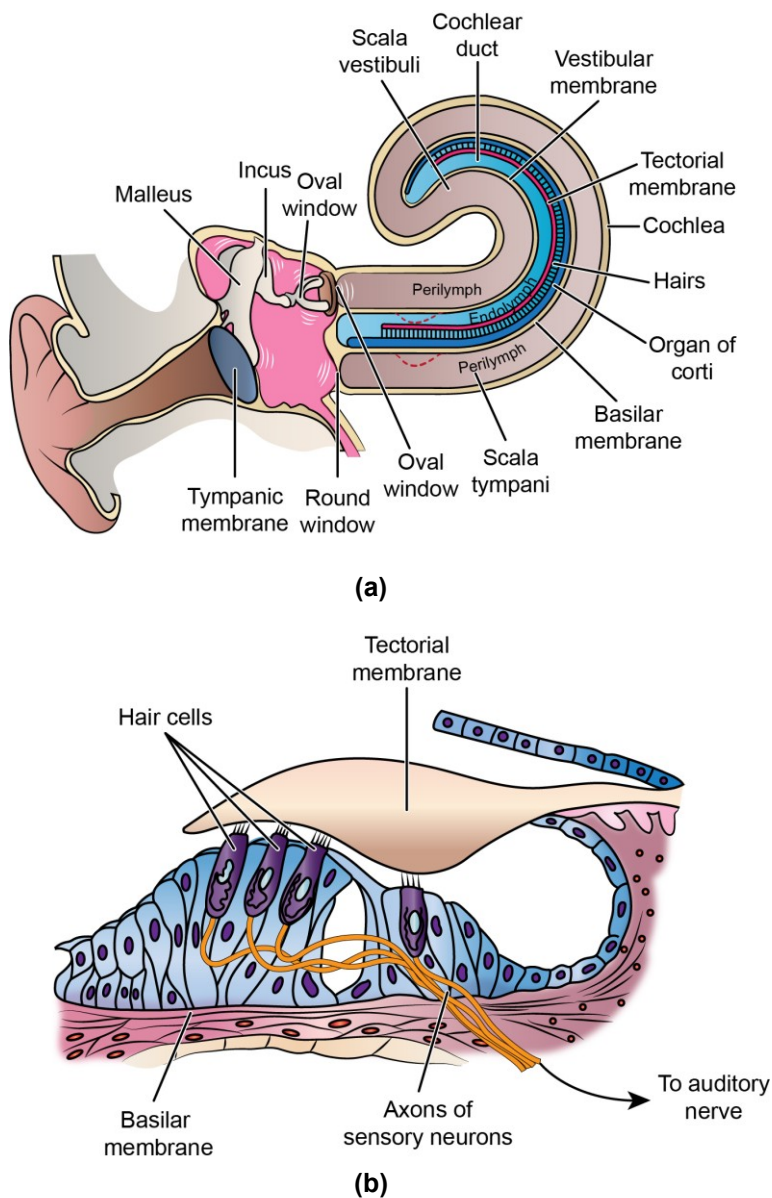


Fig. 8.16: Structure of the external, middle and inner ear showing: a) an uncoiled Cochlea; b) structure of the organ of Corti of the cochlea which is sensory part of the Cochlea.

Box 8.1

Detecting water currents, maintaining balance and hearing sound seem to be very different sensory functions. However, all three are based on mechanoreceptors, sensory cells that respond to changes in pressure or mechanical force. The basic mechanoreceptor is the hair cell which has nothing to do with hair but is a sensory cell which has a tiny hair like process on its apical surface. Hair cells are transducers that change mechanical stimuli into electric signals and these cells originate from surface ectoderm. Each hair cell is embraced by a sensory fiber of neurons that are sensitive to ionic changes in the hair cell. Through synapses or similar contact points, electrical excitation is passed on from hair cell to their embracing neuron which sends the signal on to the central nervous system.

A neuromast organ is a small collection of hair cells, supporting cells and sensory nerve fibers and the projecting hair bundles which are all usually embedded in a gelatinous cap called cupula. The neuromast organ or its modification is the fundamental component of all three types of mechanoreceptive systems, the lateral line systems, vestibular apparatus that senses equilibrium and auditory system that responds to sound.

8.4.2 Vestibular Apparatus

The membranous vestibular apparatus of the internal ear is enclosed in the bony vestibular apparatus. The membranous vestibule has two chamber like enlargements or sacs of which the upper sac is called: (i) utricle (little bottle) while (ii) the lower sac is called saccule (little sac). The utricle and saccule are connected by a duct called the sacculoutricular duct. A narrow endolymphatic duct is joined either to the saccule or the sacculoutricular duct. The utricle and saccule are filled with endolymph fluid which is actually the cerebrospinal fluid and so is more viscous than water. Each sac on its inner surface has a single patch of sensory cells called a **macula** (meaning: spot). The macula monitors the position of the head relative to the vertical position. Each macula consists of a neuroepithelium, which is a layer that is made up of supporting cells and sensory hair cells placed on a basement membrane. The layer also contains nerve fibres and nerve endings. The cilia of the sensory cells are of two types: (i) stiff, nonmotile and hairlike sensory cilia called **stereocilia** and (ii) flexible and motile, sensory cilia called **kinocilia**. The two types of cilia project from the apical ends of the sensory cells. The entire macula is covered by a delicate, acellular structure, called the **otolithic**, or **statolithic** membrane. The surface of the otolithic membrane is covered by a blanket of calcium carbonate crystals, referred to as **otoconia** or **statoconia**, (Fig. 8.17).

When an animal changes its position the sensory hair of the sensory cell generate a nerve impulse that informs the brain of the change in position (Fig. 8.17 b). The utricle and saccule are static balance organs that give information about the position of the head or body with respect to gravity. As the head is moved the stony mass moves over the hair cells sending nerve impulses to the brain.

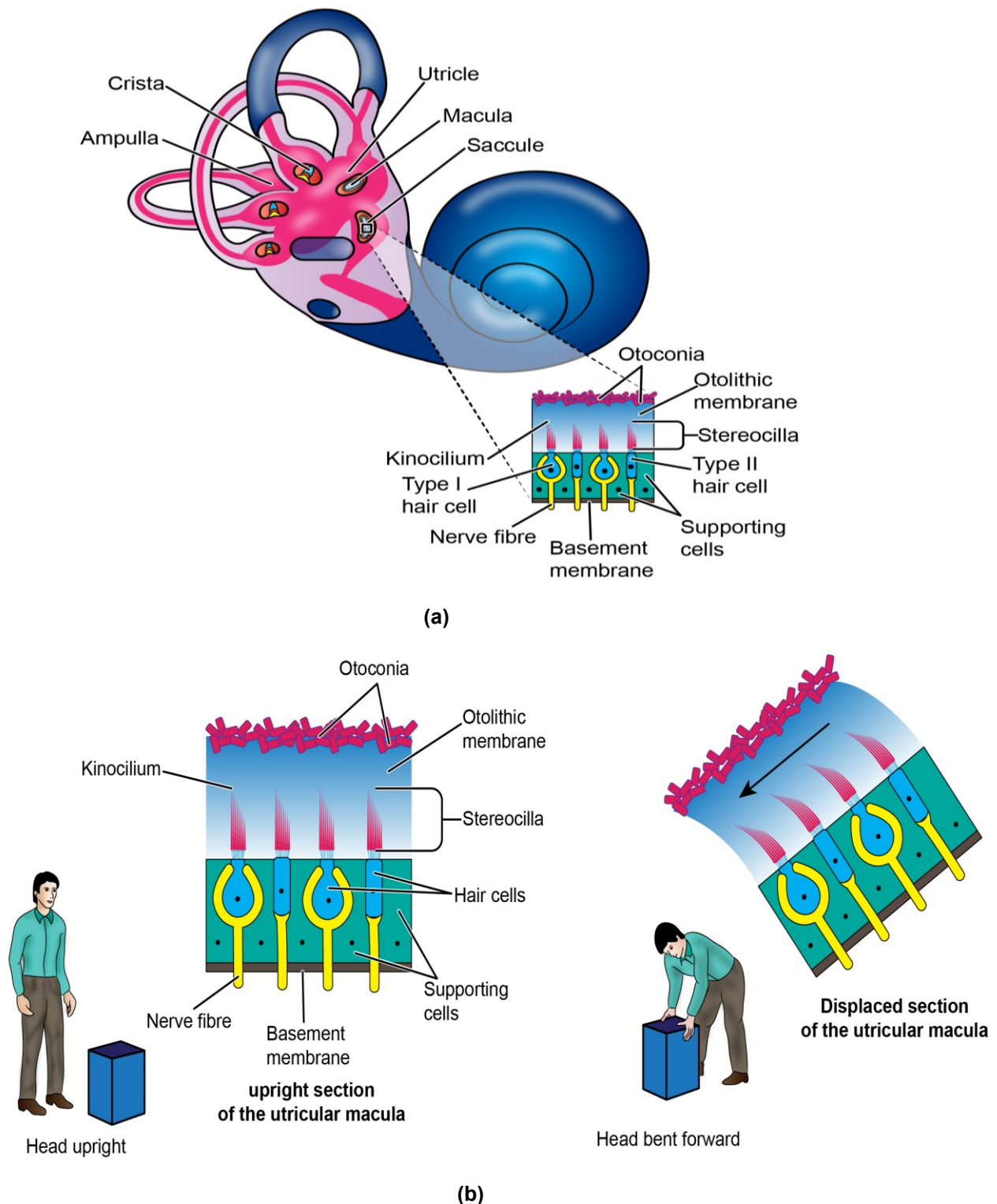


Fig. 8.17: a) Structure of macula contained in the membranous, sac like utricle; b) Role of macula as static balance organ.

SEMICIRCULAR DUCTS OR CANALS

The three semicircular ducts, lie at right angles to each other and are named in accordance to their position as superior, horizontal and posterior (Refer again to Fig. 8.15). One of these lies in the horizontal plane while the other two are vertical, one directed forwards and the other backwards. Each canal has an expanded end, called the ampulla (plu: ampullae) (Fig. 8.15).

The semicircular canals are connected to the utricle at both ends (Figs. 8.15 and 8.17). Each ampulla of the semicircular canals internally contains a sense organ called crista (Fig. 8.18 a) which is responsible for detecting kinetic (motion) sense. The crista consists of sensory cells with sensory hairs, which are embedded in a gelatinous mass called cupula terminalis in which a paper thin otolith made of calcium carbonate crystals known as **otoconia** are also embedded just above the sensory hair tips. As the animal moves or bends or tilts in any direction in relation to gravity these crystals also move and touch the hairs of sensory cells, which produce nerve impulses and convey the information of the movement that occurred to the brain

While the utricle and saccule are static balance organs that give information about the position of the head or body with respect to gravity the semicircular canals are designed to respond to rotational acceleration and are relatively insensitive to linear acceleration (Fig. 8.18 b). When the head is rotated the fluid in the canal tends not to move at first because of inertia. Since the cupula is attached, the free end is moved in a direction opposite to the movement of heads, thus stimulating the sensory hair cells and as a result setting up impulses transmitted to the brain by branches of the auditory nerve.

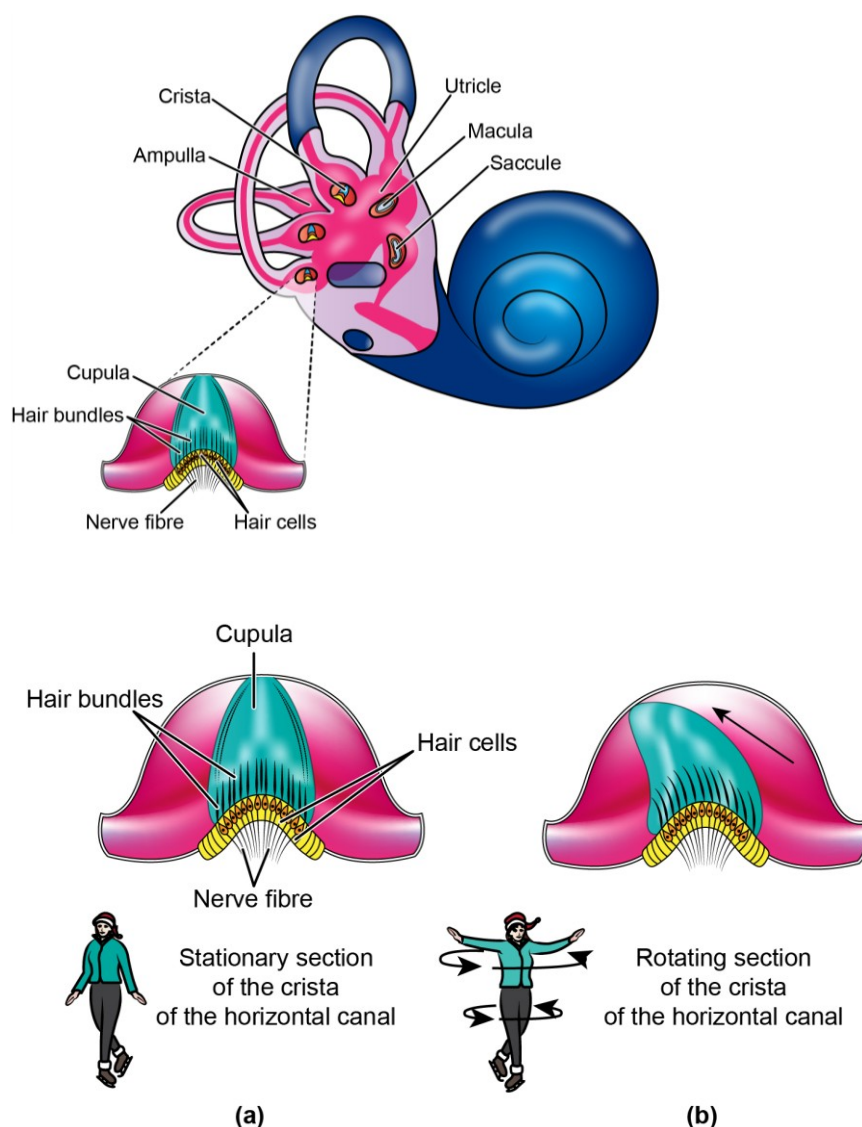


Fig. 8.18: Structure of the membranous labyrinth of human inner ear showing the semicircular canals and enlargement of an ampulla of the semicircular canal showing the sensory organ called crista. (a) Mechanism of sensory action of a crista in stationary position and (b) in rotating action.

8.4.3 Comparative Anatomy of the Ear

All tetrapods (amphibians, reptiles, birds, and mammals) have a middle ear with a tympanic membrane. Reptiles, birds, and mammals also have an external auditory meatus (or canal) which extends from the tympanic membrane to the external surface of the head. However fishes and amphibians do not have an external ear.

Mammals generally have an external structure, the pinna, that helps “collect” and carry the sound to the ear canal and then to the tympanum. The major difference in the middle ear among tetrapods is that it has a single ear bone, or ossicle (often called the columella or stapes), in amphibians, reptiles, and birds, while mammals have three middle-earbones (malleus, incus, and stapes).

OTHER MAMMALS

The shape and size of the pinna of the external ear vary greatly.

In some species of mammals the pinna is movable and so can be moved in the direction of a sound source. The middle ear is more complex and sensitive than that of other tetrapods. For instance, human ear is capable of hearing sound waves ranging from 20 to 20,000 hertz but different mammals possess capacity to hear sounds of different frequencies. For instance, whales, dolphins and porpoises can hear ultrasonic sounds of up to 150,000 hertz and elephants can also hear infrasonic sounds of 10-14 hertz. However, the ear of all species of mammals are similar to humans and consists basically as you have read earlier in this unit of three parts:

i) the external ear ; ii) the middle ear containing three small bones; and iii) the inner, or internal, ear, placed deep in the skull (see Fig. 8.14 again).

The vestibular apparatus of the inner ear of mammals is much like that of humans. However, among all the vertebrates the cochlea is extremely elongated and coiled in only mammals, except for monotremes in which the cochlea is not coiled much.

BIRDS AND REPTILES

The external ear appears for the first time in reptiles in some lizards and crocodiles and is made up of a meatus (passage) that open to the outside by an external opening. In most birds and reptiles the tympanic membrane similar to mammals is not present on the surface of the head but is present internally, at end of the external auditory meatus. In both birds and reptiles a middle-ear cavity is present next to the tympanic membrane and instead of having the three ossicles as seen in mammals, only a single ossicle or bone called the columella or stapes (that is homologous with the stapes, or "stirrup" of mammals) is present (Fig. 8.19). In reptiles and birds, the columella is connected indirectly with the eardrum via a mostly cartilaginous extracolumella and medially to the inner-ear spaces via a widened footplate in the fenestra ovalis.

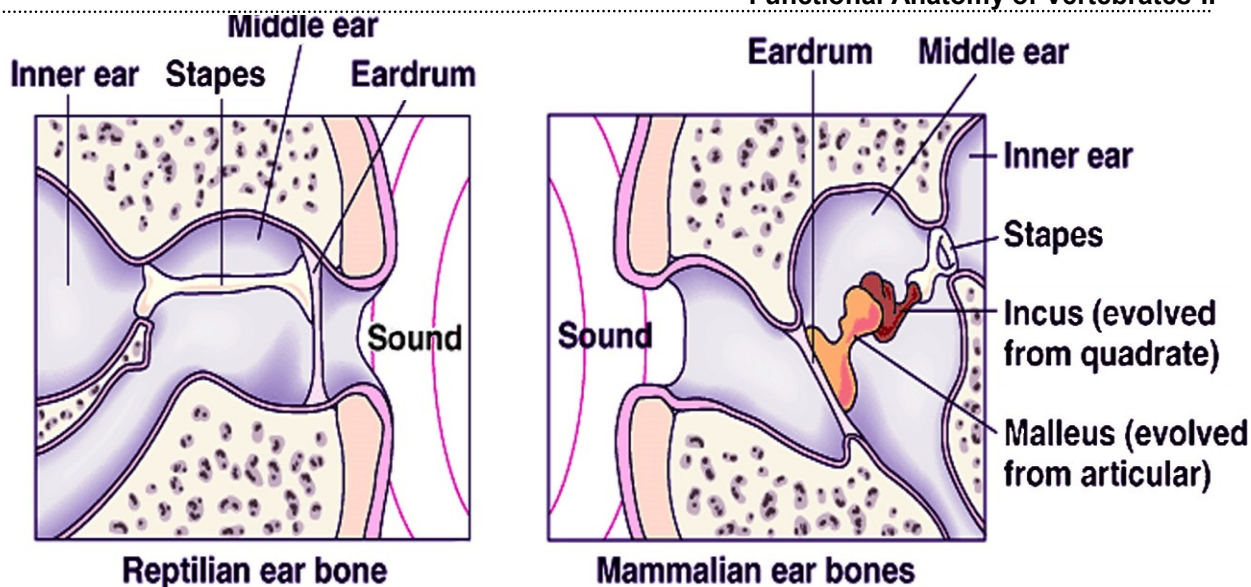


Fig. 8.19: Schematic diagram of comparative anatomy of the middle ear of reptiles and mammals.

The inner ears of both birds and reptiles (Fig. 8.20 that shows the inner ear of tetrapods) have the saccula, utricle, and lagena, as well as the semicircular canals. In reptiles and birds the lagena is elongated and a newly evolved, and organ structure called, the basilar papilla is present. The basilar papilla is elaborated to form the **organ of corti** of the inner ear and contains sensory hair cells. The basilar papilla in reptiles (except for in crocodiles where the lagena is coiled like cochlea of mammals) is generally somewhat shorter than that found in birds. In birds, the basilar papilla sensory hair cells are differentiated into short and tall sensory hair cells, which may have different functions in hearing. In reptiles both the **eustachean tubes** join together to open into pharynx by a single opening.

Birds and most reptiles except for snakes have essentially a similar mechanism of hearing. However, the ear of birds is much more sensitive due to elongation of lagena. In snakes the external and middle ear cavities are absent and hence sound vibrations travel through ground to the lower jaw and from there to quadrate bone to stapes, which carries them to lagena of inner ear for perception of hearing. Therefore, snakes cannot hear sounds travelling through air.

AMPHIBIANS AND FISHES

The external and middle ear is absent in amphibians and fishes. The structure of the middle ear in living amphibians varies considerably, and is often degenerate. The middle ear is absent in amphibian members belonging to Urodela and Apoda. As a result the inner ear in them only functions for maintenance of balance and posture. Hearing is present in anuran amphibians and has evolved due to the modification of lagena. The lagena in anurans has evolved to give rise to the sensory organ called the basilar papilla which functions for receiving sound waves. This basilar papilla of amphibians however, is totally different from that which is present in both the avian and reptilian ear and differs from them in structure and in terms of evolution and embryonic origin.

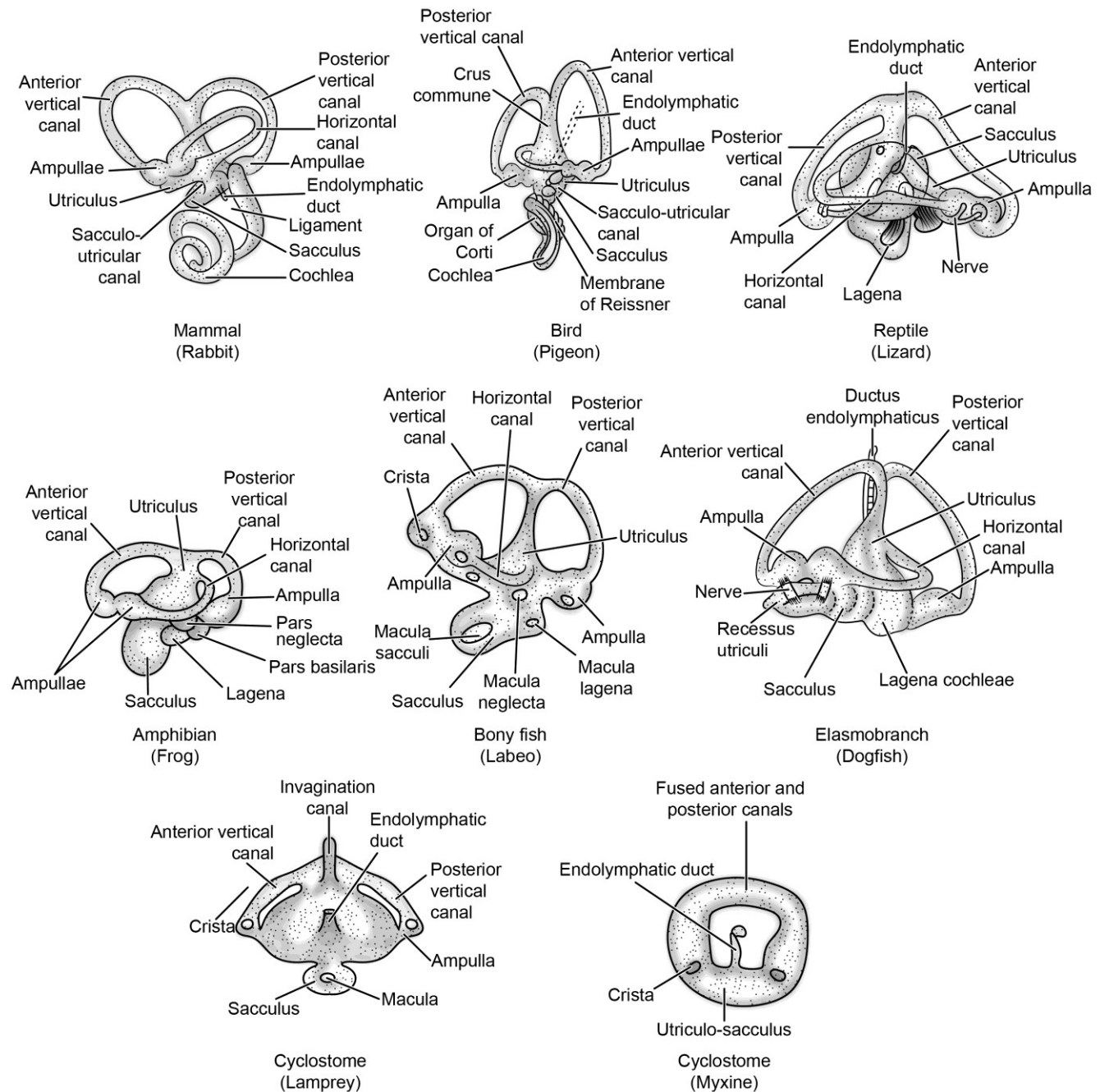


Fig. 8.20: Comparison of semicircular canals of inner ear of vertebrates.

In anuran amphibians the middle ear is made up of the tympanum or tympanic membrane which appears for the first time in ancient amphibians. This tympanic membrane is present on the surface of the body on either side of the head. Sound vibrations received by this membrane are transmitted to the basilar papilla through a columella bone which is present in the cavity of the middle ear. Thus a mechanism has evolved to receive sound vibrations from outside and to transmit them to the sense organ of lagena, so that the nerve impulse can convey information about the sound to the brain.

The jaw less and cartilaginous fishes lack a middle ear and cannot detect sound from distant sources. The inner ear is however, present in fishes (Fig.8.20). The sensory chambers of the inner ear are lined with **sensory hair cells**. Each chamber contains an **otolith (ear stone)**. Sound vibrations passing through the fish are processed as differences in vibration between the dense otoliths (dense) and fine hair cells.

In some species of fishes, the **swim bladder** transmits vibrations to the inner ear (acting somewhat like a hearing aid). In some bony fishes belonging to the Superorder Ostariophysia unique structure called the Weberian apparatus is present (Fig. 8.21). The Weberian apparatus consists of four pair of bones, called the Weberian ossicles. These ossicles or bones grow and physically connect the auditory system, specifically the inner ear, to the swim bladder (also called gas bladder, fish maw, or air bladder). The Weberian apparatus acts as an amplifier of sound waves that would otherwise be only slightly perceivable by the inner ear structure.

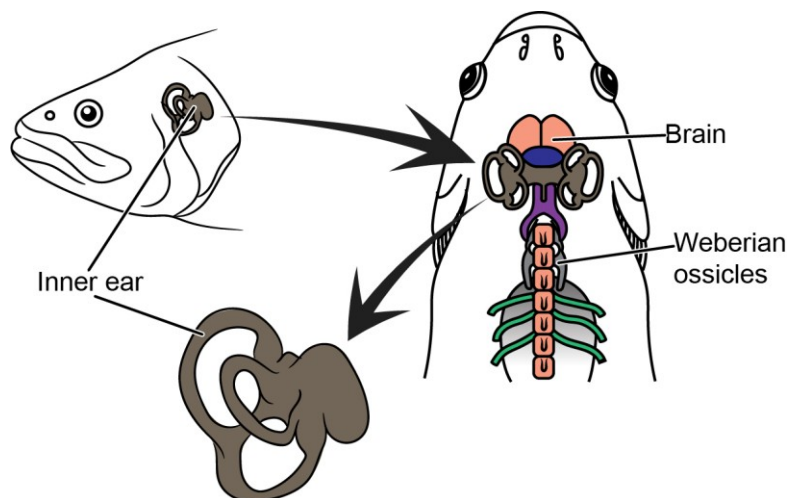


Fig. 8.21: In some fresh water fish (e.g., carp), small bones called **Weberian ossicles** connect the anterior swim bladder to the ear, enhancing vibration detection function. Inner ear and Weberian apparatus are linked to the swim bladder in fish.

Cyclostomes

In Cyclostomes, the number of semi circular canals is reduced. The hagfish has only one semicircular canal which bears an ampulla at each end. In lampreys two semicircular canals are present (see Fig 8.20 again).

SAQ 2

Match the features in column A with the vertebrate groups in column B

Column A	Column B
i) 3 semicircular columns with ampullae	a) Fishes
ii) 2 semicircular canals	b) Lamprey
iii) Utriculus, sacculus and lagena	c) Amphibians
iv) Mechanoreceptors are maculae and cristae	d) Reptiles
v) Choclea with organ of corti and External pinna	e) Birds
vi) 3 chambered ear enclosed in a bony capsule	f) Mammals
vii) Columella present in middle ear	
viii) Webarian ossicles	
ix) Tympanum	
x) malleus incus and stapes and external auditory maetus	

8.5 OLFACTORY ORGANS OF VERTEBRATES

The ability to detect smells or odours is called olfaction. Smells or odours are detected by chemoreceptors. The general features of the olfactory system are remarkably consistent across vertebrates. In higher vertebrates **smells** are detected and identified by the olfactory system with the help of its olfactory organs. Lower vertebrates such as fish and amphibians can however, detect smells that are present in the environment in the form of chemicals by means of chemosensory receptors that are located on various parts of their body.

8.5.1 Olfactory System in Humans

In vertebrates, including humans, the olfactory system and its olfactory organs consist of three main components which are as follows: i) The olfactory epithelium, ii) olfactory bulb and iii) olfactory tract. The olfactory epithelium (Fig. 8.22) is a specialized type of epithelium and is present within the nasal cavity. It contains **basal cells**, supporting cells known as **sustentacular cells** which secrete mucous and support the olfactory sensory cells which are the actual chemoreceptors. Each sensory cell has a tuft of cilia at its apical end, embedded in mucous secreted by the sustentacular cells and they communicate directly with the olfactory bulb by their axons that pass through the bony cribriform plates.

To be odorous, a substance must be sufficiently volatile for its molecules to be given off and carried into the nostrils by air currents.

The solubility of the substance also seems to play a role; chemicals that are soluble in water or fat tend to be strong odorants. No unique chemical or physical property that can be said to elicit the experience of odour has yet been discovered.

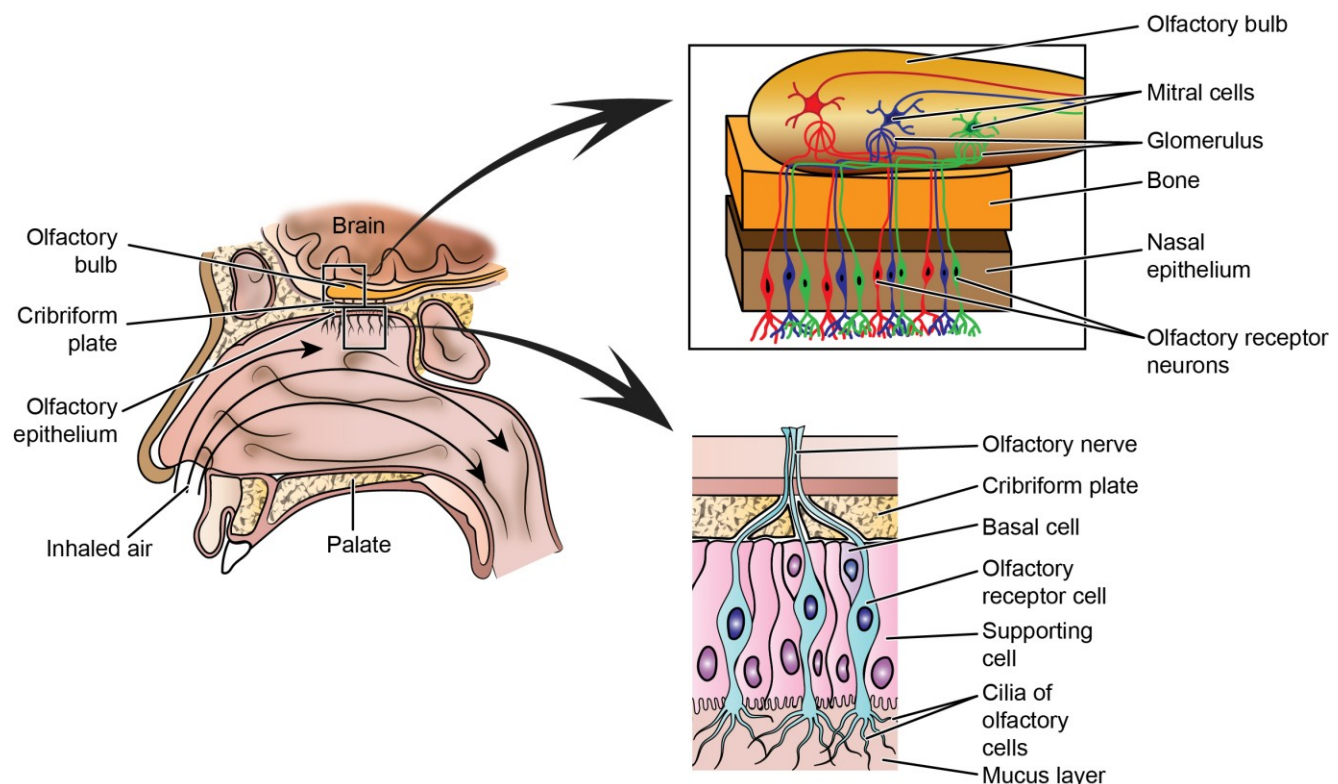


Fig. 8.22: Human olfactory system showing the olfactory bulb, cribriform plate and olfactory passage. A part of the olfactory epithelium has been enlarged to show olfactory receptor cells, supporting cells, and basal cells. Odorants dissolve in the mucus layer and contact the cilia of the olfactory cells. Axons of the olfactory cells penetrate the bony cribriform plate on their way to the CNS. The sensory cells are actual nerve cells that penetrate the epithelium with modified dendrites.

8.5.2 Comparative Olfactory System of Vertebrates

An **aroma compound**, also known as an **odourant**, **aroma**, **fragrance**, or **flavour**, is a chemical compound that has a smell or odour. For a chemical compound to have a smell or odour it must be sufficiently volatile to be transported to the olfactory system in the upper part of the nose.

In tetrapods, a small external opening or **naris** provides access to each nasal passage and the back of the nasal passage opens into the mouth through the **internal naris**. The upper part of the nasal passage contains the mucous covered sensory epithelium while the lower part is used as respiratory passage.

Mammals

In mammals, including humans the nose is a very complex organ with multiple functions that include not only olfaction, but also the conditioning like humidifying, warming, and filtering the inhaled air. In humans the olfactory receptors are located high in the nasal cavity. Most mammals are macrosmatic (a strong sense of **smell**) and have a large area of olfactory mucous membrane. Some mammals however, like seals, baleen whales, most primates are microsmatic (a poor sense of **smell**). In the toothed whales the olfactory region is practically suppressed in the adult and so their sense of smell is not developed.

Birds

The avian olfactory system does not differ much in gross anatomy from that of mammals, reptiles or amphibians. Most birds have paired external nares situated near the base of the top mandible of their bills. Birds breathe through these nares that lead air into a series of three internal nasal cavities. The function of the first two chambers is probably to warm and moisten the incoming air before it enters the respiratory system. The second chamber has an opening into the buccal cavity that allows a part of the air to go directly to the lungs. The remaining air then passes into the third chamber, which is the only one to contain the olfactory epithelium. Histologically avian olfactory epithelium is basically similar to mammals. Olfactory receptors in the epithelium connect, via paired olfactory nerves, with olfactory bulbs located at the rostral end of the brain.

Reptiles

In reptiles, each nasal organ consists of an external naris, a vestibule, a nasal cavity proper, a nasopharyngeal duct, and an internal naris. These structures serve as air passages and are lined with nonsensory epithelium. The sensory or olfactory epithelium lies principally on the roof and anterodorsal walls of the nasal cavity. The vestibule is a short tube in turtles and snakes, and is much longer and often curved in lizards. A concha (narrow curved bone covered with epithelium that projects into the nasal passage) covered with sensory epithelium projects into the nasal cavity from the lateral wall. The vomeronasal organ, an olfactory structure is used in reptiles primarily to detect non-aerial, particulate odors that are carried to the vicinity of the duct by the tongue.

Amphibians

The nasal organs of salamanders are composed of a large main cavity divided partially by a ventrolateral fold. Aquatic salamanders have the simplest and

smallest nasal cavities, but they possess large vomeronasal organs. Frogs, in general, have a complex nasal cavity consisting of three chambers and a large vomeronasal organ (to be discussed later). Caecilians have simple nasal cavities similar to salamanders but with a major modification, the sensory tentacle. The size, position, and structure of the tentacle vary among different species. However, in all caecilians, the tentacle arises from a combination of nasal and orbital tissues as a tubular evagination from the corner of the eye. Odour particles are transported via the nasolacrimal duct to the vomeronasal organ.

Fishes

In fishes there are two blind ended olfactory lateral pits called the nasal sacs in which the olfactory receptors are embedded. Water carrying chemicals follows in and out of these sacs as the fish swims.

Vomeronasal organ

Many animals, including most mammals and reptiles, but not humans, have two distinct and segregated olfactory systems: a main olfactory system, which detects volatile stimuli, and an accessory olfactory system, called the vomeronasal organ located in the vomer, between the nose and the mouth. Its sensory cells project into the lumen by means of microvilli. The neural circuit of the vomeronasal organ is also separate and runs parallel to the olfactory neural system. The vomeronasal organ is absent in most turtles, crocodiles, birds, some bats, primates and aquatic mammals. In amphibians, some reptiles especially snakes and in some mammals a separate and distinct region of the olfactory epithelium forms the vomeronasal epithelium of the **vomeronasal organ** or **Jacobson's organ**. Snakes use the vomeronasal organ to smell prey, sticking their tongue out and touching it to the organ as in snails (See Fig. 8.23).

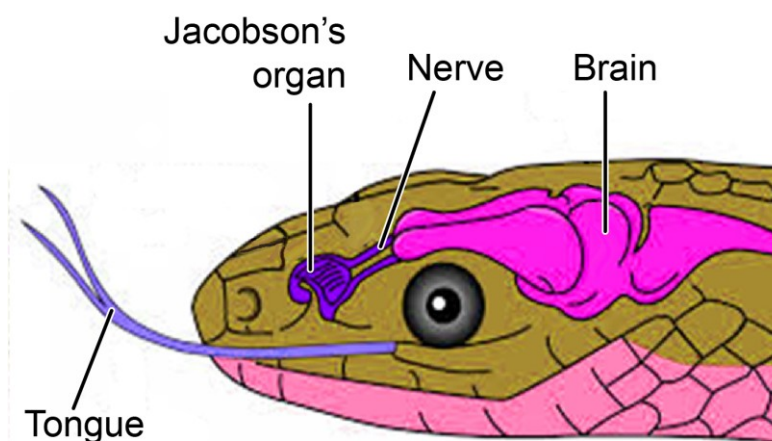


Fig. 8.23: Jacobson's organ also known as vomeronasal organ in snakes is important for detecting odours. The tongue captures the odour particles that are mixed in the fluid in the mouth and conveyed to the receptor cells. By Fred the OysterThe source code of this SVG is valid.This vector image was created with Adobe Illustrator. - Own work, CC BY-SA 4.0,

In the next section we will discuss some specialised sense organs found only in particular groups of vertebrates.

8.6 SPECIALISED SENSORY ORGANS

Some sensory structures are considered to be so unique, or so complex that they are called special sensory organs for example the electroreceptors, lateral line system, pit organ (thermoreceptors of snakes) and systems for echolocation. We will first discuss the lateral line system in fishes.

8.6.1 Lateral Line System in Fishes

Lateral line system (LLS) is a sensory system which is basically a system of tactile sense organs that is unique to aquatic vertebrates. It occurs in cyclostomes, fishes and amphibians but is not found in terrestrial vertebrates. The lateral line system detects movements, currents including minor currents, vibrations, and pressure gradients that are present in the surrounding water. The lateral line system enables the fish to determine the direction and rate of water movement. The fish can then get a sense of its own movement, that of nearby predators or prey, and even the water displacement of stationary objects.

The lateral line system is usually visible as faint lines of pores running lengthwise, along each side of the body, from near the gill covers to the base of the tail (Fig. 8.24 a). It is made up of a series of mechanoreceptors called **neuromasts** or lateral line organs. The neuromasts enable the organism to sense mechanical changes in water. Two main types of neuromasts are located in animals that have lateral lines namely i) superficial or free standing neuromasts which are located externally on the surface of the body, and ii) canal neuromasts which are located underneath the skin in the subdermal, fluid filled canals of the lateral lines. The canal neuromasts are arranged in an interconnected network along the head and the body.

In amphibians the lateral line system occurs only in larval forms and in adult forms that are completely aquatic. In Holocephali fishes the canals that are in contact with the neuromasts are fully exposed while in primitive sharks they are in the form of open grooves. However in, majority of elasmobranchs and teleosts the canals are closed and filled with mucus. The canals open to the exterior at intervals by means of tubules (Fig. 8.24b).

Neuromasts (Fig. 8.24 c) are made up of a cluster of sensory and support cells, encapsulated within a jelly like sheath called the cupula. The neuromasts are supplied with VII, IX and X cranial nerves. Each sensory cell, or hair cell, bears several small sensory cilia. Each cilium may be stimulated by water movement or pressure from a single direction. 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.

Disturbances of many kinds in the surroundings of a fish can activate the neuromasts, but water moving on the body surface provides the most active stimulation. The sensory hair can detect two types of water currents i.e. water moving from head to tail and from tail to head. Neuromasts send a steady spontaneous train of bioelectric potentials along their nerves and the rhythm of the pulse changes during stimulation. Removing the lateral line organs or blocking them causes disorientation in fishes and loss of ability for schooling behaviour.

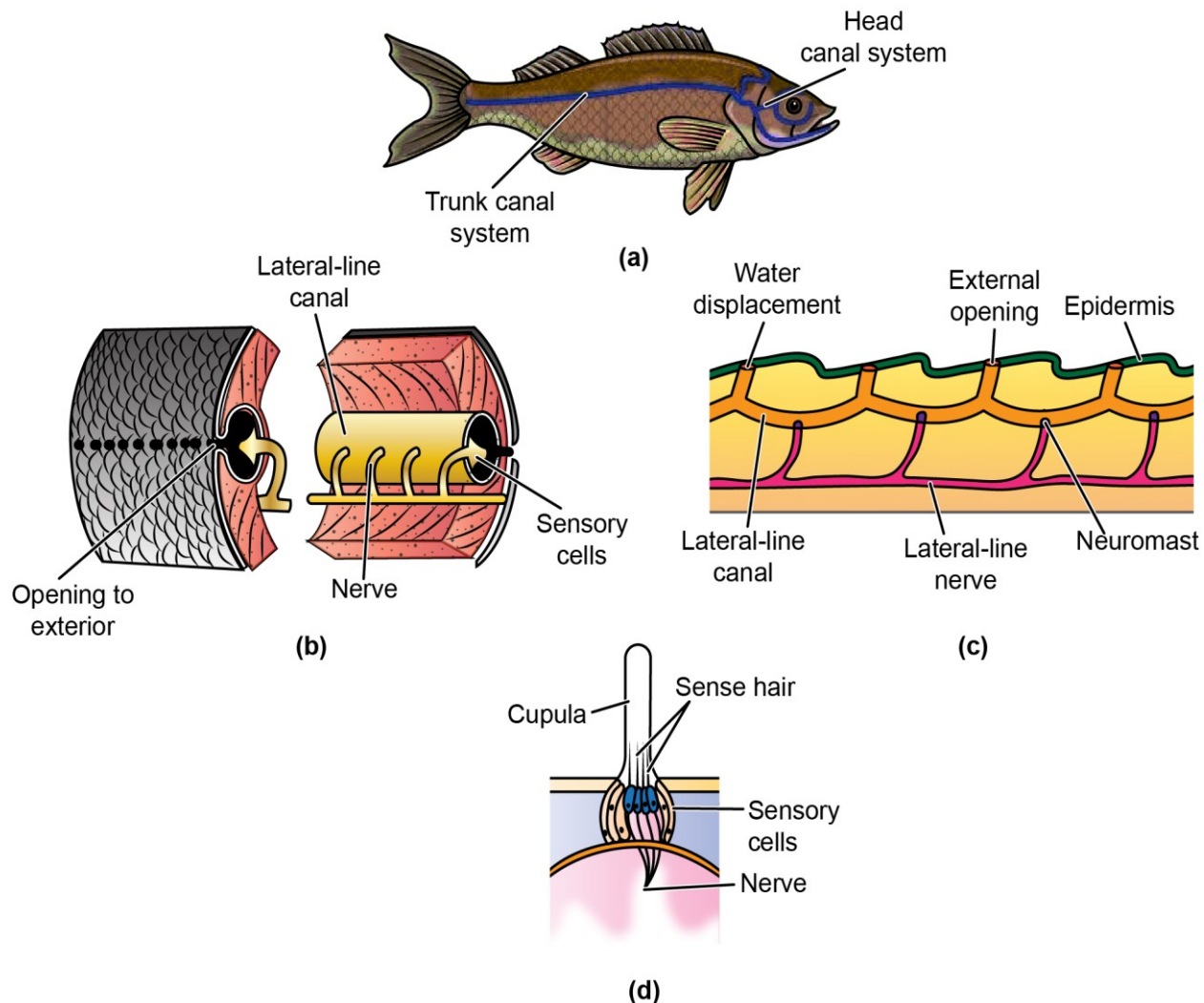


Fig. 8.24: a) Lateral line organs in fish, b) canal organ neuromast. Each opens to the exterior by a pore, c) superficial neuromast; d) section of fish showing location of lateral line canal.

Electroreception in Fishes

The neuromast system, besides functioning as an organ for detection of water currents, also responds to weak electric potential. This information helps the fish to orient itself, to avoid enemies and to participate in schooling. Most fishes produce enough electric potential when their muscles contract to make their presence detectable. Others produce a more powerful electric field by specially modified muscles or tissues—the electric organs and can monitor disturbances in their field caused by objects that enter it. 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.

Fishes that have electric organs may also use them to signal other individuals or to defend themselves. Electroreceptors are not effective in terrestrial animals, as electric currents are not conducted so easily in air as in water.

8.6.2 Pit Organs in Snakes

The pit receptors of reptiles bear a striking morphological resemblance to the external neuromasts of fishes. Hence it has been hypothesised that the pit organs are evolutionary derivatives of neuromasts. However, their innervation by the spinal or Vth cranial nerve is not consistent with this hypothesis.

Two families of snakes, Viperidae and Boidae have specialised heat sensors or receptors on the body surface in the form of pits. Pits open to the surface between epidermal scales. These pits contain free nerve endings that are excited by infrared radiation and the information is transmitted to the optic tectum of the midbrain. Apical pits are scattered on the body surface, mostly on the trunk, and provide sites for the input of tactile stimuli. In boa constrictors and pythons of family Boidae the free nerve endings lie between epidermal scales along the lips these are known as labial pits. In sub-family Crotalinae to which the snake, pit viper belongs, specialised pit receptor is found on the head. The pits are located on the posterior region of loreal scale, which is located between the external nares and the eye, and are termed as loreal pits or facial pits. These pits are directed forward and may be several millimetres wide and equally deep (Fig.8.25 a and b). These differ from the labial pits of pythons. Sensory nerve endings are suspended in a thin pit membrane halfway between the bottom of the pit and not lying at the bottom as in pythons.

The pit or cavity is divided into an inner and outer chamber. A duct between the inner chamber and the skin of the snake may prevent differential changes in pressure arising between the two chambers. The separating membrane is innervated by trigeminal nerve, which is responsible for the input from the head sensor to brain in snakes. Experimentally it was recorded that the frequency of nerve impulses increases as the receptor object warms up. Fluctuation occurs during the cooling of the object that is registered by the pit.

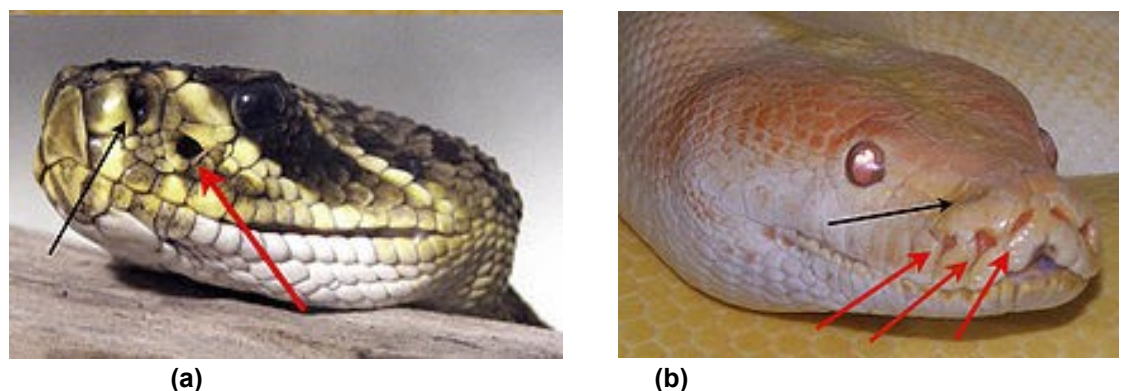


Fig. 8.25: Thermoreceptive pit organs in snakes. a) Labial pits in python, b) Facial pits in viper. Black arrow points to nostrils and red arrow indicate the pits (Wikipedia).

Since birds and mammals are warm blooded, they emit infrared radiation and experiments show that temperature changes of 0.003°C can be detected by the pit organs.

8.6.3 Echolocation in Aquatic (Dolphins) and Aerial Mammals (Bats)

Echolocation is a technique used by bats, dolphins and other animals to determine the location of objects using reflected sound. This allows the animals to move around in pitch darkness, so they can navigate, hunt, identify friends and enemies, and avoid obstacles. Amongst mammals bats and cetaceans have made hearing as a distance sense for navigation through the phenomenon of echolocation. Dolphins (Fig. 8.26) and whales use echolocation by emitting high-pitched clicking sounds. The sounds emitted by the dolphins and whales are made by squeezing air through nasal passages near the blowhole (Fig. 8.26). These soundwaves then pass into the forehead, where a big blob of fat called the melon focuses them into a beam. If the echolocating call of the dolphins and whales hits something, then the reflected sound is picked up through the animal's lower jaw and passed to its ears. Echolocating sounds are so loud that the ears of dolphins and whales are shielded to protect them. Dolphins and whales use this method to work out an object's distance, direction, speed, density and size.

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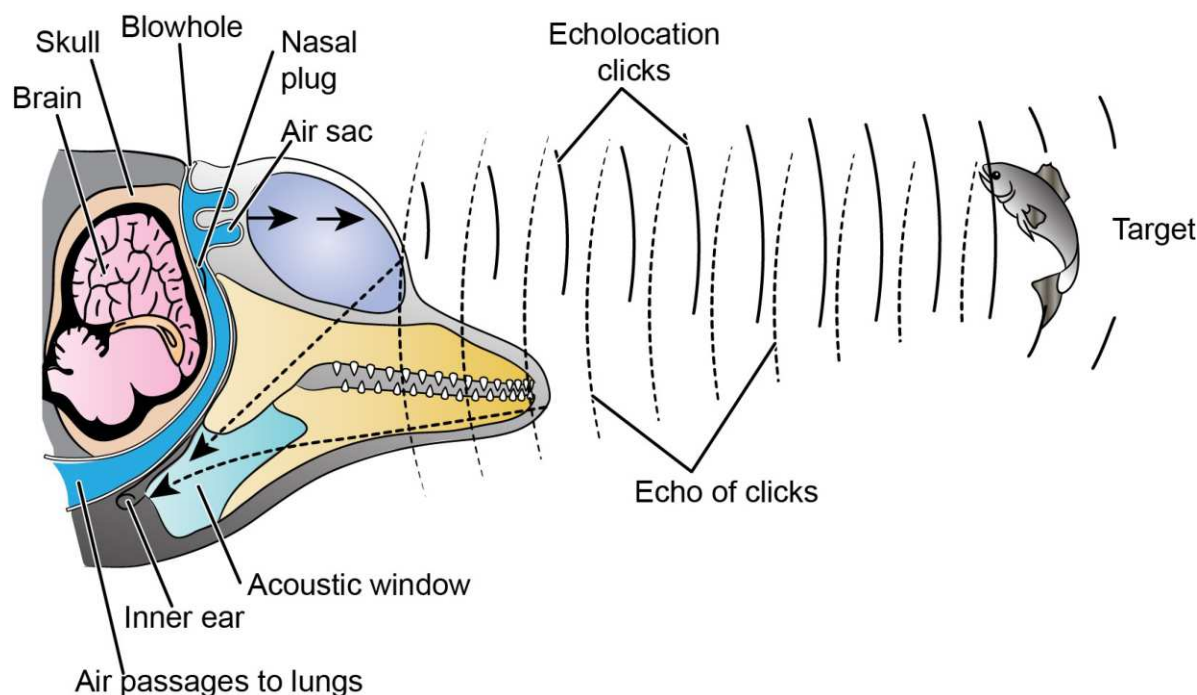


Fig. 8.26: Echolocation of male Indo-Pacific bottlenose dolphin.

Of the 900 known species of bats, more than half rely on echolocation to detect obstacles in flight and in finding food. Echolocation, along with morphological and physiological adaptations allow bats to “see” through sound. It was found that insectivorous bats produce sound waves of high frequency. The human ear cannot perceive these sounds. The bats perceive objects by emitting sound waves that are reflected by the objects as echoes and are then detected by the bat's ears. The echoes return to the ears at different times and at different loudness levels depending on the object generating the echoes. Bats can thus locate and avoid obstacles in total darkness by means of echolocation.

Most bats (microchiropteran) produce very short sound impulses each lasting only approximately one to two milliseconds. These ultrasonic bursts are produced in the larynx and emitted through the slightly opened mouth. Some

species use tongue clicks. Bats detect the difference between the emission of a sound and its return as an echo (Fig.8.27). The time differential in the arrival of the echo into the different ears gives information about the direction of the reflecting object.

The horseshoe bats (Rhinolophidae) and old world (Hipposideridae) have peculiar cutaneous growths on their noses and emit ultrasonic sounds of consistently high frequency through their nostrils. They can produce sound with the mouth closed or while catching and eating insects. The horseshoe-shaped flaps around the nostrils are used as a sound cone, almost as a megaphone, during the emission of ultrasonic sounds and the curvature of these flaps can be changed by muscle contraction. Thus, the animals are in a position to change the width of the sound cone in accordance with the different distances of the sound reflecting object by sweeping the sound beam back and forth to scan their surroundings.

The cave dwelling members of the genus *Rousettus* orient themselves with the help of large eyes when sufficient light is available. In total darkness, they can produce ultrasonic cries and use them for, echo sounds. These sounds are not made in the larynx, but by a clicking of the tongue.

Echolocation frequencies are ultrasonic ranging from 20 to 200 kilohertz that are mostly inaudible to humans. However, we can hear the tongue clicks of some bats like the spotted bat *Euderma maculatum*. In general echolocation calls are described by their frequency; their intensity in decibels and duration in milliseconds. The pitch of the calls are produced with both constant frequencies (CF calls) and varying frequencies that are modulated (FM calls). Most bats use a combination of CF and FM calls and these are species specific. Since low frequency sound travels further than high frequency sound, FM calls give bats more detailed information such as size, range, position, speed and direction of flight of the prey.

The ears and brain of bats are adapted for echolocation that is, to the sound they emit and the echoes they receive. A concentration of receptors in the cochlear basilar membrane makes them extremely sensitive to frequency changes. For bats to hear the echos and to prevent them going deaf from the high intensity calls they emit, the middle ear muscle called stapedius contracts to separate the three ossicles malleus, stapes and incus and reduces the hearing sensitivity just before it emits the call and relaxes again after the call to be able to receive its echo. The auditory cortex of bats is also large and has three important areas FM-FM, CF-CF and DSCF. The external structure of ears in bats also plays an important role in receiving echoes.

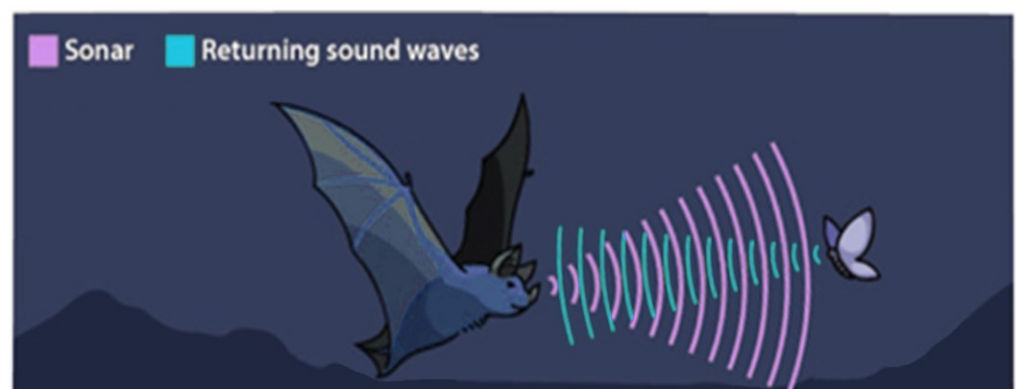


Fig. 8.27: Echolocation of an insect by little brown bat.

SAQ 3

Fill in the blank spaces with appropriate words:

- i) Lateral line organs consist of sensory papillae called which are composed of surrounded by supporting cells.
- ii) Pit organs of snakes are receptors.
- iii) is a method used by bats to orient themselves in space by detecting the differences between the of the sound and its return as an
- iv) The cave dwelling bat produces ultrasonic cries by

8.6 SUMMARY

In this unit you have studied that:

- Receptor organs are structures that are capable of responding to definite stimuli by setting up impulses which are in turn transmitted by nerve fibres to the central nervous system. Receptor organs are classified as external and internal sense organs.
- The vertebrate eye has no true homologue among other phyla and appears for the first time in cyclostomes.
- In the vertebrate eye, light must pass through various cellular layers of the retina before it can stimulate the sensory receptors, or rod and cone cells. Six broad, strap-shaped muscles move the eye. Other accessory structures associated with the eyes of different vertebrates in each case serve to adapt the animal better to its own particular environmental needs.
- The vertebrate ear, at least in higher forms, functions in a dual capacity as an organ for equilibrium and hearing. The sensory portion of the ear is called the inner ear or membranous labyrinth. The portion concerned with equilibrium is the vestibular apparatus and consists of utricle, saccule, endolymphatic duct and three semicircular canals. The portion concerned with hearing is lagena. In mammals and birds the lagena is specialised to form the coiled cochlea.
- The receptors for the sense of smell are confined to the olfactory epithelium of fishes, and olfactory epithelium of the nasal canal of tetrapods. These receptors communicate with the olfactory bulb through the bony cribriform plate.
- Neuromast organs are fluid-filled pits consisting of sensory and supporting cells and sensory terminals. They may open to exterior or occur located enclosed in canals. They are present only in fish and aquatic amphibians. Electoreception and mechanoreception are the attributed functions. Neuromast organs are innervated by cranial nerves VII, IX and X.
- Snakes have pit receptors of uncertain homology. These occur as heat sensors or receptors on the body surface in the form of pits. Pits open to

the surface between epidermal scales. These pits contain free nerve endings that are excited by infrared radiation and the information is transmitted to the optic tectum of the midbrain. Apical pits occur at the apex of body scales. Pit organs occur on the head of vipers and boas.

- Echolocation in mammals is observed in aquatic mammals like whales and porpoises and dolphins and aerial mammals like bats. They make use of reflected sound waves for orientation, navigation and for communication.

The ability to echolocate in whales, dolphins and porpoises, is used found to communicate and navigate as well as for prey detection over long distances under water. Echolocation method is highly developed in microchiropteran bats that emit high frequency and short wavelength sounds

8.7 TERMINAL QUESTIONS

1. Give **two** special features of bird eyes.
2. What are neuromasts? Give three functions of neuromasts.
3. What is the function of choroid in the eye? How does it help nocturnal vertebrates?
4. What is the visual pathway when light falls on the retina?
5. What are pit organs in reptiles? How do vipers and boas locate prey?
6. How is the mammalian ear different from the ear in reptiles and birds?
7. What kind of cells make up the olfactory epithelium?
8. How do bats prevent getting deaf from their high frequency calls? How do they get information about the immediate environment?

8.8 ANSWERS

Self-Assessment Questions

1. i) Rods; ii) Cones; iii) Sclera; iv) Lens and cornea;
v) regulates light entering the eye; vi) ciliary muscles.
2. Fishes – i); iii) iv); viii)
Lamprey – ii)
Amphibians – i); iii); iv); vi); vii); ix)
Reptiles – i); iii); iv); vi); vii); ix)
Birds – i); iii); iv); v) minus pinna; vi); vii); ix); x)
Mammals – i); iii); iv); v); vi); ix); x)
3. i) Neuromasts, hair cells
ii) Thermoreceptors/ Infrared rays
iii) Echolocation, emission, echo
iv) Clicking of tongue

Terminal Questions

1. Presence of a serrated pecten arising out of the retina.
2. Neuromasts are the sensory papillae surrounded by supporting cells, present on the surface of the skin. The three functions of neuromasts are: (1) short distance auditory function, (2) temperature reception and (3) chemical sense.
3. Choroid is the pigmented layer between the sclera and retina that shields the retina from reflected light in daylight, but in nocturnal animals it is a shiny mirror like layer called tapetum lucidum which actually gives a second chance for light – photoreceptor to react in dim light as it reflects the light back on the retina.
4. cornea → aqueous chamber → pupil → lens → vitreous chamber → retinal photoreceptors → bipolar cells → ganglion cells → optic nerve → visual cortex
5. Pit organs in reptiles are pits or depressions on the body of reptiles especially snakes that hold the thermoreceptors that respond to infrared rays or radiant heat. Vipers, boas and pythons can detect even very mild fluctuation in temperature and also detect warm-blooded animals at a distance of several feet, and thus locate them accurately.
6. Mammalian ear has an external pinna that is not found in any vertebrate; the middle ear has three small ear bones the malleus, incus and stapes while reptiles have a single bone columella in the middle ear; tympanum lies in a depression on either side of the head in reptiles and at the end of the external auditory meatus in mammals. Reptile inner ear has sacculus, utricle and lagena along with the 3 semicircular canals while in mammals the lagena is modified to form the 3 chambered coiled cochlea which contains the organ of Corti having hair cells or sound receptors.
7. The olfactory epithelium has (i) olfactory receptor cells with olfactory cilia that lie embedded in mucous in the nasal cavity and interact with the odour molecules. (ii) supporting cells and (iii) basal cells.
8. The muscle in the middle ear contracts thereby, separating the ear ossicles from each other just before the bat sends its high frequency call; this reduces the hearing and just after the call the muscle relaxes allowing the echo to be received by the inner ear.

Acknowledgement of Figures

Fig. 8.16: Source: <http://www1.appstate.edu/~kms/classes/psy3203/Ear/cochlea4.jpg>

Fig. 8.21: Source: From Blausen.com staff (2014). "[Medical gallery of Blausen Medical 2014](#)". *WikiJournal of Medicine* 1(2). DOI: [10.15347/wjm/2014.010](#). ISSN 2002-4436.

Fig. 8.23: Source: By Fred the Oyster! The source code of this SVG is valid. This vector image was created with Adobe Illustrator. - Own work, CC BY-SA 4.0

ENDOCRINE SYSTEM |

Structure

9.1	Introduction	9.4	Reptiles
	Objectives	9.5	Amphibians
9.2	Endocrine Glands in Mammals	9.6	Fishes
	Neuroendocrine Gland:		Elasmobranchs
	Hypothalamus and Pituitary Glands		Bony Fishes
	Pineal Glands	9.7	Agnatha
	Endocrine Glands of Metabolism:	9.8	Summary
	Thyroid Glands	9.9	Terminal Questions
	Endocrine Glands of Metabolism:	9.10	Answers
	Parathyroid Glands		
	Endocrine Glands of Metabolism:		
	Pancreas		
	Endocrine Glands of Metabolism:		
	Adrenal Glands		
	Endocrine Tissue of		
	Gastrointestinal Tract		
	Endocrine Tissue of Gonads		
9.3	Aves (Birds)		

9.1 INTRODUCTION

In the previous unit 7 and 8 of this course you studied about one of the two great communication networks-**the nervous system and its sense organs**. The other organ system that works in an integrated manner with the nervous system and its organs in communication and regulating activities of the organism is the **endocrine system** about which we will be studying in the present unit.

The endocrine system is networks of glands in our body that secrete hormones that help cells communicate with each other. The secretions of

hormones, of the endocrine glands, have a wide range of action. It could be said that while regulation by nervous system and its organs is localised and rapid, the regulation by the endocrine system is more general and relatively slow.

A **hormone** is a biological compound that ensures homeostasis or the maintenance of the constancy of the internal environment. It further regulates general metabolism, functions of various systems and mental abilities. This **biological** compound also plays a vital role in morphogenesis, in reproductive processes and behaviour associated with sex that includes courtship, nest building, parental care and migration. Hormones travel through the bloodstream to their target cell and bind to their specific receptors and activate the various processes. Originally, hormones were defined as chemicals produced by ductless endocrine glands that travel through the blood to exert their effect at some distance from where they are produced. Now, we know that animals, apart from the hormones produced by endocrine glands have several other chemical messengers which include neurotransmitters, local chemical messengers such as histamine that participate in inflammatory and immune reactions, growth factors that stimulate growth, prostaglandins that are lipids and produce a number of effects and chemical signaling molecules the pheromones that are released into the environment and affect behaviour.

Objectives

After studying this unit you should be able to:

- ❖ describe the location, structure and functions of the endocrine glands of mammals;
- ❖ list the secretions of the different endocrine glands in mammals; and
- ❖ discuss the variation in structure and function of endocrine glands of aves, reptiles, amphibian, fishes and agnatha.

9.2 ENDOCRINE GLANDS IN MAMMALS

Endocrine glands as mentioned above are ductless glands of the endocrine system that secrete their products, hormones, directly into the blood.

Hormones fall into one of three categories: 1) **Endocrine hormones** travel long distances through vascular tissues to the target tissue; 2) **Paracrine hormones** travel to nearby cells through the interstitial spaces between cells. 3) Some hormones are released outside of a cell, then directly affect that cell itself. These are known as **autocrine hormones**.

The major glands of the endocrine system include the hypothalamus, pituitary gland, pineal gland, thyroid gland, parathyroid gland, pancreas, adrenal glands, ovaries and testes. The hypothalamus and pituitary gland are neuroendocrine organs and will be discussed together. We shall begin with the description of the endocrine structures as found in mammals. In this unit, we shall first study the endocrine glands of the mammals, the hormones they secrete and the functions they perform. This would be followed by a study of the endocrine glands in different classes of vertebrates.

9.2.1 Neuroendocrine Glands: Hypothalamus and Pituitary Gland

A detailed description of the location and structure of the **hypothalamus** has been provided in the previous unit (Block 2, Unit -7) which you may have completed by now. It is advisable to go through unit 8 before you begin studying this unit. In this unit we will discuss the location and structure of hypothalamus in relation to the pituitary gland. The **pituitary gland** is a small unpaired structure found attached to the ventral side of the brain (Fig. 9.1). More specifically, the organ, also known as hypophysis cerebri is found attached to the **hypothalamus** on the floor of diencephalon by a narrow stalk and is located in a depression, sella turcica in the sphenoidal region of the skull.

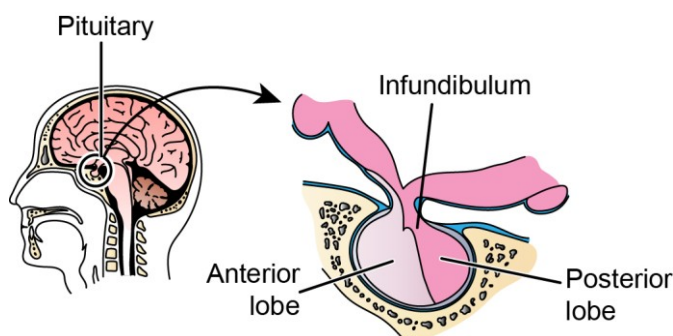


Fig. 9.1: Diagrammatic representation of pituitary gland.

The pituitary consists of two major parts, a larger anterior lobe, the adenohypophysis (pars buccalis) and a smaller posterior lobe, the neurohypophysis (pars nervosa). Both the structures are ectodermal derivatives. The pituitary (hypophyses) originates from two sources, one as an outgrowth from the floor of the diencephalon - the infundibulum and the other as an evagination of the roof of the stomodaeum - the Rathke's pouch. The distal part of Rathke's pouch becomes separated from it and comes into close contact with the infundibular outgrowth to develop into adenohypophysis (Fig. 9.2). The infundibular outgrowth is connected with the hypothalamus by the infundibular stalk and forms the neurohypophysis.

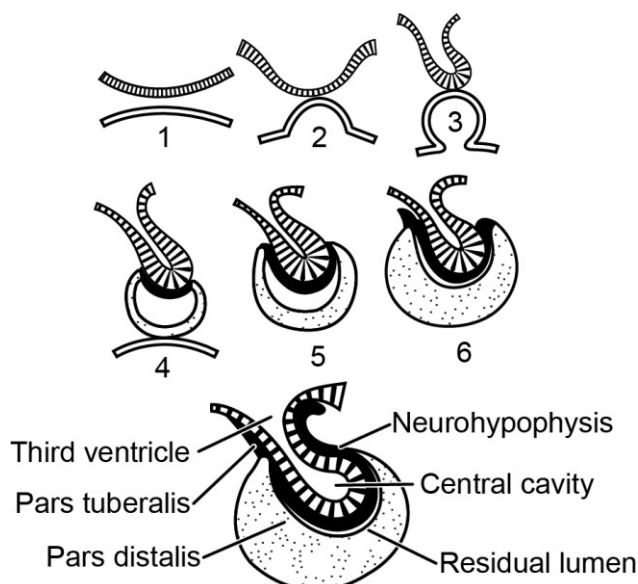


Fig 9.2: Stages in embryonic development of pituitary gland.

The adenohypophysis (anterior pituitary) shows further divisions: The part of the adenohypophysis that is in immediate contact with neurohypophysis is **pars intermedia** and the rest of it is greatly thickened to form **pars distalis**. The highly vascular adenohypophysis is formed of cells arranged in a chord-like trabeculae separated by thin walled sinusoids. There are two types of cells, the secretory, granular chromophil cells and the non-secretory, non-granular chromophobe cells. The neurohypophysis is differentiated into **pars nervosa**, the **infundibular stem** and the **median eminence** (Fig. 9.3). **Pars nervosa**, though derived from the brain does not contain any nerve cells, but consists of neuroglial cells and pigmented cells called pituicytes. The infundibular stem connects the pars nervosa with the brain. The median eminence containing a rich supply of blood capillaries is the swollen base of the infundibulum. The pars intermedia and the pars distalis together form anterior pituitary, and the pars nervosa, infundibular stem and median eminence collectively form the posterior pituitary. The anterior lobe has two sources of blood supply (Fig. 9.3). One source is the internal carotid artery and the other source is the hypophyseal portal vein. The portal circulation provides a link between neurosecretory cells of the hypothalamus and endocrine cells of the anterior pituitary. The posterior lobe is supplied with inferior hypophyseal artery.

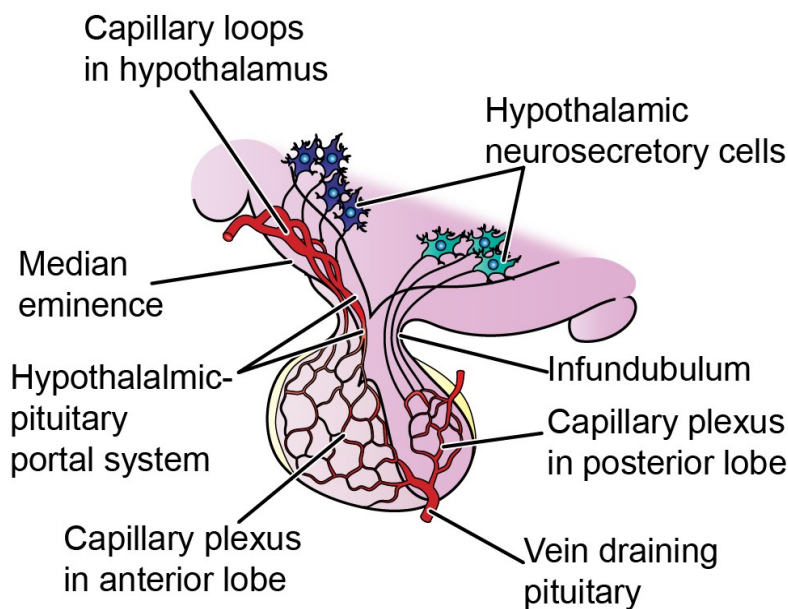


Fig. 9.3: The pituitary gland – blood circulation.

The secretion of pituitary hormones is regulated by the neurosecretion from **hypothalamus**, which lies on the floor of diencephalon. The neurosecretory materials from the neurosecretory cells of hypothalamus are transported by the axons and enter into the median eminence. The portal vein from the median eminence transports the materials to the anterior pituitary where they regulate the secretion of specific hormones such as adrenocorticotrophic hormone, somatotrophic hormone, follicle stimulating hormone and luteinizing hormone (Table 9.1). Certain other neurosecretory fibres travel through the infundibular tract and enter into the posterior lobe and release into it the neuropeptides oxytocin and vasopressin. Table 9.1 provides the list of hormones secreted from pituitary gland, the site of synthesis and their possible functions and action of some of the hypothalamic hormones.

Table 9.1: Hormones of the pituitary gland and hypothalamus.

Region	Hormone	Site of synthesis	Functions	Hypothalamic control
Pars Distalis	Somatotropin (STH) Growth hormone	Acidophil cells	Stimulates soft tissue and bone growth, protein synthesis, mobilization of glycogen and fat stores	Growth hormone-releasing hormone (GHRH), Growth hormone release-inhibiting hormone (GHIH) or somatostatin.
	Adrenocorticotropin (ACTH)	Basophil cells	Stimulates glucocorticoid synthesis by adrenal cortex	Corticotropin-releasing hormone (CRH)
	Thyrotropin (TSH)	Basophil cells	Stimulates thyroid hormone synthesis and secretion	TSH-releasing hormone (TRH)
	Gonadotropins (GH)	Basophil cells		
	1. Follicle stimulating hormone (FSH)		Female: follicle maturation and estrogen synthesis Male: stimulates sperm production	Gonadotropin-releasing hormone (GnRH)
	2. Luteinizing hormone (LH)		Female: stimulates ovulation, corpus luteum formation, estrogen and progesterone synthesis. Male: testosterone secretion.	Gonadotropin-releasing hormone (GnRH)
	3. Prolactin or luteotropic hormone (LTH)	Basophil cells	Mammary gland: growth, milk synthesis in females, immune response and angiogenesis in mammals, parental behavior, electrolyte and water balance in lower vertebrates.	Dopamine (prolactin release-inhibiting hormone or PIH) Prolactin-releasing factor (PRF)

Region	Hormone	Site of synthesis	Functions	Hypothalamic control
	Melanophore stimulating hormone (MSH) Melanotropin	Acidophil cells	Increased melanin synthesis by melanocytes in epidermis of ectotherms; function not clear in endotherms	Melanocyte-stimulating hormone-inhibiting hormone (MSHIH).
Pars Intermedia	Vasopressin or antidiuretic hormone (ADH)		Water reabsorption in mammalian kidneys.	
	Oxytocin	Hypothalamic neurons	Milk ejection and uterine contractions in female, sexual behavior and pair bonding in monogamous species	
Neurohypophysis (Posterior lobe)	Vasotocin	Hypothalamic neurons	Increases water reabsorption	

9.2.2 Pineal Gland

In all vertebrates the dorsal part of the brain, the diencephalon (figure 9.4), gives rise to a sac like evagination called the pineal complex, which lies just beneath the skull in a midline position.

The pineal gland produces the hormone melatonin. Melatonin secretion is strongly affected by exposure to light. Its production is lowest during daylight hours and highest at night. In non-mammalian vertebrates, the pineal gland is responsible for maintaining circadian rhythms—self-generating (endogenous) rhythm that are about 24 hours in length. A circadian rhythm serves as a biological clock for many physiological processes that follow a regular pattern. In mammals, an area of the hypothalamus called the suprachiasmatic nucleus has become the primary circadian pacemaker, although the pineal gland still produces melatonin at night and serves to reinforce the circadian rhythm of the suprachiasmatic nucleus.

The pineal gland produces subtle effects on circadian and annual rhythm in nonphotoperiodic mammals (such as humans).

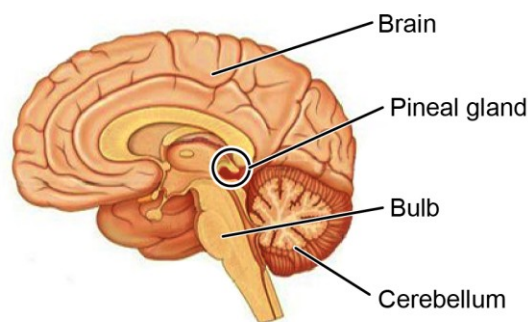


Fig.9.4: Schematic representation of pineal gland.

Box 9.1: Brain Neuropeptides

The blurred distinction between endocrine and nervous systems is nowhere more evident than in the growing list of hormone like neuropeptides that have been discovered in the central and peripheral nervous systems of vertebrates and invertebrates. In mammals, approximately 40 neuropeptides (short chains of amino acids; have been located. Many have dual functions—behaving both as hormones, carrying signals from gland cells to their targets, and as neurotransmitters, relaying signals between nerve cells. For example, both oxytocin and vasopressin have been located at widespread sites in the brain. In an experimental study when people and experimental animals were injected with small quantities of vasopressin, it was observed that vasopressin enhanced learning and improved memory. This effect of vasopressin in brain tissue is unrelated to its well-known antidiuretic function in the kidney. Several hormones, such as gastrin and cholecystokinin (formerly considered only as part of the enteroendocrine system of the gastrointestinal tract), have been discovered in the cerebral cortex, hippocampus, and hypothalamus. In addition to its gastrointestinal actions, cholecystokinin controls feeding and satiety and may serve other functions as a brain neuroregulator. Endorphins and enkephalins, neuropeptides that bind with opiate receptors and influence perception of pleasure and pain, also function in brain circuits that modulate several other functions unrelated to pleasure and pain, such as control of blood pressure, body temperature, body movement, feeding, and reproduction. Even more intriguing, endorphins are derived from the same prohormone (POMC) that gives rise to the anterior pituitary hormones ACTH and MSH.

SAQ 1

- a) Fill in the blanks by using suitable words.
 - i) is found attached to hypothalamus on the floor of diencephalon by a narrow stalk.
 - ii) The two major parts of pituitary are and
 - iii) The two divisions of adenohypophysis are and
 - iv) The three regions of posterior pituitary are, ... and
- b) List the hormones secreted by anterior pituitary and their functions.

9.2.3 Endocrine Glands of Metabolism: Thyroid Gland

A set of hormones are involved in maintaining the delicate balance of metabolic activities such hormones act by altering the activity of enzymes of metabolic process either by accelerating or inhibiting the metabolic process.

Thyroid gland is generally located in the region of the neck. It is a two lobed structure, the two lobes being connected by an isthmus on the ventral side of the larynx. Thyroid gland is derived from endoderm and it arises as an unpaired median evagination of the floor of the pharynx at the level of the first pair of pharyngeal pouches. Subsequently it detaches itself from the pharynx and becomes a bilobed structure. The gland is formed of a number of spherical follicles, each follicle having a central lumen which is surrounded by secretory epithelial cells (Fig.9.5).

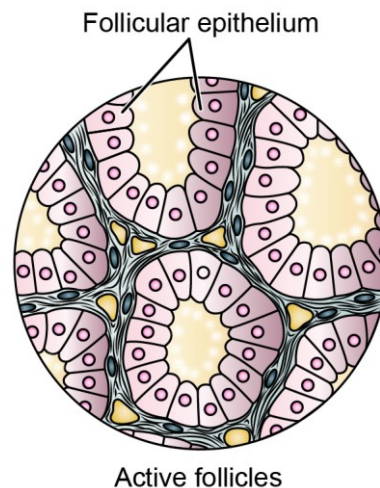


Fig. 9.5: Thyroid gland: Diagrammatic representation.

The secretions of the cells are kept stored in the lumen until they are released. In between the adjacent follicles, that is, in the interfollicular spaces, there is a rich supply of blood vessels. The hormone thyroxine secreted by the thyroid gland is a derivative of the amino acid tyrosine. The follicular epithelial cells of the thyroid gland absorb the diffusible iodide ions (derived from the food) from the blood vessels and convert them into iodine molecules. The free iodine is then incorporated into tyrosine residues of thyroglobulin molecules leading to the synthesis of triiodothyronine (T3) and thyroxine (T4).

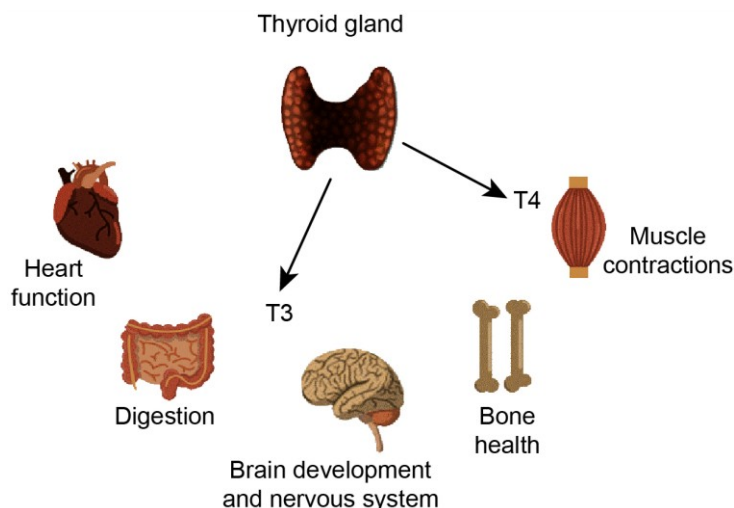


Fig. 9.6: Functions of thyroid gland.

Thyroid secretions play a significant role in the maintenance of the normal metabolism of the organism (Fig 9.6). It accelerates the rate of oxidative metabolism and regulates the growth and morphogenesis. Thyroid facilitates carbohydrate utilisation by promoting glucose release from glycogen molecules. Thyroid is also known to regulate water and salt content of the body in conjunction with the anti-diuretic hormone of the pituitary gland. Thyroid also maintains normal activity of gonads and the excitability of nerves and muscles.

9.2.4 Endocrine Glands of Metabolism Parathyroid Glands

Parathyroid glands are found in close proximity to thyroids and are found generally in two pairs in mammals including man. They are endoderm derivatives from the third and fourth pharyngeal pouches of the embryo and lose their connection with the walls of the clefts in adults. The glandular epithelium is made of columnar cells and they release their secretions in the numerous sinusoids or blood spaces between the columns and from there, they are carried to target organs. There are two types of cells; large and oxyphil cells and parathyroid chief cells (Fig. 9.7). Parathyroid glands secrete two types of hormones - the **parathormone** and **calcitonin**. The two hormones are involved in the regulation of calcium metabolism of the body and are antagonistic in their functioning,

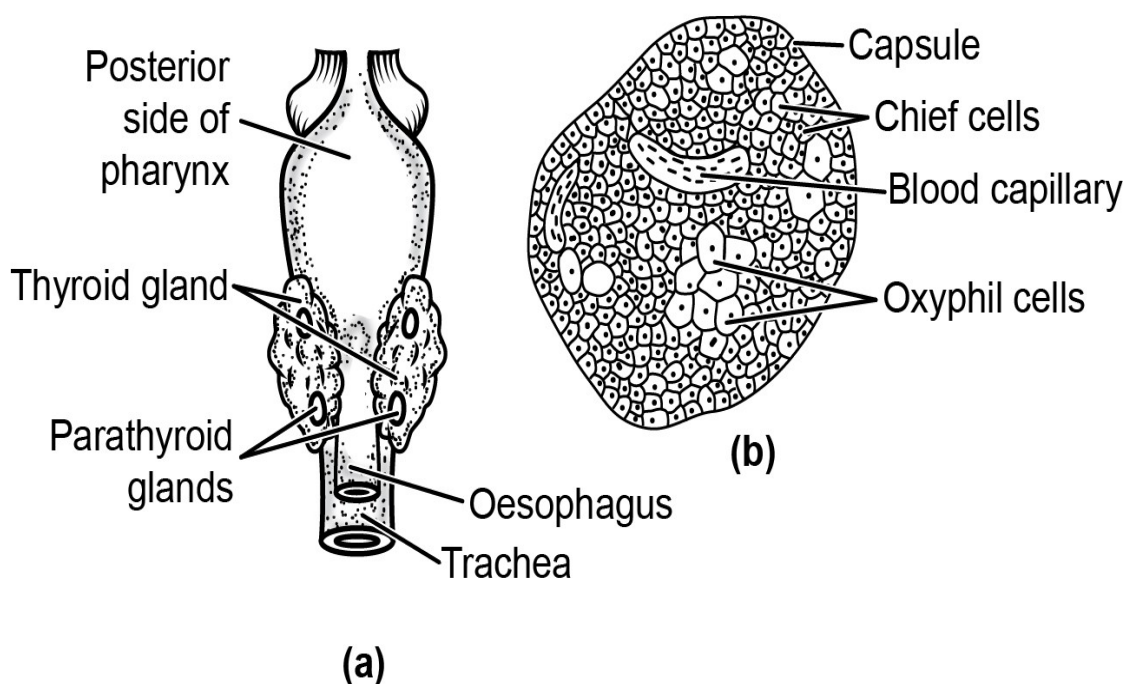


Fig. 9.7: Parathyroid gland: (a) Location (b) Diagrammatic representation.

The parathormone regulates the uptake of calcium and its deposition in bones, calcitonin mobilises calcium from bones and promotes restoration of calcium levels of the blood (Fig. 9.8).

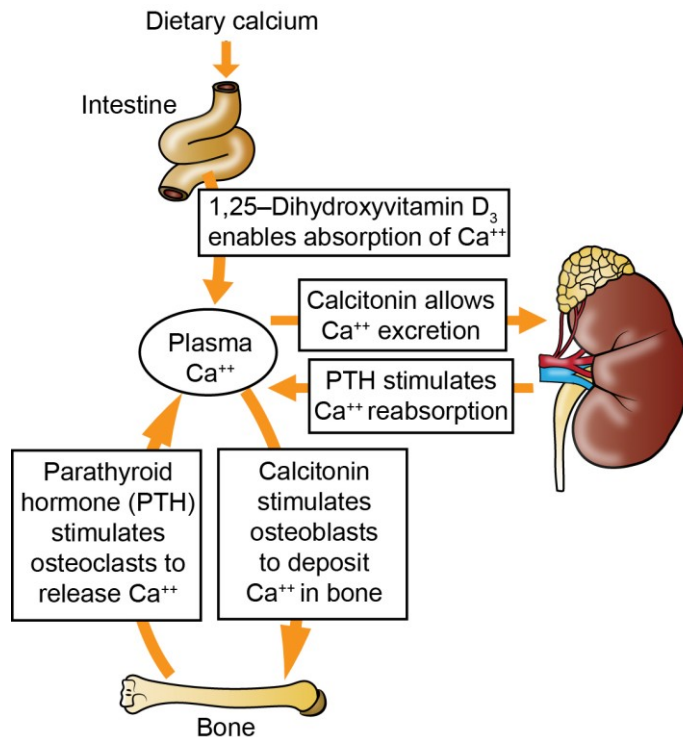


Fig. 9.8: Regulation of calcium levels in blood.

9.2.5 Endocrine Glands of Metabolism: Pancreas

Pancreas has both exocrine and endocrine elements in it. The acinar tissue produces pancreatic juices that are released into intestine for performing digestive functions. The endocrine functions are performed by the islet tissue, the hormones of which are released into blood. The islet tissue, more specifically known as islets of Langerhans (Fig. 9.9) has two types of cells, the **alpha (α)** and **beta (β)** cells, each of which produces a specific hormone. Pancreas arises as an evagination of the gut and is thus endodermal in origin.

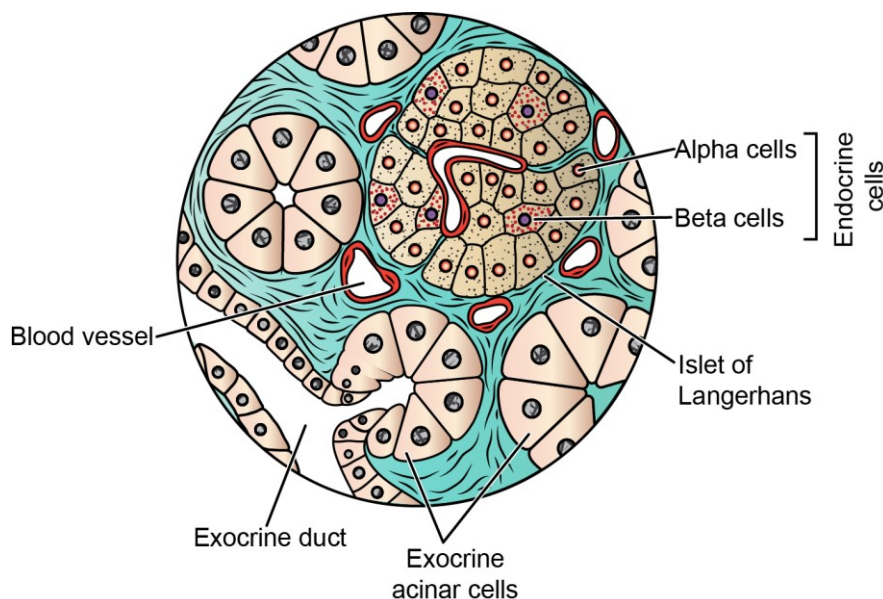


Fig. 9.9: Pancreas showing both exocrine and endocrine tissue.

The alpha (α) cells produce a hyperglycemic hormone **glucagon** and the beta (β) cells produce a hypoglycemic hormone **insulin**. The two hormones in conjunction regulate the glucose metabolism of the organisms. Insulin also promotes fatty acid synthesis in liver. The inability of beta cells to produce functional insulin cause **diabetes**.

9.2.6 Endocrine Glands of Metabolism: Adrenal Glands

Adrenal glands in general lie in close association with the anterior end of kidneys. The glands show two distinct regions, the outer cortex and the inner medulla. In primitive vertebrates, like agnathans and fishes, the two regions are spatially separated, but in higher forms the cells are interspersed. In mammals, the medulla is encapsulated in the cortex (Fig. 9.10). Nevertheless, the two regions of the gland differ in their origin, structure and function.

Adrenal cortex

In mammals, cells of adrenal cortex are budded off from the mesodermal inter-renal tissues. The cells are arranged in masses known as the inter-renal bodies in non mammalian vertebrates. In mammals they surround the medulla to form cortex. The cortex shows three regions, the outer glomerulosa, the middle fasciculata and the inner reticulosa (Fig 9.10). The cortical tissue designated as steroidogenic tissue secretes steroidal hormones, the glucocorticoids and mineralocorticoids. Glucocorticoids, such as cortisol play a significant role in carbohydrate and protein metabolism. They promote gluconeogenesis. Mineralocorticoids such as (Desoxycorticosterone and aldosterone), on the other hand regulate water and electrolyte balance of the body. Essentially, they cause the retention of sodium and increased elimination of potassium and phosphates. They also cause a resorption of sodium in kidney tubules and a reduction of resorption of potassium.

Adrenal medulla

Adrenal medulla arises from the neural crest cells of the neuroectoderm. A group of cells budd off from the neural crest cells, the pheochromoblasts, become glandular and form the cells of adrenal medulla (Fig.9.10). The medullary cells have a characteristic histochemical reaction, staining dark brown with chromates and hence known as chromaffin cells and the tissues composed of them is known as chromaffin tissue. The secretions of these cells, known as catecholamines, are adrenaline and noradrenaline (also known as epinephrine and norepinephrine respectively). Both the hormones are derived from tyrosine.

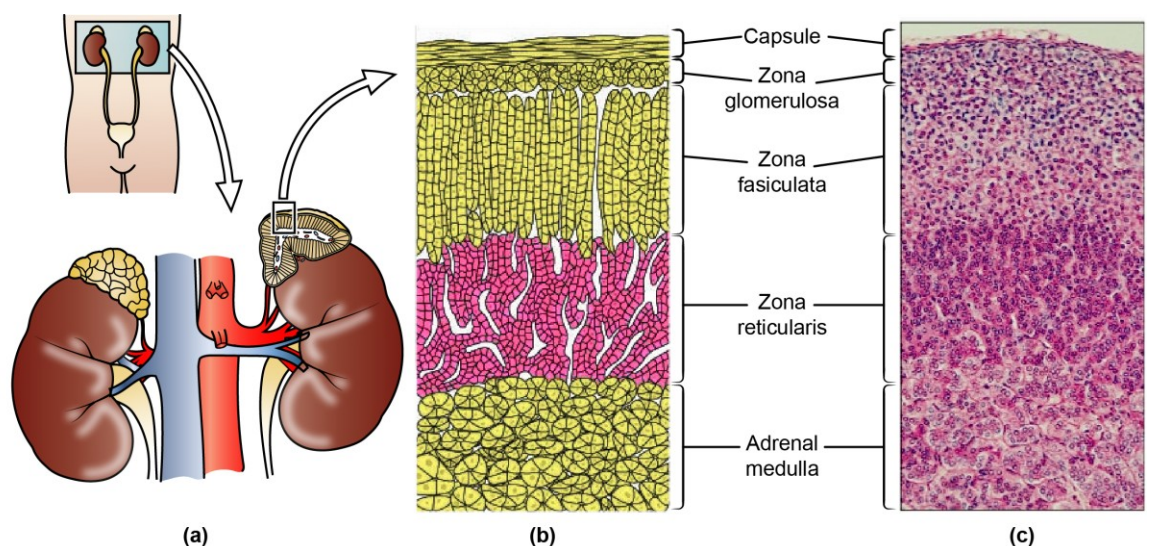


Fig. 9.10: (a) Location (b) Diagrammatic representation (c) Stained section of adrenal glands showing adrenal medulla and cortex.

The effects of both the hormones are more or less the same. They cause a rise in blood pressure by vasoconstriction. Adrenaline constricts vessels of the visceral area and the skin; in small doses it dilates the vessels of muscles and in large doses constricts them. It has no effect on pulmonary and cerebral circulation and it dilates the coronary arterioles. Noradrenaline has a constriction action on muscles of blood vessels. In man the peripheral resistance is increased by noradrenaline and lowered by adrenaline. Both the hormones stimulate the constriction of spleen thus causing an increase in the circulating blood volume and the concentration of erythrocytes in circulation. Both the hormones also increase the rate of heart beat. The two hormones cause an increase in blood sugar levels, by effecting glycolysis in liver. Adrenaline also promotes indirectly carbohydrate metabolism by stimulating the release of ACTH from pituitary. The ACTH in turn releases glucocorticoids which regulate carbohydrate metabolism. The secretion of adrenaline is regulated by sympathetic nervous system.

9.2.7 Endocrine Tissue of Gastrointestinal Tract

There are a few gastrointestinal hormones, polypeptides in nature, that are secreted by the mucosa of gut and are concerned with the regulation of gastrointestinal activity in mammals. Some of these polypeptides are gastrin, secretin and cholecystokinin. Many other polypeptide hormones are being added to the list but their functions are not clearly defined. Gastrin secreted by gastric mucosa regulates the secretion of HCl in the stomach. The hormone is stimulated to be produced by the distension of the stomach as well as by some of the food substances and is released into blood. Gastrin in turn acts on the parietal cells to release HCl into the stomach. The HCl secreted serves as a feedback to inhibit further gastrin production. Thus gastrin serves to regulate the volume of HCl production in the stomach. The proper concentration of acid determines the peptic activity within the stomach.

Both secretin and cholecystokinin are secreted by duodenal mucosa. Secretin is released when the stomach pH is low or in the presence of digested fat or bile. The hormone initiates the release of large quantities of enzyme rich pancreatic juice. Cholecystokinin is secreted under the 'stimulation of partially digested proteins. The two hormones inhibit stomach motility and secretion. Once the chyme leaves the stomach and arrives at intestine, the activity of the stomach slows down and hormones production is inhibited.

9.2.8 Endocrine Tissue of Gonads

Gonads, the testis and ovary, perform dual functions. One, they are the sites of gametogenesis, the sites at which the sperm and ova are produced respectively; and two, they are the centers of intense endocrine activity - namely, they are the sites at which the hormones that regulate the reproductive activity of the organism are synthesised and secreted.

Testis

Testis is composed of seminiferous tubules in which sperm are produced and of interstitial cells or Leydig cells (Fig. 9.11) which secretes the male hormones. Androgen, testosterone and androsterone, the androgens, derived

from testis play a significant role in male reproduction and of the two, testosterone is seven to ten times more potent than androsterone. Androgens promote growth and stimulate the synthesis of cell proteins. They stimulate the adrenal mineralocorticoids and cause the retention of sodium, potassium, phosphorus and sulphur that are utilised in the building up of tissues. Their synthesis and release is under the control of lutenising hormone, otherwise known as interstitial cell stimulating hormone (**ICSH**), a gonadotropic hormone. Reciprocally, the androgens regulate the secretion of the gonadotropins, either by stimulating their synthesis or as in most cases, inhibiting their secretion. Androgens in low titers are essential for spermatogenesis and in high titres suppress the gonadotropin release.

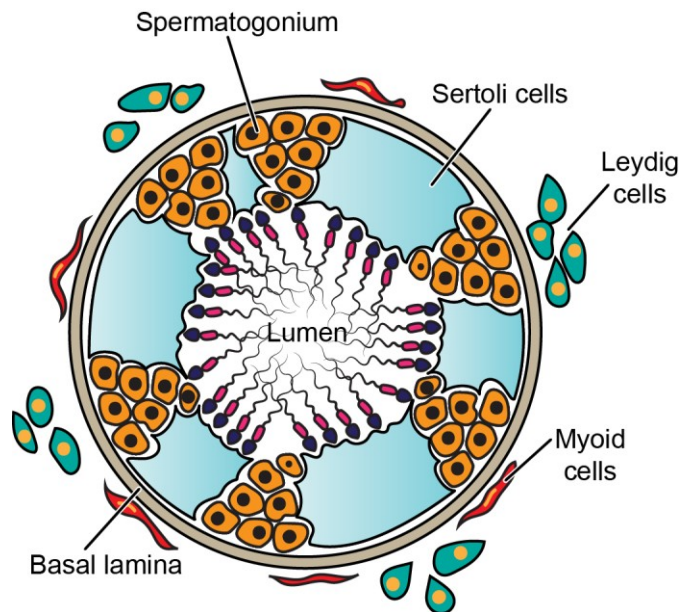


Fig. 9.11: Section of testis showing interstitial cells of Leydig.

Ovary

Ovary consists of a fibrous tissue, the stroma and the Graafian follicles in which ova develop (Fig. 9.12). Besides the production of ova, ovary is also an endocrine centre. The two steroid hormones produced by ovary are estrogens and progesterone. Ovary also secretes a proteinaceous hormone, relaxin.

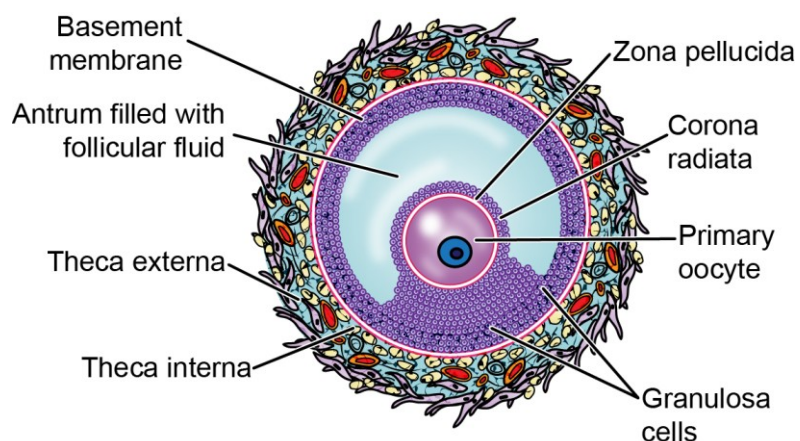


Fig. 9.12: Section of ovary to showing Graafian follicle with granulosa cells and fluid filled antrum.

Estrogens are a group of related chemical compounds; the important ones are estradiol, estriol and estrone. Estradiol is more potent than the other two. Estrogens regulate the development and maintenance of the morphological and functional state of the reproductive system. They also regulate the development of accessory genital organs and secondary sexual characters, such as the development of uterine tubes, vagina and the mammary glands. Ovulation and the preparation of the endometrium for the implantation of the ovum are other functions controlled by estrogens.

Besides, estrogens also influence nitrogen and electrolyte metabolism, water balance and formation of bones. Estrogens also promote the retention of water and sodium chloride, decrease phosphate levels in blood and reduce the elimination of calcium and phosphorus. Progesterone is secreted by corpus luteum under the influence of luteotropic hormone from pituitary glands. It is the ruptured follicle of the ovary that transforms into a yellowish coloured corpus luteum and assumes an endocrine function. Progesterone is also secreted by placenta, later during pregnancy. In pregnant women it can be detected in urine. Like estrogens, the progesterone also performs a variety of functions. It prepares the uterine wall for the implantation of fertilised ovum and maintains gestation. Progesterone supplements the estrogen activity in the development of mammary gland.

Relaxin is a polypeptide hormone secreted under the influence of estradiol and progesterone. The hormone relaxes the pubic symphysis at the time of parturition.

Thus far we made a general survey of some of the important endocrine secretions. Now let us begin the study of hormones in specific groups of vertebrates. Before we do so, please attempt the following SAQ.

SAQ 2

- i) State whether the following statements are true or false.
- a) Thyroid is derived from ectoderm and arises as an unpaired median evagination on the floor of the pharynx.
- b) Thyroxine is a derivative of the amino acid tyrosine.
- c) In mammals parathyroid glands are paired structures.
- d) Parathormone mobilises calcium from bones and calcitonin regulates the uptake of calcium as well as its deposition in bones.
- e) The alpha cells of pancreas produce a hypoglycemic hormone and the beta cell produce a hyperglycemic hormone.
- f) Adrenal cortex is a derivative of neuroectoderm and adrenal medulla is derived from inter-renal mesodermal tissue.
- g) Cortisol regulates carbohydrate and protein metabolism.
- h) The regulation of secretion of HCl in the stomach is carried out by a hormone, the secretin.
- i) Secretin and cholecystokinin are secreted by duodenal .mucosa.
- j) Estrogen, progesterone and protein are the steroid hormones produced from the ovary.

- ii) Match the endocrine gland with the hormone it secretes.
- | | |
|-------------------------------|--------------------------|
| a) Pars distalis of pituitary | 1) Triiodothyronine |
| b) Parathyroid | 2) nor-epinephrine |
| c) Pancreas | 3) anti-diuretic hormone |
| d) Adrenal medulla | 4) calcitonin |
| e) Neurohypophysis | 5) glucagon |
| f) Thyroid gland | 6) somatotropin |

9.3 AVES (BIRDS)

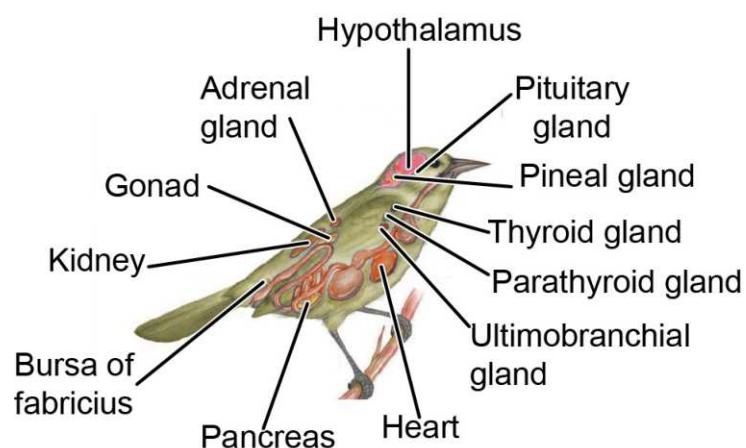


Fig 9.13: Location of endocrine glands in birds.

Pituitary gland

In birds the adenohypophysis (pars distalis) of the pituitary lies away from the brain. It shows two regions, the cranial and caudal regions. The median eminence is a separate structure and is also divided into two parts. The anterior part receives the fibres of the hypothalamohypophyseal tract and these fibres reach the pars nervosa to release the hormones arginine **vasotocin** and **mesotocin**, a derivative of oxytocin. These hormones are involved in the regulation of water balance, heart rate and reproduction. Mesotocin is also involved in enhancing fatty acids and sugar in the blood. The distal lobe of the pituitary has been shown to contain the following hormones: Growth hormone or somatotropin, prolactin, thyrotropin, follicle stimulating hormone, luteinizing hormone, adrenocorticotrophic hormone and melanotropin. Pars intermedia in other vertebrates produces the last two hormones. The hormones have the same actions as in other vertebrates. Prolactin influences the production of brood pouches and broodiness, and in pigeons stimulates the production of milk in both sexes.

Pineal gland

In non-mammalian vertebrates, the pineal gland is responsible for maintaining circadian rhythms—self-generated (endogenous) rhythms that are about 24 hours in length. A circadian rhythm serves as a biological clock for many

physiological processes that follow a regular pattern. In birds similar to mammals in which seasonal rhythms in reproduction are regulated by photoperiod, melatonin plays a critical role in timing gonadal activity.

Thyroids and Parathyroid gland

The paired thyroid glands produce T3 and T4 hormones. The turnover rate of both the hormones is much higher than in mammals. This could be attributed to higher body temperature and metabolism. Thyroids also control growth and moulting and possibly have a role in migration and reproduction. Birds have large parathyroids, which develop from fifth and sixth branchial pouches and generally remain separated from thyroid. The parathormone of birds is a potent hormone and probably regulates the mobilisation of calcium from bones to the eggshells at the time of egg laying.

Pancreas

In bird pancreas produces both insulin and glucagon as in mammals; and ten times less insulin is produced than glucagon, which mobilises sugar from the liver and raises its level in blood. Glucagon also promotes a strong lipolytic action. Essentially hormonal activities in birds commensurate with their high metabolic demands.

The cortical and medullary cells of adrenals may be found separately or intermingled with one another. Corticosterone is the main cortical hormone in birds and aldosterone may be secreted in small amounts. Marine birds have large adrenal glands.

9.4 REPTILES

Pituitary gland

In reptiles also the pituitary contains the usual three parts. There is also the portal system that carries blood from capillaries in median eminence to pars distalis.

The pars distalis contains five different types of chromophilic cells that secrete different tropic hormones. Lactotropes that secrete prolactin, somatotropes that secrete growth hormone, basophilic thyrotropes that secrete thyrotropin, corticotropes that secrete corticotropin and gonadotropes that secrete gonadotropins are the five types of cells.

The pars intermedia that is distinctly large in those reptiles which change colour, secretes melanophore stimulating hormone (MSH). In burrowing forms, the organ is very small. The colour changing mechanism is very pronounced in certain lizards such as chameleon and *Anolis* (also known as American chameleons). The colour may change with the environment and thus serves the lizards to conceal themselves. Colour changes also occur during courtship or when the organism is under threat. Changes in temperature or environment are other factors that bring about varied colour patterns. The physiology of colour changing mechanism varies with lizard. In *Anolis* the melanophores are not innervated. Darkening effect is caused by MSH from pituitary and paling

effect is caused by adrenaline. In chameleons, however, the colour changing mechanism is under the control of sympathetic nervous system. Colour changes are largely controlled through eyes, and probably by some local control mechanism as well, as the covered areas of the skin tend to become pale. Reptiles, like other tetrapods secrete the two gonadotropins, FSH and **LH**. The neurohypophysis contains arginine vasotocin, the main anti-diuretic hormone and mesotocin. It appears that oxytocin-like hormone is present in neurohypophysis, as the injection of the extracts of the organ to the viviparous lizard *Lacerta vivipara* results in premature oviposition.

Thyroids and Parathyroid gland

Reptiles have well-developed thyroid glands. Thyroid have a role in moulting, reproduction and egg-laying of lizards and snakes. Injection of thyroxine (T₄) causes marked enhancement of oxygen consumption at 30°C but has no effect at 20°C. Apparently the higher temperature is the most preferred temperature for the activity of thyroxine.

Parathyroids of reptiles are structurally similar to those of mammals. Parathyroidectomy in lizards causes the blood calcium levels to be reduced to half its normal level and phosphate levels to rise. In the absence of parathyroid gland, the animal becomes hyperexcitable and has tetanic convulsions after exercise. Injections of the extracts of parathyroid gland restore normalcy in the animal. Essentially there is a definite mechanism for the regulation of calcium levels in the blood but the details are not as clearly understood as in the case of mammals.

Adrenal glands

The adrenal glands are located very close to the gonads except in the case of turtles. The gland is a mixture of steroid secreting and catecholamine secreting tissues and the two areas are not very clearly defined. As in mammals, the steroid secretion is under the control of pituitary and hypophysectomy invariably causes atrophy of the steroid secreting tissues.

9.5 AMPHIBIANS

Pituitary gland

In amphibians the three main parts of the pituitary, pars distalis, pars intermedia and pars nervosa are clearly distinguishable. Pars distalis lacks any divisions and resembles that of other tetrapods. The releasing factors of the hypothalamus pass through the median eminence via the portal system and control the secretions of pars distalis. Pars distalis is known to produce two growth hormones (1) lactotropin (LTH), a hormone that controls larval growth and (2) somatotropin (STH), that controls adult growth. Metamorphosis is regulated by thyroxine whose secretion is regulated by thyrotropin (TSH) secreted by pituitary. The secretion of thyrotropin itself is regulated by a releasing factor of hypothalamus, the TRF. ACTH is also secreted by pars distalis and its secretion is regulated by hypothalamic ACTH-RF. Pars distalis also produces two gonadotropins, FSH and LH.

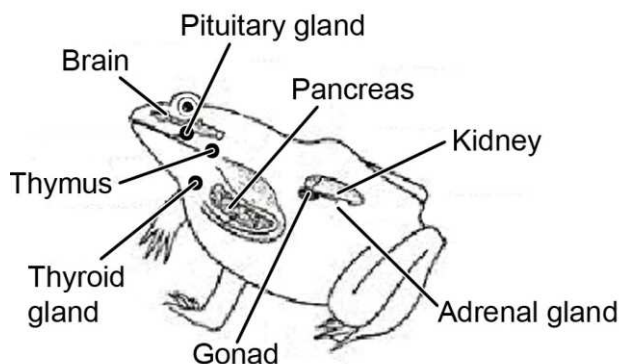


Fig. 9.14: Location of endocrine glands in frogs.

Thyroids and Parathyroid gland

Amphibians possess paired thyroids. These are located in close association with the external jugular vein, one on each side (Fig. 9.14). Thyroxine controls growth and metamorphosis in amphibians. Thyroidectomy in young tadpoles keeps them in larval state throughout their lives, but when fed on thyroid metamorphosis resumes and adult form emerges; similarly precocious metamorphosis is witnessed on administration of thyroxine to young tadpoles. In amphibian adults there is no evidence that thyroids stimulate oxygen consumption.

Among vertebrates, parathyroids for the first time appear in amphibians as regulators of mineral metabolism by secreting parathormone. The parathyroids are derived from pharyngeal pouches. Parathyroidectomy in frogs results in reduction of the calcium levels of blood and increase in phosphorous levels. It is believed that parathyroids might have evolved by the modification of the chloride secreting cells, the ionocytes of the gills of fishes. **Ultimobranchial bodies** that develop from the floor of the last pharyngeal pouch secrete calcitonin, a hormone that has antagonistic functions to that of parathormone. The hormone functions by mobilising calcium from the endolymphatic sacs, particularly at the time of metamorphosis.

Adrenal gland

In amphibians, the ectodermal, adrenaline secreting chromafin tissue of the suprarenals is closely associated with steroid secreting mesodermal interrenal tissues. In fact amphibians are the first vertebrates in which such an association is found. Whereas in anurans the adrenals appear as compact orange masses on kidneys, in urodeles they form an extended series. The action of amphibian adrenaline is similar to those of mammals, namely, that it accelerates heart beat, enhances blood pressure and dilates lungs. It also causes hyperglycemia and dilates pupils of eyes and causes the contraction of melanophores. Adrenal cortex appears to have a role in carbohydrate metabolism as well as in maintaining the water balance of the body.

Pancreas

Pancreas of amphibians contains both exocrine and endocrine tissues. The islets of Langerhan's, constitute the endocrine tissue, contain both α and β cells which secrete glucagon and insulin respectively. The action of insulin in lowering blood sugar levels and of glucagon in enhancing it has been well demonstrated in amphibians.

9.6 FISHES

9.6.1 Elasmobranchs

Pituitary gland

In elasmobranchs, usual parts of the pituitary, the pars distalis (anterior), the pars intermedia and the neurohypophysis are present. In addition, the pituitary also has a ventral lobe that is partly separate (Fig. 9.15). The ventral lobe is believed to be part of anterior pituitary, containing a gonadotropin and thyrotropin. Removal of the ventral lobe causes regression of the gonads in dogfish. Adenohypophysis is known to contain lactotropic hormone and adrenocorticotrophic hormone. The neurointermedia receives a number of fibres from neurohypophysial tract. This region contains melanophore-stimulating hormone (MSH). Arginine vasotocin that regulates water metabolism is also known to be present. Besides, three neural octapeptides of unknown function are also present.

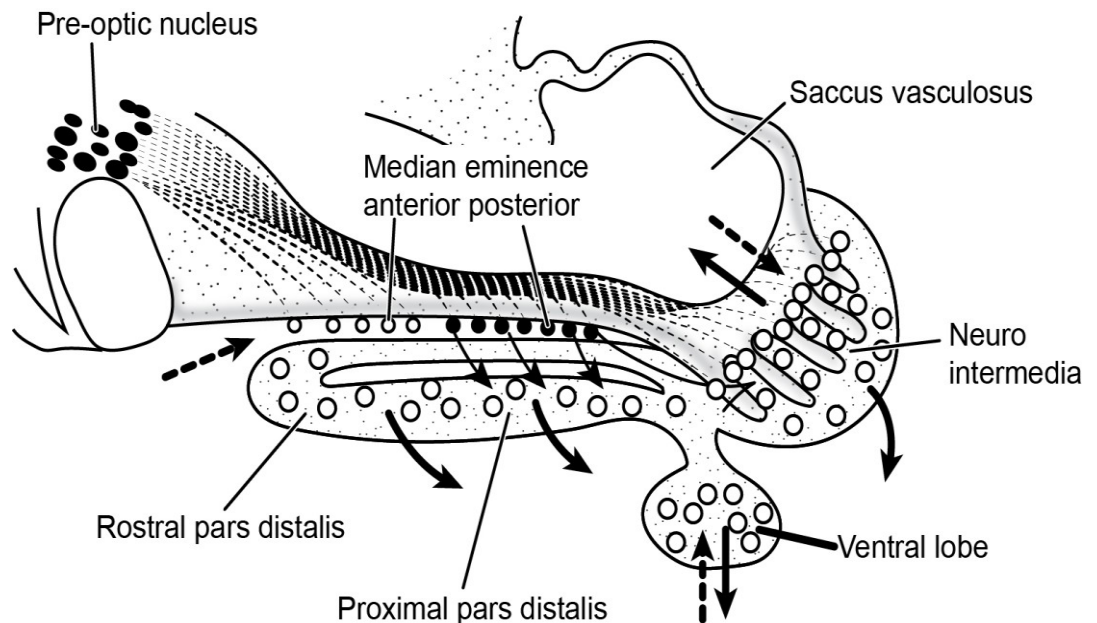


Fig. 9.15: Selachian pituitary. Solid arrows show veins, broken arrows—arteries and thin arrows portal veins.

Regulation of the pituitary is carried out by hypothalamus by way of a portal system that passes through the median eminence (Fig. 9.15). But the portal system does not reach the ventral lobe of the pituitary. It is believed that the regulation of ventral lobe is achieved by way of the systemic blood stream by a relay in the pars distalis. In elasmobranchs, unlike teleosts, there is no direct innervation of pars distalis.

Thyroid and Parathyroid gland

Thyroid in elasmobranchs arises as a down growth from the floor of the pharynx. It remains attached to the floor of the pharynx by a narrow stalk containing a small ciliated pit. The functions of thyroid in elasmobranchs are not clearly known, but the gland shows cyclical changes related to migration and reproduction. In dogfishes, removal of thyroid results in non-deposition of yolk in eggs.

In fishes there are **no parathyroids**. Follicular structures known as **ultimobranchial glands** are known to produce calcitonin, a hormone that regulates calcium metabolism.

Adrenal gland

In elasmobranchs, unlike in mammals, the cortical and medullary parts of the adrenal glands are found widely separated. The part corresponding to medullary tissue is known as suprarenal bodies. They occur as segmental series of glands and project into the dorsal wall of the posterior cardinal sinus. The more anterior ones are fused to form an elongated structure on either side of oesophagus. These structures are shown to be rich in noradrenaline. The segmental series of suprarenal bodies continue along the whole length of the abdomen, and more posteriorly they are embedded in the kidney tissue (Fig.9.16). The posterior renal bodies, larger in males as compared to females stain positively for the presence of adrenaline.

Interrenal bodies located in the kidney region represent the region corresponding to adrenal cortex. In some species they are unpaired and located medially, and in others they are paired. The interrenal bodies are not associated with the suprarenal bodies in anyway and it appears that the functioning of the two bodies is not interdependent in elasmobranchs. The gland is stimulated by stress or by mammalian ACTH. Removal of the interrenal bodies results in the death of the organism, but extracts of the tissue can prolong the life. Secretions of interrenal bodies have been shown to regulate carbohydrate metabolism of the animal and activity of the gonads; apparently they have no role in electrolyte balance. The steroid secreted by the interrenal bodies has been shown to be 11 α -hydroxycorticosterone and there is no evidence of aldosterone being secreted.

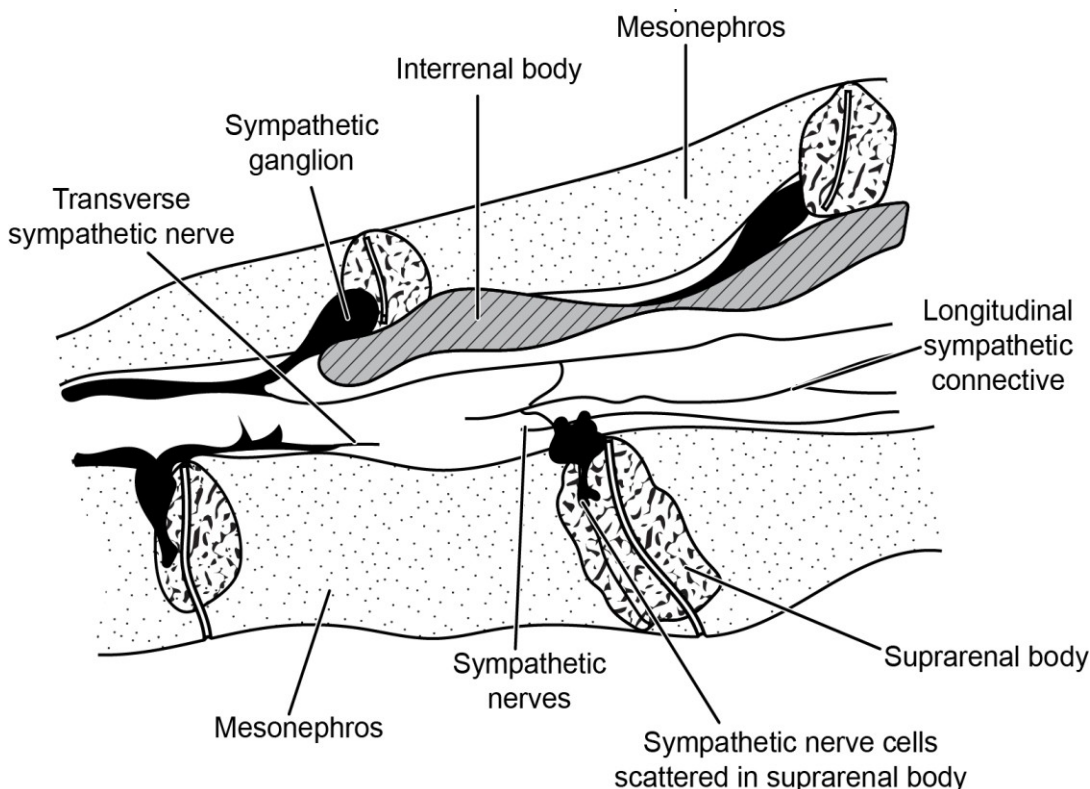


Fig. 9.16: Suprarenal and intrarenal bodies in hind mesonephric region dogfish.

Pancreas

Pancreas in elasmobranchs does not occur as islets, as it occurs in mammals but as outer layer of some of the ducts. The pancreas of elasmobranchs secretes both insulin and glucagon.

Gonads

As in mammals, in elasmobranchs also, the gonads have endocrine tissue that produces steroid hormones. The interstitial cells of the testis secrete testosterone, androstenedione and progesterone. Similarly ovarian follicles are shown to produce progesterone.

9.6.2 Bony fishes

Pituitary gland

Pituitary of bony fishes, like other vertebrates shows two regions, the adenohypophysis and the neurohypophysis. The adenohypophysis surrounds the neurohypophysis and interdigitates with it. It shows three divisions, the pars rostral distalis and the pars proximal distalis and pars intermedia, the last region surrounding neurohypophysis (Fig. 9. 17). Rostral pars distalis contains acidophil lactotrobes, corticotrobes and the basophilic thyrotrobes. The internal carotid artery that supplies arterial blood to the pituitary forms the primary capillary plexus in the anterior neurohypophysis. It then continues into the pars distalis region as a system of sinusoids among the secretory cells, forming the secondary capillary plexus. Such an arrangement of blood supply in bony fishes is in contrast to the one found in other vertebrates in which long external portal vessels are found instead of a portal system of short capillaries.

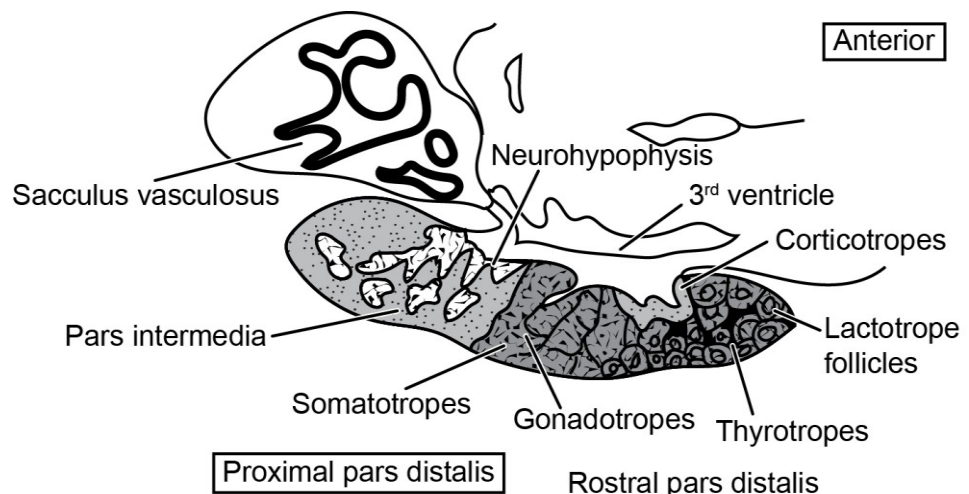


Fig. 9.17: Pituitary of eel, mid sagittal section.

Two types of nerve fibres enter into pituitary from hypothalamus: Type A fibres and Type B fibres. Type A, peptidergic fibres end mainly around the capillaries or the cells of the neurohypophysis. Type B cells that are mainly aminergic pass on to innervate the cells of pars distalis. Fishes possibly produce only one gonadotropin, the luteinizing hormone (LH). Interestingly, injection of a fish gonadotropin into mammals produces some effects of both FSH and LH; but only mammalian LH and not FSH induces gametogenesis and steroid secretion in fishes.

Lactotropes, cells that secrete prolactin, are not regulated by hypothalamus. This is evidenced by the fact that the lactotropes of the pituitary transplanted ectopically (away from the brain) are activated when transferred from dilute seawater to fresh water. Prolactin of fishes is concerned with osmoregulation. It reduces the exchange of sodium across the surface of the body and gills. In some fishes, prolactin facilitates water permeability of the gills and enhances renal water excretion. The activity of lactotropes increases and the prolactin titres are high in blood when migrant fishes move from seawater to fresh water.

The pars intermedia produces melanophore-stimulating hormone that regulates the colour changes. Pars intermedia has two types of cells and besides controlling colour changes, the lobe is also known to regulate other activities such as water and electrolyte balance, calcium levels of blood and probably reproduction as well.

Two octapeptides have been identified from the neurohypophysis of the bonyfishes. One is the arginine vasotocin and the other is the isotocin or ichthyotocin, a homologue of oxytocin. Both these peptides are secreted from the neurosecretory **A** fibres of pituitary.

Thyroid glands

Thyroid gland is not a compact body but appears as scattered masses of tissue along the ventral aorta. The thyroid secretes both triiodothyronine and thyroxine, hormones, which are identical to those, found in mammals. The functions of thyroid in bony fishes remain uncertain. Thyroid tissues may occur in several parts of the body, kidneys, heart, eye and other parts as well, particularly in those fishes that are deprived of iodine. The cyclic activity of thyroid corresponds with the maturation of gonads implying a role for thyroid in the reproductive process. However, thyroid does not appear to have any role in the respiratory metabolism of bony fishes, nor in growth or osmoregulation.

Adrenal glands

The suprarenal and interrenal tissues of adrenal gland of bony fishes are found in masses around the thickened walls of the posterior cardinal veins. Relatively little is known about the functions of the adrenal tissues of bony fishes. Removal of the adrenal glands results in the loss of sodium in freshwater and gain of sodium in seawater. In both cases, the organisms fail to survive. Although adrenal tissues produce a number of steroids, there is no evidence of aldosterone production. Dorsal to kidneys, a group of cells called corpuscles of Stannius which do not produce any steroids, but which may be involved in the regulation of calcium levels is present.

Ultimobranchial glands

Bony fishes lack parathyroid glands. Calcitonin, which in higher vertebrates is produced by parathyroid glands, is produced by a mass of cells developed from the floor of the last branchial pouch, the ultimobranchial glands. The calcitonin of bony fishes differs markedly from that of mammals in the amino acid composition and is 25 times more potent than the latter. In fishes calcitonin has a more important role in the reproductive physiology than in calcium metabolism.

Pancreas

Endocrine tissue of pancreas known as Brockman bodies lie isolated from the exocrine tissue and may occur scattered in the abdomen, in spleen and even in ovaries. Both insulin and glucagon are produced by the specific types of cells.

Urophysis

Urophysis (Fig. 9.18) refers to masses of secretion produced by neurosecretory cells at the hind end of the spinal cord. These cells produce masses of neurosecretion. The function of the cells appears to be regulation of the salt content of the body. At least four hormones have been isolated from urophysis, urotensin I, urotensin II, urotensin III and urotensin IV. These hormones appear to regulate several aspects of the physiology of the organism including osmoregulation, cardiovascular functions and reproduction.

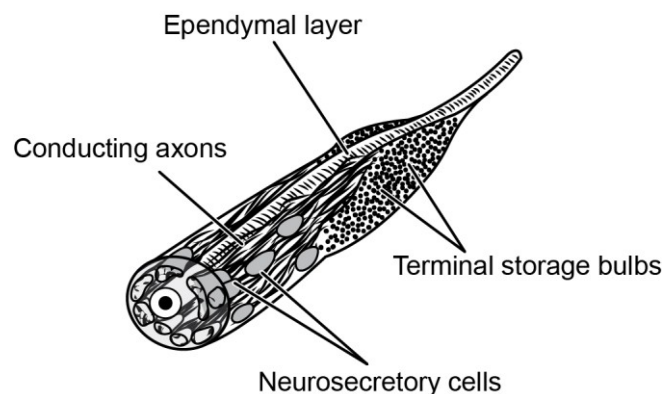


Fig. 9.18: Urophysis in eel.

9.7 AGNATHA

In agnathans pituitary and adrenals are present and function as endocrine organs. In lampreys (Fig. 9.19) pituitary is located and pressed against the underside of hypothalamus. Earlier it was thought that the pituitary functions independently in lampreys but Pituitary lacks a median eminence but a posterior thickening of the infundibular floor forms a neural lobe, the pars nervosa – a structure comparable with the neural lobe of higher vertebrates. The neural lobe of the pituitary, the neurohypophysis (Fig. 9.19) contains a hormone that regulates the water content of the body. The hormone, arginine vasotocin is produced in the neurosecretory cells of the preoptic nucleus of the brain, carried down the axons and stored in the neural lobe.

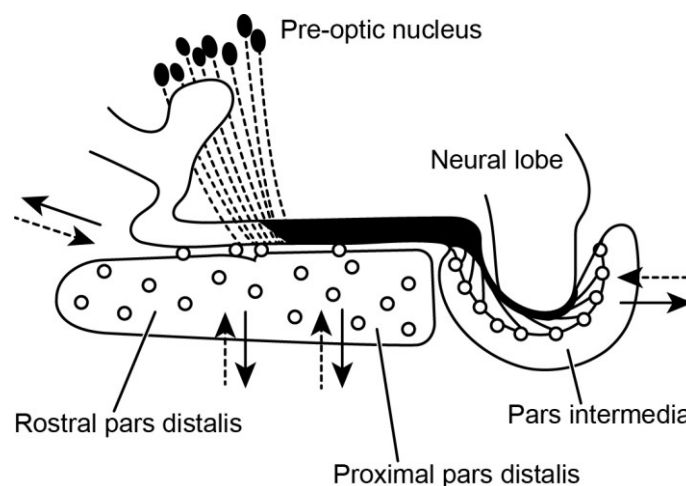


Fig. 9.19: Pituitary of lamprey.

Adenohypophysis, the glandular portion of the pituitary, shows three distinct regions. One, the rostral and two, the proximal regions of the pars distalis are separated from the third region, the posterior region, the pars intermedia by a connective tissue (Fig. 9.19). Pars intermedia is shown to secrete as in other vertebrates, the melanocyte stimulating hormone (**MSH**) and the secretion appears to be under the control of the pineal eye by way of hypothalamus. Removal of hypophysis results in the non-development of gametes and secondary sexual characters, suggesting that the pituitary is the source of gonadotropic hormone. The basophil cells of the proximal pars distalis secrete the gonadotropic hormone. The acidophil cells of the proximal pars distalis produce a corticotropic hormone. The basophil cells located at the rostral parts of pars distalis tend to proliferate at the time of metamorphosis. Lampreys do not possess compact adrenal glands, but cells which represent cortical and medullary parts in higher vertebrates are present. The interrenal cortical cells are present as a group in the region of pronephros just beneath the cardinal veins. The suprarenal medullary cells, in the form of chromaffin cells are found in the walls of heart and large blood vessels. These cells answer positively for the presence of catecholamines. Adrenaline and noradrenaline have been shown to be present in the tissues of the heart.

With the advancement in molecular genetics it has been noted that in lampreys, olfactory stimuli may play a major role in regulating GnRH secretion. Research shows that GnRH in lampreys is divided into GnRH- I , GnRH- II , and GnRH-III , and is mainly distributed in the hypothalamus, where it controls the pituitary gland and thus plays an important role in gonadal development and maturation of gametes. The lamprey endocrine system also plays a part in metamorphosis. In the initial metamorphosis stage of parasitic and non-parasitic lampreys, the levels of thyroid hormone and liothyronine in serum drop sharply. In fact, the compounds that can affect thyroid hormone synthesis, such as KClO_4 and goitrogens, are capable of initiating metamorphosis in lampreys, and also lowering the level of serum thyroid simultaneously.

The hypothalamus of higher vertebrates produces corticotrophin releasing hormone (CRH) under stress. However, there are no such steroid substances in lampreys. The mode of endocrine changes in lampreys under stress might be the prototype of how the endocrine system varies in higher vertebrates when they face ambient stresses.

The lamprey endocrine system is simpler than that of mammals, and the endocrine organs and related molecules are more primordial. Comparing the histology and biochemistry of the primitive lamprey endocrine system with the well-differentiated human endocrine system has enabled researchers to better comprehend the evolution of the vertebrate endocrine system.

SAQ 3

Choose the correct word(s) from the alternatives provided.

- a) In agnathans a hypothalamo-hypophyseal portal system linking hypothalamus and anterior pituitary is **present /absent**.
- b) In lampreys, pituitary is regulated by hypothalamic regulating **factors/feed back** from other tissues.

- c) The pituitary of lampreys **produces/does not produce** a gonadotropic hormone.
 - d) Lampreys and mammals **have/do not** have a similar type of compact adrenal gland.
 - e) The **dorsal/ventral** lobe of pituitary in elasmobranchs secretes a gonadotropin and a thyrotropin,
 - f) Adrenal **cortex/medulla** in elasmobranchs is known as suprarenal bodies.
 - g) The steroid hormone secreted by the interrenal bodies of elasmobranchs is **Aldosterone/1-alpha-hydroxycorticosterone**.
 - h) Melanophore stimulating hormone of the bony fishes is secreted from the **pars distalis/pars intermedia** region of the pituitary.
 - i) Thyroid gland in bony fishes occurs as a compact body in **the neck region/ scattered Masses of tissue** along the ventral aorta.
 - j) Removal of adrenal glands in bony fishes results in **loss/gain** of sodium in freshwater fishes.
-

9.8 SUMMARY

After a study of this unit you have learnt:

- About the endocrine glands of different groups of vertebrates. We begin the study with the description of the endocrine glands of mammals. In mammals the unpaired pituitary gland consists of two major parts, the adenohypophysis and the neurohypophysis. The adenohypophysis shows further divisions, the pars intermedia and the pars distalis. The neurohypophysis is differentiated into pars nervosa, the infundibular stem and the median eminence. Pars distalis secretes a number of tropic hormones that regulate the secretion of various endocrine glands in the body. Pars intermedia secretes melanotropin and the neurohypophysis releases two neuropeptides, oxytocin and vasopressin.
- The agnathans lack a hypothalamo-hypophyseal portal system and pituitary appears to be independent of hypothalamus. Pars intermedia secretes melanophore-stimulating hormone and the pituitary appears to secrete a gonadotropin as well. In elasmobranch fishes the anterior pituitary secretes thyrotropin and a gonadotropin. Lactotropic hormone and ACTH are the other tropic hormones secreted by the pituitary. Neuropeptide arginine vasotocin is secreted by the neurohypophysis. Pituitary of bony fishes has adenohypophysis and neurohypophysis, and the adenohypophysis shows three regions, pars rostral distalis, pars proximal distalis and pars intermedia. Lactotropin, corticotropin and thyrotropin are the three tropic hormones secreted from rostral pars distalis. Luteinizing hormone is the only gonadotropin that is produced. Arginine vasotocin and isotocin are the two neuropeptides secreted from

the neurohypophysis and the function of these hormones is not well understood. Amphibian pituitary shows three main parts of the pituitary, pars distalis, pars intermedia and pars nervosa. Amphibian pituitary secretes all the tropic hormones produced by a mammalian pituitary including the two gonadotropins. The secretion of thyrotropin and ACTH are regulated by the respective regulating factors produced by the respective releasing factors released from the hypothalamus. The neural lobe of the pituitary produces vasotocin and mesotocin, the two hormones that regulate water metabolism. The reptilian pituitary is more or less similar in structure and functioning to that of amphibians. In birds the pituitary shows cranial and caudal regions. While the pars nervosa releases neuropeptides such as vasotocin and mesotocin, the pars distalis secretes a number of tropic hormones including melanotropin and ACTH, two hormones, which are, produced by pars intermedia in other vertebrates.

- The thyroid gland, an endoderm derivative, synthesises and releases a tyrosine derivative, thyroxine. Thyroxine regulates growth and morphogenesis as well as accelerates the oxidative metabolism. Thyroid does not appear to be present in Agnatha, and both in elasmobranchs and bony fishes although it is present, its functions are not clearly known. In amphibians thyroid gland regulates metamorphosis. In reptiles, it appears higher temperature favours thyroid activity. And in birds thyroid produces both T₃ and T₄ hormones. The turnover rate of both the hormones is higher in birds than in mammals.
- The parathyroids, which are found in close proximity to the thyroids, produce two hormones that function antagonistically, the parathormone and calcitonin. The two hormones regulate calcium and phosphate metabolism. Parathyroids are absent in agnathans. In fishes also there are no parathyroids, but structures known as ultimobranchial glands derived from the floor of the last branchial pouch secrete calcitonin that regulates calcium metabolism. In amphibians, parathyroids derived from pharyngeal pouches appear to regulate calcium levels of blood. Parathyroids of reptiles are structurally very similar to those of mammals and their removal causes lowering of blood calcium levels in them. Parathormone of the birds besides regulating blood calcium levels also mobilises calcium for deposition into eggshells.
- The pancreas have both exocrine and endocrine tissue the exocrine tissue produces digestive enzymes while the endocrine tissue or islets of Langerhans produce glucagons (by α cells) and insulin (by β cells). Pancreas are absent in jawless fishes pancreas of bony fishes and elasmobranchs secrete both glucagon and insulin though no islets cells are present. Pancreas of amphibians, reptiles and birds are similar to mammals in action.
- The adrenal glands are present in all groups of vertebrates. The two regions of which the gland is composed of are the cortex and medulla, are spatially separated in Agnatha and lower fishes; but in higher forms the cells of the two regions are found interspersed. The cortex, a mesodermal derivative, secretes steroidal hormones -glucocorticoids

and mineralocorticoids. Glucocorticoids are concerned with regulation of carbohydrate metabolism and mineralocorticoids are concerned with the regulation of sodium and potassium metabolism. Adrenal medullary region secretes two catecholamines, the adrenaline and noradrenaline. Adrenaline acts as a vasodilator in small doses and as a vasoconstrictor in large doses. Both the hormones cause an increase in heart rate, blood volume and concentration in erythrocytes. Adrenaline also regulates carbohydrate metabolism. In Agnatha although cortical cells could be located in the region of pronephros, no steroid hormone has been identified. Medullary tissue represented in the form of chromaffin cells are found in the walls of heart and large blood vessels. Catecholamines have been shown to be present in the tissues of heart. In fishes inter renal bodies located in the kidney region represents the cortical tissue. They may be either paired or unpaired. The steroid secreted by the cortical cells, identified as 11 α -hydroxycorticosterone regulates carbohydrate metabolism but steroids that regulate mineral metabolism have not been identified. In amphibians the cortical and medullary tissues are found to be closely associated as in other higher vertebrates. Although the details of the hormones secreted by the amphibian adrenals are not known, the glands are known to regulate both carbohydrate and mineral metabolism. Adrenals in reptiles is a mixture of steroid secreting and catecholamine secreting tissues. The steroid secreting tissue appears to be under the control of a pituitary hormone. In birds the cortical and medullary tissues may be found separately or together. Both corticosterone and aldosterone have been identified.

- That ovary and testis are the two endocrine centres that secrete the hormones that regulate the reproductive activity of the vertebrates. Leydig cells of testis secrete male hormones, testosterone and androsterone. The synthesis and release of these androgens are under the control of the gonadotropic hormone, the interstitial cell stimulating hormone from pituitary. Similarly the ovary synthesises and releases two steroids estrogens and progesterone, besides a peptide hormone relaxin. Estrogens maintain the functional state of the reproductive system, besides regulating the development and functions of accessory reproductive structures and secondary sexual organs. Progesterone secreted under the influence of luteotropic hormone from pituitary is released from the ruptured follicle of the ovary that transforms into corpus luteum. Progesterone besides preparing the uterine wall for the implantation of the ovum, also maintains gestation.

9.9 TERMINAL QUESTIONS

1. Describe the structure and functions of pituitary gland of mammals.
2. Give a comparative account of thyroids of vertebrates.
3. Briefly write the functions of the following hormones.
 - a) Adrenocorticotrophic hormone
 - b) parathormone
 - c) aldosterone

4. Testosterone (e) progesterone.
5. Briefly describe the structure and functions of adrenal cortex and medulla

9.10 ANSWERS

Self-Assessment Questions

1.
 - a)
 - i) Hypophysis cerebri,
 - ii) Adenohypophysis and neurohypophysis,
 - iii) Pars distalis and pars intermedia,
 - iv) Pars nervosa, infundibular stem and median eminence,
 - v) Oxytocin and vasopressin
 - b) Refer to Table 9.1.
2.
 - i) F, b) T, c) T, d) F, e) F, f) F, g) T, h) F, i) F, j) F.
 - ii) a) 6, b) 4, c) 5, d) 2, e) 3, f) 1.
3.
 - a) absent
 - b) feedback
 - c) produces
 - d) do not have
 - e) ventral
 - f) medulla
 - g) 1-alpha-hydroxycorticosterone
 - h) pars intermedia
 - i) scattered masses of tissue along ventral aorta
 - j) loss

Terminal Questions

1. Refer to Subsection 9.2.1.
2. Refer to Sections 9.2.2, 9.4, 9.5, 9.6 & 9.7
3. Refer to Subsection 9.2.1, 9.2.3, 9.2.5 and 9.2.7.
4. Refer to Subsection 9.2.5.