

## UNIT – V

### CHAPTER – 16 : DIGESTION AND ABSORPTION

All the living organisms require the presence of energy to do various functions of life. They get this energy from the food they eat. Food is also needed for growth and development of the body. Nutrition is defined as, the substance in total from which an organism derives its energy to do work and other materials for its growth, development and maintenance of life.

#### DIGESTION:

*“The breaking down of complex and insoluble organic substances such as carbohydrates, proteins and fats into simpler and soluble substances like glucose, amino acids and fatty acids respectively so that they can be easily absorbed into the body is known as digestion. This is a hydrolytic process and is carried out by various enzymes.”*

#### **Alimentary or Digestive system:**

Alimentary canal is a tube present in all higher animals starting from mouth and reaching up to anus. Various glands located on its wall produce digestive juices that help in the process of digestion. Two glands namely liver and pancreas are also associated with it. They also produce the digestive juices. The digested food is also absorbed into the alimentary canal and undigested and indigestible food is passed out of the body through anus.

#### Mammalian Alimentary System:

In man the total length of alimentary canal is about 21 feet and consists of the following parts:

Mouth leads into a buccal cavity. The opening of the mouth is provided with lips. At the floor of the buccal cavity a muscular tongue is present. It helps in the ingestion, mastication and swallowing of food. It has got taste buds on its surface. Most of the mammals possess teeth on both the jaws. They are present in the cavity or socket of gums (thecodont dentition). The number and types of teeth vary in mammals. In man, there are 32 teeth of four different types namely incisors, canines, premolars and molars. This type of dentition is known as heterodont dentition. Their number can be represented by the dental formula: In each half of jaw;

$$\begin{array}{rcl} \text{Upper jaw} & \text{I(2); C(1); PM(2); M(3)} & \\ \hline & & = 32 \\ \text{Lower jaw} & \text{I (2); C (1); PM (2); M (3)} & \end{array}$$

The incisor teeth are chisel-shaped and have sharp cutting edges. Canines are dagger-shaped and pierce the food. They are very large and well developed in predatory animals. Premolars and molars are broad and strong crushing teeth. Thus the incisors are used for biting; the canines for

tearing the food; and premolars and molars for grinding the food. With the help of the teeth, tongue and jaw movements, food is chewed and mixed with saliva in the mouth.

### *Salivary glands:*

There are three pairs of salivary glands namely parotids, submaxillary (submandibular) and sublingual glands. Their secretion is collectively known as saliva that is poured into the buccal cavity. Saliva usually contains enzymes and mucin. The enzyme present in saliva is known as ptyalin that helps in the digestion of carbohydrates; while mucin helps to lubricate the food for swallowing.

The mouth leads to a funnel-shaped pharynx, which communicates with a long muscular tube called oesophagus. The oesophagus opens into a muscular sac like structure called as stomach. In man, it is somewhat J-shaped and occupies the left side of the abdomen. The stomach opens into the small intestine. The stomach has many glands on its wall. Stomach wall produces gastric juice, which chiefly contains HCl, mucin and two protein digesting enzymes – rennin and pepsin. The muscles of the stomach wall churn and mix the food with gastric juice. Stomach through its pyloric region opens into small intestine. It is differentiated into three regions viz., duodenum, jejunum and ileum. Duodenum is U-shaped and gets the common bile duct and pancreatic duct from the gall bladder and pancreas. Jejunum is longer and more coiled. Ileum is the last part of small intestine and opens into the large intestine. Its wall has numerous long, finger-like projections called villi, which enhance absorption. Small intestine is the main region where digestion and absorption of food occurs. It has large number of tubular glands that produce the intestinal juice containing a number of enzymes, which digest various types of food. Digestion of different nutrients is completed in the small intestine by the action of pancreatic juice, intestinal juice and bile juice. The end products of digestion are then absorbed from the small intestine.

The small intestine opens into the large intestine. It is comparatively much shorter and wider than the small intestine. It does not have villi. It is also differentiated into three regions: caecum, colon and rectum. Caecum is a small pouch-like structure and its main part is vermiform appendix. However, caecum is very well developed in herbivorous animals like horse and ass. The colon is longest and has four parts; ascending colon, transverse colon, descending colon and pelvic colon. The pelvic colon opens into the rectum. Rectum is the last part of large intestine. Both in colon and rectum most of the water is reabsorbed back while the undigested food is removed from the body as faecal matter through anus. This is known as Egestion.

### **Glands associated with alimentary canal:**

**Pancreas:** It is located in between the loops of duodenum. It is the second largest gland of the body. It secretes pancreatic juice that contains large number of digestive enzymes for digesting starch, lipids, proteins and nucleic acids. The pancreatic juice is released into the pancreatic duct, which joins with the common bile duct.

**Liver:** It is the largest gland of the body lying immediately below the diaphragm in the right upper part of abdomen. The cells of the liver (hepatic cells) produce bile juice that contains bile pigments and bile salts. These bile salts help in the digestion and absorption of fats. Bile juice does not contain any enzyme. Bile juice flows out of the liver through hepatic ducts forming the common bile duct that opens into the duodenum (when the food is present in the duodenum). When there is no food in the duodenum, then bile juice is stored in the gall bladder. The gall bladder is a small elongated, muscular sac below the liver. When the food comes into duodenum, it contracts to release the bile juice.

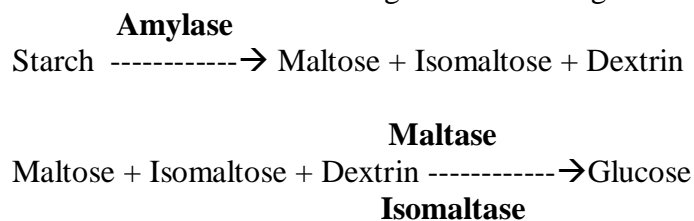
### **Digestion of Carbohydrates:**

Carbohydrates are of three types: polysaccharides, disaccharides and monosaccharides. During the process of digestion both poly-and disaccharides are broken down to monosaccharides and in this form they can be absorbed into the body. Some of these complex carbohydrates are starch and cellulose, present in cereal grains, potato, fruits and tubers; sucrose present in cane sugar; lactose present in milk etc. Enzymes that act on carbohydrates are collectively known as carbohydrases.

In the mouth cavity, the food is mixed with saliva. It contains an enzyme called salivary amylase or ptyalin. Salivary amylase acts on starch and convert it into maltose, isomaltose and small dextrins or 'limit dextrin'(disaccharides). Chewing and mastication of food increases the action of salivary amylase on starch by increasing the surface area of food on which the enzyme acts. About 30 percent of starch present in food is hydrolysed in the mouth. The action of salivary amylase continues for sometime even in the stomach but soon HCl present in the gastric juice destroys the entire enzyme.



Pancreatic juice and intestinal juice also contain carbohydrates digesting enzymes. Pancreatic juice contains pancreatic amylase that acts on starch to digest it into maltose, isomaltose and dextrin. Intestinal juice contains number of carbohydrates like maltase, isomaltase and sucrase and lactase. Maltase and isomaltase act on maltose, isomaltose and dextrins and convert into glucose; sucrase acts on sucrose to convert it into glucose and fructose; and lactase acts on lactose to convert it into glucose and the galactose.



### **Sucrase**

Sucrose -----→ Glucose + Fructose

### **Lactase**

Lactose -----→ Glucose + Galactose

Only human being can digest lactose present in the milk. But with advancing age, they also cannot digest milk. This is because less of lactase is produced. In them, lactose remains undigested and gets fermented in the intestine producing gases and acids. This results in intestinal disorder and diarrhoea. So these persons must consume curd or yoghurt (sweetened curd) as lactase is fermented to lactic acid in them. This will not pose any digestive problem to them.

Many of the herbivorous animals can digest cellulose by the microorganisms (bacteria and protozoa) present in their alimentary canal. These microbes ferment cellulose into short chain fatty acids such as acetic acid and propionic acid. These acids are then absorbed and utilized by the animal. This is, thus, an example of symbiotic digestion. Microbes may be present in the rumen and reticulum part of stomach (cow and buffaloes); or in the large intestine (horse and donkeys).

### **Digestion of proteins:**

Proteins are complex organic compounds made up of single units called amino acids. In the process of digestion, proteins are broken down to amino acids. Enzymes that hydrolyze protein are collectively known as proteases or peptides. Many of these enzymes are secreted in their inactive form or proenzymes. These inactive enzymes are converted to their active form only at the site of action.

Protein digestion starts in the stomach. The gastric glands of stomach produce a light coloured, thin and transparent gastric juice. It contains hydrochloric acid and pepsinogen. The  $H^+$  ions present in HCl converts pepsinogen into pepsin. The presence of HCl makes the medium highly acidic so that pepsin can act on proteins to convert them into peptones. HCl also helps to kill bacteria and other harmful organisms that may be present along with the food. Calf gastric juice contains another milk coagulating protease, called rennin. It is secreted as inactive pro-rennin. In the presence of HCl, the inactive prorennin is converted into their active form, i.e., rennin. Rennin acts on the casein protein of milk and converts it into paracasein, which in the presence of calcium ions forms calcium paracaseinate (curdling of milk). The function of rennin is then taken over by pepsin and other milk-coagulating enzymes. Adult cows or human infants do not produce rennin.

Both pancreatic juice and intestinal juice are poured into small intestine. Pancreatic juice contains *trypsinogen*, *chymotrypsinogen*, *carboxypeptidases*, *lipases*, *amylases*, *DNAases* and *RNAases*. All these enzymes of pancreatic juice can act only in the alkaline medium. This change in the medium of food, from acidic to alkaline, is done by the bile juice. Therefore, bile juice acts on the food before the action of pancreatic juice. In the intestinal lumen, pancreatic and intestinal juices mix together. Then a protease of intestinal juice, called *Enteropeptidase* or *Enterokinase* acts in coordination with pancreatic proteases. This enterokinase converts inactive

trypsinogen into active trypsin. In predatory animals, trypsins can hydrolyse fibrinogen of blood into fibrin leading to blood coagulation. But it is unable to bring about coagulation of milk. The inactive *Chymotrypsinogen* is activated to chymotrypsin by trypsin. Chymotrypsins can hydrolyse casein into paracasein, which then coagulates to form calcium paracaseinate. But it acts in the alkaline medium. Chymotrypsin acts on other proteins and converts them into peptides. *Carboxypeptidase* hydrolyses the terminal carboxyl groups from peptide bonds to release the last amino acids from the peptides thus making the peptide shorter.

The intestinal juice contains aminopeptidases and dipeptidases; and enterokinase or enteropeptidase. Out of these enterokinase activates the trypsinogen. Aminopeptidase hydrolyses the terminal amino group from peptide bonds to release the last amino acid from the peptides thus making the peptide shorter. Dipeptidase acts on dipeptides to release the individual amino acids.

### **Digestion of fats:**

Fat digestion starts only when the food reaches the small intestine. It starts with the action of bile juice from liver. Bile juice contains bile salts, which are secreted by the liver in the bile. Bile salts break down the bigger molecules of fat globules into smaller droplets by reducing the surface tension of fat droplets. This process is known as *emulsification of fats*.

Lipase is the enzyme that acts on emulsified fats. It is present both in the pancreatic juice and intestinal juice. Lipase converts emulsified fats into diglycerides and monoglycerides releasing fatty acids at each step. At the end of digestion, all fats are converted into fatty acids, glycerol and monoglycerides.

### **Absorption:**

During the process of digestion proteins are changed to amino acids, carbohydrates to glucose, fructose and galactose, fats to fatty acids, glycerol and monoglycerides. These end products of digestion are finally absorbed in small intestine. So absorption can be defined as a process by which nutrient molecules are taken into the cells of the body. For this purpose, intestine has vast surface area of absorption by the presence of numerous villi. Further, this area is increased by microvilli present on the free surface of epithelial cells.

**Passive absorption:** When the nutrients are absorbed by simple diffusion, then it is known as passive absorption. Various amino acids and monosaccharides diffuse into the blood capillaries of villi. This is dependent on the fact that these nutrients are more in concentration in the intestine than in the cells. Further, these molecules are small and water soluble. All the amino acids and monosaccharides are not absorbed in this way.

Water is absorbed from the intestine to the intestinal cells and finally to the blood by the process of osmosis. This occurs when the solute concentration in the blood is higher

(hypertonic). Thus, whenever any solute is absorbed from the intestine, it also results in the absorption of water.

**Active absorption:** This process occurs against the concentration gradient, i.e., nutrients may be more in intestinal cells than in the lumen of intestine. It requires the expenditure of energy i.e., ATP. Various nutrients like amino acids, glucose, galactose,  $\text{Na}^+$  ions can be absorbed by active transport. After their passive absorption, they are completely absorbed by active transport. For the active absorption of  $\text{Na}^+$  ions, a mechanism of sodium pump operates in the cell membranes.

### **Micelles in fat absorption/Role of bile juice in the absorption of fats:**

As the fatty acids and glycerol are insoluble in water, the intestine cannot directly absorb them. So they cannot reach the blood stream directly. Instead, they are passed into lymph capillaries of the villi called lacteals. Digested fats are first incorporated into small, spherical droplets called micelles with the help of bile salts and phospholipids in the intestinal lumen. In the lacteals, fats are resynthesised into very small fat molecules called chylomicrons. An obstruction in the bile duct may prevent the entry of bile juice into the small intestine (obstructive jaundice) as a result unabsorbed fats are removed from the body along with the faecal matter. Thus bile plays an important role in the absorption of fats.

**Balanced diet:** To maintain normal functioning of our body, we need varieties of food so that all the systems are well maintained. A diet, which contains adequate amount of all the essential nutrients, is known as balanced diet. It varies according to age and occupation. A balanced diet should have the following three qualities:

- It must be rich in various essential nutrients like vitamins, minerals and some amino acids.
- It should provide enough raw materials needed for the growth and development, repair and replacement of cells, tissues and organs of the body.
- It should provide the necessary energy required by the body.

### **Disorders of Digestive System:**

1. **Jaundice:** The liver is affected; skin and eyes turn yellow due to the deposit of bile pigment.
2. **Vomiting:** It is the ejection of stomach contents through the mouth and controlled by the centre in the medulla oblongata.
3. **Diarrhoea:** Abnormal bowel movement and the faecal discharge with more liquidity, which leads to dehydration.
4. **Constipation:** the feces are retained within the rectum due to irregular bowel movement.
5. **Indigestion:** food is not properly digested leading to a feeling of fullness due to inadequate enzyme secretion, anxiety, food poisoning, over eating and spicy food.

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## **CHAPTER – 17: Breathing and Exchange of Gases**

Every living cell requires continuous expenditure of energy for various life processes like growth, development and multiplication. This energy is derived from the oxidation of organic compounds. The biological oxidation of these compounds constitutes the process of respiration. Respiration is thus defined as, ***“the biochemical oxidation of organic compounds like glucose to yield energy”***.

### **Organs for respiratory exchange in various animals:**

- In simple animals like *Amoeba*, *Paramecium*, the body organisation is very simple, so gases can diffuse in and out from the general surface of the body. The air diffuses across the membrane from the side where its partial pressure is more to the side where its partial pressure is less. However, there are no special organs of respiration.
- There are no special organs for respiration in *Hydra* as the body organisation is very simple and the cells are more or less directly exposed to the environment. Dissolved oxygen enters into the cells of *Hydra* through the general body surface, as there is less oxygen concentration within the cells. Carbon dioxide produced after respiration also comes out in a similar way. This process is termed as diffusion.
- There are no special respiratory organs in earthworms and leeches but the exchange of gases occurs through the skin (cutaneous respiration). The skin is always kept moist by the secretions of mucous glands, and is richly supplied with blood capillaries. Oxygen from the atmosphere dissolves into mucous and diffuses in. It is then transported to the body tissues by hemoglobin of the blood. In them, hemoglobin is dissolved in plasma and not present in the corpuscles unlike other animals.
- In insects, gas exchange occurs through a tracheal system because in them the integument has become impermeable to gases to reduce the water loss. Trachea are fine tubes that open to the outside by spiracles. Each trachea branches into tracheoles that again branch extensively in the tissues and finally end into air sacs.

Inspiration and expiration occur through the spiracles. When the abdominal muscles relax, the air is drawn into the spiracles, trachea and tracheoles. This then diffuses through the body fluids to reach the cells. When the abdominal muscles contract, the air is driven out through the tracheal system via the spiracles. Thus in insects expiration is an active process but inspiration is passive.

- In the marine annelid *Nereis* respiration occurs by the whole body surface, but more specially by thin, flattened lobes of parapodia, which possess extensive capillary network. They are richly supplied with blood capillaries and are highly permeable to respiratory gases.
- Aquatic animals like prawns, fishes and tadpoles (of frog) respire with the help of gills. Gills are richly supplied with blood and can readily absorb oxygen dissolved in water. The surface of the gills is increased by the presence of gill plates. Each gill plate has many flat and parallel membranes like gill lamellae. Water moves over these gills in single direction only. The oxygen absorbed by the gills from the water is taken by blood and carbon dioxide is given out into the water.

- In amphibians like frogs and toads, some cutaneous respiration takes place across their moist and highly vascular skin, particularly during hibernation. However, they mainly respire through the lungs and the moist mucus membrane of the buccal cavity. Toads have less of cutaneous respiration than frogs.

### **Human Respiratory System:**

All mammals have lungs for the purpose of respiration. This is known as pulmonary respiration. The mammalian respiratory system consists of the nasal cavity, nasopharynx, larynx, trachea, bronchi, bronchioles and lungs.

1. *Nasal cavity*: It is a large cavity lying dorsal to the mouth and is lined by mucous secreting epithelium. The nasal cavity opens outside through a pair of external nostrils or nares. Bones and cartilages support the nasal cavity. The nasal cavity is divided into two parts by a nasal septum. The cavity opens inside into pharynx through two internal nostrils. Air while passing through the nasal cavity is filtered, and only the clean air free from dust particles and foreign substances enters the pharynx. The air also gets warmed and moistened in this chamber. It is important to note that air can also be inhaled through mouth directly, but this is not advisable because the air will not be filtered, warmed and moistened. This gradually will harm the respiratory system.
2. *Nasopharynx*: It is a chamber situated behind the nasal cavity. At the level of soft palate, it becomes continuous with the mouth cavity or oral pharynx. It also receives the openings of eustachian tubes on its lateral sides and is thus connected to the middle ear.
3. *Larynx*: It is a chamber situated in the region of neck. It is supported by four cartilages : thyroid is the largest and in the form of a broad ring incomplete dorsally, cricoid is a complete ring lying at the base of thyroid, a pair of arytenoids lying above the thyroid but in front of cricoid, and epiglottis situated behind the tongue that serves to cover the entrance to the trachea so that food particles may not enter into it. Larynx is also known as voice box since it helps in the production of sound.
4. *Trachea*: It is a tube starting from larynx running through the neck and the thoracic cavity. The trachea runs through the neck in front of the oesophagus. The trachea or windpipe is about 12 cm long and divided into two bronchi in the thoracic region.
5. *Bronchi and bronchioles*: The two bronchi enter into right and left lungs of either side. Inside the lungs they further branch into many smaller bronchioles with a diameter of about 1 mm. These bronchioles further divide into terminal and then into respiratory bronchioles. Each respiratory bronchiole divides into a number of alveolar ducts that further divide into atria, which swell up into air sacs or alveoli.
6. *Lungs*: A pair of conical shaped lungs is situated in the double walled sacs called pleural cavities. They are spongy and richly supplied with blood vessels and capillaries. They have about 300-400 millions of alveoli through which exchange of gases occur. Lungs have



various bronchioles ending into alveoli where exchange of gases occurs. The alveoli are thin walled pouches the walls of which have epithelial linings supported by basement membrane.

### **Mechanism of breathing or pulmonary respiration:**

- Respiration involves the following steps:
- Breathing or pulmonary ventilation by which atmospheric air is drawn in and Carbon dioxide air released out.
- Diffusion of gases of oxygen and carbon dioxide across alveolar membrane.
- Transport of gases by the blood.
- Diffusion of oxygen and carbon dioxide between blood and tissues.
- Utilisation of oxygen by the cells for catabolic reactions and release of carbon dioxide.

### **Mechanism of Breathing:**

*Inspiration:* During this process, some intercostal muscles contract thus pulling the ribs upwards and outwards. Lateral thoracic walls also move outwards and upwards. At the same time the diaphragm becomes flattened as it moves down towards the abdomen. This results in the increase in the volume of thoracic cavity thus lowering the pressure in the lungs. To fill up this gap, air from outside rushes in to bring about inhalation or inspiration. Hence, inspiration is brought about by contraction of the diaphragm and some intercostal muscles; these muscles are known as inspiratory muscles.

*Expiration:* During this process, the ribs return back to their original position, inwards and backwards, by the relaxation of intercostal muscles and also the diaphragm becomes dome-shaped again. Lateral thoracic walls also move inwards and downwards. This decreases the volume of the thoracic cavity thus increasing the pressure inside the lungs. So the air from the lungs rushes out through the respiratory passage bringing about expiration or exhalation.

A person breathes about 12 to 16 times per minute while at rest. However, this breathing rate is higher at the time of muscular exercise and in small children.

In forceful expiration, a different group of intercostal muscles and some abdominal muscles contract to reduce the volume of the thorax more than that in ordinary expiration. So more air is expelled out. Such muscles are known as expiratory muscles.

**Pulmonary air volumes:** Air flows into and out of the lungs because of the pressure gradient. *Spirometer* is an instrument used to measure the amount of air exchanged during breathing. Some terms regarding pulmonary air volumes are as follows:

1. **Tidal volume:** It is the volume of air that is breathed in and breathed out while sitting at rest (effortless respiration) or “quiet breathing”. It is about 500 ml in an adult person.
2. **Vital capacity:** It is the volume of air that can be maximum expelled out after a maximum inspiratory effort. It is about 4,500 ml in males; and 3,000 ml in females. The higher the

vital capacity, the greater will be the capacity for increasing the ventilation of lungs for exchange of gases. It is more in athletes and mountain dwellers.

3. **Residual volume:** It is the volume of air that remains inside the lungs and respiratory passage( about 1.5 litres ) after a maximum forced exhalation.
4. **Inspiratory reserve volume (IRV):** It is the volume of air that can be taken in by forced inspiration over and above the normal inspiration or tidal volume. It is about 2,000 ml to 3,500 ml.
5. **Expiratory reserve volume (ERV):** It is the volume of air that can still be given out by forced expiration over and above the normal inspiration or tidal volume. It is about 1,000 ml.
6. **Total lung capacity:** It is the volume of air in the lungs and respiratory passage after a maximum inhalation effort. It is equivalent to vital capacity plus residual volume. It is about 5,000 to 6,000 ml in adult males.

### **Pulmonary exchange of gases:**

In most of higher animals including man, the air from outside reaches up to the alveoli of lungs in the process of breathing. This inspired air contains about 21 per cent oxygen, 0.04 per cent carbon dioxide, 78.6 per cent nitrogen and small amounts of other gases and atmospheric moisture. In this inspired air the partial pressure of oxygen ( $P_{O_2}$ ) is 158 mm Hg; and that of carbon dioxide ( $P_{CO_2}$ ) is 0.3 mm Hg. The lungs and alveoli also contain some air even after expiration. But this air has more of carbon dioxide and less of oxygen than the inspired air. So when this air mixes with the inspired air the partial pressure of oxygen in alveolar air now becomes 100 mm Hg and that of carbon dioxide becomes 40 mm Hg. However, the percentage of oxygen now becomes 13.1% and that of carbon dioxide 5.3%.

The pulmonary artery contains deoxygenated blood and this has  $P_{O_2}$  much less (40 mm Hg) than that of alveolar  $P_{O_2}$ . So oxygen from the alveolar air diffuses into the blood capillaries (oxygenation). This oxygenated blood is collected from alveoli of lungs by the pulmonary veins. It has a  $P_{O_2}$  of about 95 mm Hg and at this partial pressure, the oxygenated blood has 19.8 per cent oxygen. Further, the deoxygenated blood in the pulmonary artery has a  $P_{CO_2}$  of 46 mm Hg and  $P_{CO_2}$  of alveolar air is 40 mm Hg. So the blood while passing through the alveoli of lungs also unloads carbon dioxide. The pulmonary vein carrying oxygenated blood, thus, has carbon dioxide at the partial pressure of 40 mm Hg. At these partial pressures the carbon dioxide contents of the blood decreases from 52.7 per cent to 49 per cent.

### **Gas transport in blood:**

#### **Oxygen transport :**

The hemoglobin pigment of blood mainly transports oxygen. From alveoli of lungs, oxygen can readily diffuse into erythrocytes and combines loosely with hemoglobin (Hb) to form a reversible compound oxyhemoglobin ( $HbO_2$ ). Combining of oxygen with hemoglobin to

form oxyhemoglobin is a physical process. There is no change in the valency of iron atom; it is ferrous in oxyhemoglobin and also in hemoglobin. This reaction, therefore, is an “oxygenation” process and not oxidation. When fully oxygenated, hemoglobin has about 97 per cent of oxygen. Hemoglobin is dark red in colour; whereas oxyhemoglobin is bright red in colour.

Inside the tissues, as the partial pressure of oxygen is less, oxyhemoglobin gets dissociated into oxygen and hemoglobin. Further, as  $P_{O_2}$  is much lower and  $P_{CO_2}$  is much higher in active tissues than in passive tissues, so much of oxygen is released from oxyhemoglobin in active tissues. High tension of oxygen favours the formation of oxyhemoglobin while low tension of oxygen favours its dissociation. However, very little of oxygen is found in the blood plasma. Each decilitre of blood releases up to 4.6 ml, of oxygen in the tissues, 4.4 ml from oxyhemoglobin and 0.17 ml from the dissolved oxygen in the plasma.

### **Carbon dioxide transport :**

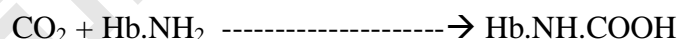
Carbon dioxide is produced in the tissues as an end product of tissue respiration. For its elimination, it gets dissolved in tissue fluid and passes into the blood. In the tissues, 100 ml of blood receives about 3.7 ml of carbon dioxide. It is transported both by the plasma and hemoglobin of blood. From the tissues, carbon dioxide diffuses into the blood plasma and forms carbonic acid ( $H_2CO_3$ ) in the presence of an enzyme carbonic anhydrase. Inside the erythrocytes, some of the carbonic acid forms bicarbonates and is thus transported. As carbonic acid, carbon dioxide is transported by blood plasma.

#### **Carbonic anhydrase**



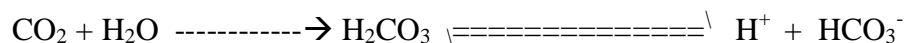
If all the carbon dioxide produced by the tissues is carried by blood plasma in this way, then pH of the blood will be lowered to about 4.5. This would immediately cause death. So only about 10% of the  $CO_2$  produced by the tissue is actually transported as carbonic acid.

About 20% of the total  $CO_2$  produced is transported by the hemoglobin of blood as carbaminohemoglobin.



About 70 % of the total  $CO_2$  produced is transported as bicarbonate ions of the blood. Bicarbonates are formed both in the erythrocytes and in the plasma of blood.

In erythrocytes.  $CO_2$  from the plasma enters the erythrocytes and combines with water to form carbonic acid in the presence of the enzyme carbonic anhydrase. Carbonic acid soon dissociates to form  $H^+$  and  $HCO_3^-$  ions.



Hence, carbon dioxide is carried in the blood in three major forms; bicarbonates in plasma and erythrocytes, carbaminohemoglobin in erythrocytes, and small amounts of dissolved carbon dioxide in plasma.

On reaching the lungs, blood is oxygenated. Oxyhemoglobin is a stronger acid than deoxyhemoglobin. So it donates  $H^+$  ion, which joins bicarbonate ( $HCO_3^-$ ) to form carbonic acid and this carbonic acid is cleaved into water and carbon dioxide by an enzyme carbonic anhydrase. Oxygenation of hemoglobin releases carbon dioxide from carbaminohemoglobin. By this way, every decilitre of blood releases about 3.7 ml of carbon dioxide in the lungs. Then this carbon dioxide is removed from the lungs by exhalation.

### **Gas exchange in tissues:**

In the tissues, gases are exchanged by diffusion (as in the lungs). In tissues, as the partial pressure of oxygen is very low (about 40 mm Hg), so the oxygen gets unloaded here. When the blood leaves the tissues it has  $P_{O_2}$  of 40 mm Hg. However, for carbon dioxide it is just the reverse. The blood entering into tissues has  $P_{CO_2}$  of 40 mm Hg; while  $P_{CO_2}$  of tissues is 46 mm Hg. So some of carbon dioxide from tissues gets loaded into the blood.

### **Disorders of Respiratory System:**

1. **Asthma:** difficulty in breathing causing wheezing due to inflammation of bronchi and bronchioles.
2. **Emphysema:** alveolar walls are damaged due to which respiratory surface is decreased, causes of this is cigarette smoking.
3. **Occupational Respiratory Disorders:** long exposure to the dust of industries like stone breaking, etc cause an inflammation on lung tissues and leads to lung damage.

### **Distinguish between:**

#### **1. *Inspiratory muscles and expiratory muscles* :**

Inspiratory muscles are a group of intercostal muscles, the contraction and relaxation of which bring about inspiration and expiration respectively. Expiratory muscles are a group of different intercostal muscles and some abdominal muscles which contract to reduce the thoracic cavity more than that in ordinary expiration as in forceful respiration.

#### **2. *Tracheoles and bronchioles* :**

Tracheoles are the finer branches of tracheal tubes present in insects that ramify into the tissues. Bronchioles are the finer branches of bronchus that branch further to open into alveoli of lungs in mammals.

#### **3. *Carbaminohemoglobin and oxyhemoglobin* :**

Carbaminohemoglobin is a reversible compound formed when hemoglobin combines with carbon dioxide; oxyhemoglobin is a reversible compound formed when hemoglobin combines with oxygen.

In carbon monoxide poisoning, Hb combines irreversibly with CO to form carboxyhemoglobin.

#### **4. *Inspired air and alveolar air* :**

Inspired air is the air taken inside the lungs during inspiration. It contains about 21% oxygen and 0.03% carbon dioxide. This air now mixes up with the air already present inside the lungs, which has more of carbon dioxide and less of oxygen. This mixed air is now called as alveolar air and it has 13.1% oxygen and 5.3% carbon dioxide.

**Explain why the following things happen:**

***1. Far more oxygen is released from oxyhemoglobin in a more active tissue than in a less active one.***

The dissociation of oxyhemoglobin to oxygen and deoxyhemoglobin depends upon the partial pressures of oxygen and carbon dioxide in the tissues. In a more active tissue, the  $P_{O_2}$  is lower and  $P_{CO_2}$  is higher as compared to that of a less active tissue. So far more oxygen is released from oxyhemoglobin in a more active tissue than in a less active one.

***2. Oxygenation of blood promotes the release of carbon dioxide from the blood in the lungs.***

The oxygenation of blood in the lungs depends on the partial pressures of oxygen in the pulmonary artery and in the alveolar air. Further, the oxygen affinity of hemoglobin is enhanced with the fall in partial pressures of carbon dioxide that results from the elimination of carbon dioxide from the blood into the lungs. In the lung alveoli, hemoglobin is exposed to high  $P_{O_2}$  and less  $P_{CO_2}$ .

***3. Oxygen leaves the blood from tissue capillaries, but carbon dioxide enters the blood in tissue capillaries.***

Inside the tissue capillaries, there is more of  $P_{CO_2}$  and less of  $P_{O_2}$ . The blood coming to tissues has more of  $P_{O_2}$  and less of  $P_{CO_2}$ . So oxygen is unloaded from the blood and carbon dioxide is loaded to the blood in the tissue capillaries.

***4. Erythrocytes can carry out anaerobic metabolism only.***

Erythrocytes can carry out anaerobic metabolism only because they lack mitochondria.

***5. Gaseous exchanges continue in the lungs without interruption during expiration.***

Gaseous exchanges continue in the lungs uninterrupted because some air is always present inside the lung alveoli even during expiration.

***6. Contraction of inspiratory muscles causes inspiration while relaxation causes expiration.***

Contraction of inspiratory muscles increases the volume of pleural cavities; while expiration is brought about passively by the relaxation of those muscles. As the muscles relax, the diaphragm moves up towards the thorax and the intercostal muscles move the lateral thoracic walls inwards and downwards. This decreases the volume of pleural cavities and the air rushes out.

***7. Oxygen enters the blood from the alveolar air but carbon dioxide leaves the blood to enter the alveolar air.***

Inside the alveoli of lungs, there is more of  $P_{O_2}$  and less of  $P_{CO_2}$ . The blood coming to lung alveoli has more of  $P_{CO_2}$  and less of  $P_{O_2}$ . So oxygen is loaded to the blood and carbon dioxide is unloaded from the blood in the alveoli of lungs.

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## **CHAPTER - 18 : BODY FLUIDS AND CIRCULATION**

All parts of the body require nourishment and oxygen, and metabolic wastes need to be removed from the body. So there is a need to transport various substances like digested food materials to provide energy and growth of the body, hormones, metabolic wastes, enzymes, various gases (oxygen and carbon dioxide) etc. from one part of the body to other. These functions are carried out by an extracellular fluid, which flows throughout the body. This flow is known as circulation and this transport of substances is done by a system is called circulatory system.

### **Functions of the circulatory system :**

- It transports nutrients from their sites of absorption to different tissues and organs for storage, oxidation or synthesis of tissue components.
- It also carries waste products of metabolism from different tissues to the organs meant for their excretion from the body.
- It transports respiratory gases between the respiratory organs and the tissues.
- It carries metabolic intermediates from one tissue to another for their further metabolism; for example, blood carries lactic acid from muscles to the liver for its oxidation.
- It also transports informational molecules such as hormones, from their sites of origin to the tissues.
- It uniformly distributes water,  $H^+$ , chemical substances to all over the body.

### **Blood Vascular System :**

Higher animals have a well-developed circulatory system so that transport of substances in the body can be done very effectively. In them, the circulatory system consists of a central pumping organ called as heart and various blood vessels (arteries, veins and capillaries). Arteries conduct the blood from the heart to other tissues; veins bring blood from other tissues to the heart. Some of the invertebrates and all vertebrates possess this system. The circulatory system was first discovered and demonstrated by *William Harvey*.

The blood vascular system may be of two types, the open and the closed circulatory systems.

### ***Open circulatory system :***

In many advanced invertebrates such as prawns, insects and molluscs, the blood does not remain confined to blood vessels but it flows freely through the body cavity and channels called lacunae and sinuses in the tissues. The body cavity is known as hemocoel and the blood is hemolymph. In insects, the tissues are in direct contact with the blood. Hemolymph circulates in the whole body due to the contractile activity of heart.

### ***Closed circulatory system :***

In closed circulatory system the blood flows through proper blood vessels named arteries, veins and blood capillaries. Arteries within the tissues divide into arterioles, which then branch further to form capillaries. Capillaries then unite to form venules, which come out of the tissues and veins. Arteries have thick, elastic and muscular walls which are made up of three concentric



layers viz., tunica externa, tunica media and tunica interna. All these layers have got smooth or involuntary muscles. Contraction and relaxation of smooth muscles alter the diameter of arteries and thus regulate the flow of blood through them. Capillaries are extremely fine, thin blood vessels the walls of which are made of a single layer of endothelial cells. The muscles and elastic fibers are absent in them. These capillaries are highly permeable to water and small macromolecules. Various nutrients, respiratory gases, metabolites and other substances are exchanged between the blood and tissues through these capillaries.

Structurally veins resemble arteries except that the three layers are very thin and more elastic. In the veins the muscles and elastic connective tissues are poorly developed. But the collagen fibers of the outer layer are very well developed. In most of the veins the middle coat is extremely thin with practically no muscles. In many veins semilunar valves are present in their lumen. These valves allow the flow of the blood only in one direction i.e., towards the heart.

### **Distinguish between arteries and veins :**

Arteries	Veins
1. Blood flows away from the heart.	Blood flows towards the heart.
2. Blood flows with jerks and with great pressure.	Blood flows smoothly and with less pressure
3. They always carry oxygenated blood except the pulmonary artery.	They always carry deoxygenated except the pulmonary vein.
4. Lumen of arteries is small.	Lumen of vein is large.
5. Valves are absent.	Semilunar valves are present to prevent the back flow of blood.
6. They are deep seated.	They are usually superficial.
7. Their walls are elastic, thick and muscular.	Their walls are non-elastic, thin and fibrous.
8. Non-collapsible.	Collapsible.

### **The heart :**

The heart is the central pumping organ of the blood vascular system. It is a hollow muscular structure and is made up of cardiac muscles. It works throughout life rhythmically without getting tired. It is enclosed in a double membraneous sac called pericardium that is filled with pericardial fluid. Mainly there are two chambers in a heart – auricle or atrium that receives the deoxygenated blood from various parts of the body; and a ventricle that distributes the oxygenated blood to the body. The number of these chambers varies in different animals.

In *fishes*, the heart is only two chambered – one auricle and one ventricle. Both these chambers contain deoxygenated blood.

In *amphibians*, the auricle is divided into right and left auricles. The blood after oxygenation from lungs is returned back to left auricle. Right auricle receives deoxygenated blood from various parts of the body. However, in the ventricle there is mixing up of deoxygenated and oxygenated blood.

In *reptiles* (except crocodiles), the division of the ventricle also starts but it is not complete. So the heart is incompletely four-chambered. However, there are two auricles- left

and right auricles. In them the oxygenated and deoxygenated blood are kept separate. But in the ventricle, this separation is not perfect.

*Crocodiles, birds and mammals* have a complete four-chambered heart. In them the ventricle septum is complete so that there is no mixing up of oxygenated and deoxygenated blood at all.

A structure called sinus venosus is present in the hearts of fishes, amphibians and reptiles. It receives deoxygenated blood from anterior and posterior caval veins and then that blood is poured into the heart. There is no sinus venosus in mammals.

### **Human Heart :**

The mammalian heart including man is a hollow, cone-shaped, muscular structure that lies in the thoracic cavity above the diaphragm and in between the two lungs. It is about the size of a fist measuring about 12 cm in length and 9 cm in breadth. It weighs about 300 grams. It is a four chambered organ—two atria or auricles and two ventricles. Deoxygenated blood is received into right auricle by superior vena cava (from anterior region) and inferior vena cava (from posterior region) of the body. These vena cavae open directly into right auricle as there is no sinus venosus. Right auricle also gets blood from coronary veins (from the heart muscles itself). The right and left auricles are separated by interauricular septum. Similarly, right and left ventricles are also separated by interventricular septum. Deoxygenated blood is then passed from the right auricle to the right ventricle through the atrioventricular aperture guarded by tricuspid valve (having three flaps). The blood is then pumped into lungs for oxygenation via pulmonary artery. After oxygenation, the blood is brought back into left auricle via four pulmonary veins. From left auricle, blood (now oxygenated) goes to left ventricle through atrioventricular aperture and this opening is regulated by bicuspid (having two flaps) or mitral valve. The left ventricle has also got chordae tendinae and papillary muscles which prevent the valves (both bicuspid and tricuspid) from being pushed into auricles at the time of ventricular contraction. Thus the walls of left ventricle are thicker than the walls of right ventricle. The oxygenated blood from left ventricle is then distributed to all parts of the body with the help of aorta. The openings of the aorta and other major arteries are guarded by semilunar valves that prevent the back flow of blood.

#### **Course of Circulation through Mammalian Heart :**

During a heart beat, there is contraction and relaxation of auricles and ventricles in a specific sequence. The contraction phase is known as systole, while relaxation phase is known as diastole. Various series of events that occur during a heart beat is known as cardiac cycle.

When both the auricles and ventricles are in relaxed or diastolic phase. This is referred to as joint diastole. During this phase, the blood flows into the auricles from the superior vena cava and inferior vena cava. The blood also flows from the auricles to their respective ventricles through the atrio-ventricular valve. There is no flow of blood from the ventricles to the aorta and its main arteries as the semilunar valves remain closed in this phase.

At the end of joint diastole, the next heart beat starts with the contraction of atria (atrial systole). In this phase, it now forces most of its blood into the ventricle, which is still in the diastolic phase. During auricular systole, the blood cannot pass back into the superior and inferior vena cava because they are compressed by the auricular contraction and their openings to the auricles are blocked. Thus auricles act as main vessel to collect and pump the venous blood into the ventricles. Thus at the end of auricular systole, the auricles get empty.

After the atrial systole is over, the auricular muscles relax and it enters into auricular diastolic phase. During auricular diastole, it again gets filled up with the venous blood coming from the superior and inferior vena cavae. Along with the auricular diastole, the ventricular systole starts. This results in an increased pressure of blood in the ventricle and it rises more than the pressure of blood in the auricle. Soon the atrio-ventricular valves are closed and thus the back flow of blood is prevented. This closure of AV-valve at the beginning of ventricular systole produces a sound “lubb” and is known as the first heart sound. Initially, when the ventricle starts contracting, the pressure of blood within it is lower than the pressure of blood within the aorta and so the semilunar valves do not open. Therefore, the ventricle contracts as a closed chamber. As the ventricular systole progresses more, the pressure of blood within the ventricle increases more than that of aorta as a result the semilunar valves now open and blood flows (with a speed) into the aorta and its main branches. The back flow of blood in the auricles is prevented, as the AV-valves remain closed.

Now at the end of ventricular systole, ventricular diastole starts. As the auricles are still continuing with their diastole, so all the four chambers are now in diastole. This is known as joint diastole. In the ventricular diastolic phase, the pressure of blood in the ventricles falls below the pressure of blood in the aorta, so the semilunar valves get closed to prevent the back flow of blood from the aorta to the ventricles. This closure of semilunar valves at the beginning of ventricular diastole produces a sound “dup” and is known as the second heart sound. After the closure of the semilunar valves, the ventricles become closed chambers again. Also, as the ventricular pressure is more than the atrial pressure, so the AV-valves remain closed. However, as the ventricular diastole continues, the pressure of blood in the ventricles falls below the pressure of blood in the auricles. At this point, the AV-valves open and blood starts flowing again from the relaxed auricles to the relaxed ventricles. Now when the joint diastole is over, the auricular systole starts and the blood is pumped into the ventricles.

### **Heart Rate and Pulse:**

In the resting condition, human heart beats at the rate of about 70 times per minute. But, the heart beat rate increases during exercise, fever, and emotions like anger and fear. During each heart beat, the blood is pumped from the ventricles of the heart into the aorta to be distributed to all parts of the body. This happens during the ventricular systole and is repeated every 0.8 seconds. The blood from aorta then goes to other arteries of the parts. This causes a rhythmic contraction in the aorta and its main arteries. It can be felt as regular jerks or pulse in the regions where arteries are present superficially like wrist, neck and temples. This is known as arterial pulse.

The pulse rate is, therefore, same as that of heart beat rate. This heart beat rate differs from species to species. In general, the smaller the animal, the greater the heart beat. Hence, larger animals have lower heart rates. For example, an elephant has a normal heart beat rate of about 25 times per minute, whereas mouse has a normal heart beat rate of several hundreds per minutes.

### **Automatic rhythmicity of the heart:**

The mammalian heart is a myogenic heart i.e., the heart beat originates from a muscle (but it is regulated by nerves). In the right atrium near the region where superior vena cava opens, a specialised muscle called sinu-auricular node (SA-node) is present from where the heart beat

originates. It is also called as pace maker and is richly supplied with blood capillaries. A wave of contraction (systole) originates from it and spreads over to the whole heart.

At the junction of right atrium and right ventricle, a tissue called auriculo-ventricular node (AV-node) is present that picks up the wave of contraction propagated by SA-node. This is also known as bundle of His. Branches of this spread over the ventricle forming the Purkinje system. The wave of contraction spreads over the ventricle through AV-node and its Purkinje system.

The heart is supplied with vagus (parasympathetic) and sympathetic nerve fibers. The vagus nerve is inhibitory and so when stimulated slows down the heart beat; while the sympathetic nerve is acceleratory and so when stimulated fastens the heart beat. This happens because these nerves release chemicals (hormones) when stimulated.

### **Circulation:**

In vertebrates, the heart pumps blood into a closed circulatory system. The left ventricle ejects blood into the aorta, which gives off arteries to tissues and organs(except lungs), then the blood is returned from these tissues and organs through two veins, superior and inferior vanae cavae to the right atrium. This is known as the systemic circulation. The right ventricle pumps blood into the pulmonary trunk which divides into pulmonary arteries going to the lungs; then blood is returned to the left atrium from the lungs through the pulmonary veins. This is called the pulmonary circulation.

In some cases, before the blood can finally return to the heart, a vein returning blood from a system of capillaries divides again into a second capillary system in the tissues. Such type of vein is called as portal vein; and it constitutes a portal system along with the capillary system to which it supplies blood.

Veins after collecting deoxygenated blood from the organs normally pour the blood into right auricle. But sometimes, they pour their blood into some other organ by the portal veins before the heart. The blood from that organ is then collected and poured into the heart. For example, a hepatic portal vein returns blood from the intestine and breaks into a portal system of capillaries in the liver. This helps the absorbed nutrients from the small intestine to reach first into the liver via the hepatic portal vein. The cells of the liver can take up these nutrients. Similarly, the blood coming from hypothalamus may be poured into anterior pituitary by a hypophysial portal vein. This portal system enables the hormones of hypothalamus to reach the anterior pituitary.

### **Arterial Blood Pressure:**

The pumping action of the heart maintains a pressure of blood in the arteries. This is called Arterial blood pressure. It helps to pump blood at a high velocity along the arteries in the closed circulatory system. The blood pressure is far lower in the open circulatory system.

### **Blood Flow in Veins:**

The blood pressure is low in veins, because the blood flows through narrow arterioles and capillaries to enter wider veins. At many places in the body, this blood pressure is not sufficient to drive the blood through the veins back to the heart. Veins have thinner walls than arteries and are more easily compressed. There are also many valves inside the veins. These valves permit the flow of blood in the veins towards the heart and prevent blood flow in the reverse direction.

Contraction of muscles and changes of body posture compresses the veins to move the blood inside them. During this both cases, blood moves towards the heart only, because the venous valves prevent the blood flow in the opposite direction. This is a major process for venous blood flow.

For example, if a person stands immobile for a long time, blood flow in the leg veins remains suspended. This may lead to an accumulation of fluid in his leg tissues and a consequent swelling of his feet. If he walks for some time, the swelling subsides as blood begins to circulate again in the veins.

### **Lymph and Tissue Fluid:**

It occurs in the spaces in between the cells of a tissue and is called as interstitial fluid or tissue fluid. The exchange of any material (solid, liquid or a gas) that occurs between the blood and the tissue cells always takes place through this fluid. Under the pressure of blood in the capillaries some of the water and desired solutes are filtered out from the blood plasma into the tissue spaces to form the tissue fluid. The composition of this tissue fluid is very similar to that of plasma except that it has much less protein. Proteins are less because some of the proteins are not filtered out from the capillary walls (impermeable).

Some of the tissue fluid enters tiny channels called lymph vessels and the fluid collected in them is called lymph and this system is known as lymphatic system. These lymph vessels unite to form larger lymph vessels which ultimately drain into two large lymph vessels called thoracic duct and the right lymphatic duct. These open into veins returning the lymph finally into venous blood and so in the general circulatory system. This movement of lymph is mainly due to the squeezing action of the surrounding muscles. So the lymphatic system is slow and uncertain. Exercise increases the rate of lymph circulation.

Generally, the rate of lymph formation is equal to the rate of its return to the blood stream. But sometimes, the formation rate of lymph exceeds the rate of its return to blood. The increased volume of fluid around the cells then creates a swelling, called dropsy or oedema.

### **Functions of Lymph:**

1. It serves to return interstitial fluid into blood.
2. The plasma proteins macromolecules synthesized by the liver cells, cannot pass into the blood vessels, but can diffuse into the lymph vessels through their wall and they come to the blood through lymph.
3. It also carries absorbed fats and lipids from the small intestine to the blood in the form of chylomicron droplets.

### **Disorders of Circulatory System:**

1. **High Blood Pressure (Hypertension):** It is the term for blood pressure that is higher than normal of 120/80. In the instrument 120 is Systolic / pumping pressure, 80 is Diastolic, resting pressure. If repeated check which shows 140/90 and higher shows Hypertension. It may lead to heart diseases and also affect vital organs like brain and kidney.
2. **Coronary Artery Disease (CAD) :** it is also known as Atherosclerosis, due to damage in the blood vessels of heart tissues. Basically it is due to, deposition excess of Calcium, fat, cholesterol and fibrous tissues which makes the lumen of arteries narrower.

3. **Angina:** It is also known as “angina pectoris”, it is symptom of acute chest pain due to less oxygen supply to heart.
4. **Heart Failure:** It is the state when heart is not pumping blood effectively to other organs of the body.

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## **CHAPTER –19 : EXCRETORY PRODUCTS AND THEIR ELIMINATION**

All plants and animals produce harmful substances due to a number of metabolic activities occurring in their body tissues. Carbon dioxide produced during respiration is removed by lungs. Ammonia is the chief nitrogenous waste produced as a result of metabolism of proteins and amino acids. This is a highly toxic substance to the body tissues and is eliminated as such by aquatic animals. While on land, ammonia combines with carbon dioxide to form a less toxic substance called urea which is eliminated from the body. Thus the process of excretion can be defined as the elimination of waste products from the body which otherwise are toxic if retained within the system. The organs that are involved in this process constitute the excretory system.

### **Nitrogen Excretion:**

The elimination of nitrogenous waste products is a major function of the excretory system. The nitrogenous products vary from species to species. Most of the nitrogenous wastes are formed due to the catabolism of proteins. Normally, according to the species, proteins are catabolised into ammonia, urea or uric acid.

### **Ammonotelism:**

*Ammonotelic organisms* are those which eliminate their nitrogenous metabolic wastes mainly as ammonia. Ammonia is constantly produced in the organisms by the deamination of amino acids and it is highly toxic if retained in the system. So it must be immediately removed from the body as soon as it is formed. Elimination of ammonia requires large amounts of water. This can be done only in aquatic forms of life. In aquatic animals (like aquatic invertebrates, body fishes and aquatic amphibians etc.), it is quickly eliminated in the surrounding water because it is highly soluble.

### **Ureotelism:**

*Ureotelic organisms* are those which eliminate their nitrogenous metabolic wastes mainly as urea. Urea is formed in the liver by combining ammonia with carbon dioxide and is comparatively less toxic than ammonia. The synthesis of urea from ammonia requires the expenditure of energy. The elimination of urea requires less water. It is the main product of excretion in man and all other mammals, aquatic mammals like whales and seals, and desert mammals such as camel and kangaroo, terrestrial and semiaquatic amphibians like toads and frogs, cartilaginous fishes such as sharks and sting rays. Some animals can concentrate the amount of urea present in their urine. Man can concentrate urea in the urine more than hundred times its concentration in the blood. Earthworms excrete ammonia when sufficient water is present but eliminate urea when the conditions are dry. Tadpoles eliminate nitrogenous wastes as ammonia but the adult frog mainly eliminates urea.

### **Uricotelism:**

*Uricotelic organisms* are those which eliminate their nitrogenous metabolic wastes mainly as uric acid. Uric acid is the least toxic nitrogenous waste product and requires very less water for its elimination. Therefore, uric acid is formed only in those animals which have limited supply of water. In the cloaca of reptiles and birds, uric acid accumulates and is further concentrated there. It passes out of the body as whitish semi-solid substance. Uric acid is also eliminated by

insects. In man and other primate mammals, urine contains a little of uric acid in addition to urea.

### **Excretory System:**

The excretory system consists of organs and tissues participating in the removal of waste products. Some of these excretory organs constitute the urinary system which forms and eliminates urine and helps mainly in the excretion of nitrogenous waste-products, water and some mineral salts. Apart from this urinary system, they have some accessory excretory organs and tissues such as the skin, lungs and liver. The mode of excretion varies in different kinds of animals.

### **Excretory Organs of Invertebrates:**

The organs of excretion and osmoregulation vary greatly in different groups of animals. Protozoans like Amoeba and Paramecium have got contractile vacuoles for osmoregulation. In sponges, the metabolic wastes are eliminated from the body by the canal system. In Hydra, cells release waste products into the coelenteron from which it goes out through the hypostomal opening. In planarians and other platyhelminthes worms, there are special cells called flame cells that perform the function of excretion. Annelids like Nereis, earthworm etc, have got nephridia as the organs of excretion. Prawns have got green glands that serve as excretory system for them. All insects, millipedes, spiders and scorpions have fine thread like tubules called malpighian tubules at the junction of midgut and hindgut. These tubules lie freely in the body cavity and can filter metabolic wastes from the hemolymph. These malpighian tubules are 60-80 in number and are arranged in 6 to 8 bundles. Each tubule is a fine hollow tube, about 16 mm long, and is lined by glandular epithelium. The epithelium collects the nitrogenous wastes like uric acid from the hemolymph in which the tubules are bathed. The excretory wastes are then poured into the hindgut from where they are thrown outside the body. Most of the water of the excretory materials are reabsorbed into the rectum. Scorpions also have coxal glands as the organs of excretion.

### **Vertebrate Urinary System:**

In vertebrates, kidneys are the urine-forming organs. In the case mammals, the urinary system consists of two kidneys, two ureters, a urinary bladder and a urethra.

Organs of excretion in man:

The excretory organs in man consist of the following parts:

1. **Kidneys:** They are a pair of bean-shaped structures lying in the abdomen, one on each side of the vertebral column below the diaphragm. The left kidney is placed a little higher than the right kidney. Human kidney is about 10 cm in length, 5 cm in breadth and 9 cm in thickness. The outer surface of the kidney is convex while the inner surface is concave. In the concave depression there is an opening called hilum through which blood vessels (renal

artery and renal veins), nerves, lymphatic ducts and ureters enter or leave the kidney. The hilum, inside the kidney, expands into a funnel-shaped area called renal pelvis.

Two distinct regions can be seen in the kidney – an outer granular portion called the renal cortex and an inner medulla. In the cortex are present the malpighian bodies which filter the waste products from the blood. The medulla portion contains the collecting ducts of nephrons and thus passes the urine to the pelvis of the kidney. Conical pyramid-shaped masses of medulla project into the pelvis and are called as medullary pyramids. They form the major calyces and minor calyces.

2. **Ureters:** From each kidney arises a thin muscular tube called ureter. It emerges out from the hilum of each kidney. It is about 30 cm in length. Urine enters the ureter from the renal pelvis and is passed down the ureters. These two tubes bring the urine downwards and open into urinary bladder.
3. **Urinary bladder:** It is a single sac-like structure in which urine is stored for some time before it is voided out. It is present in the pelvic region of the body. Both bladder and ureters are lined by transitional epithelium, which may be considerably stretched and do not get torn out even when bladder and ureters are completely filled with urine.
4. **Urethra:** The urinary bladder opens to the outside through a tube called as urethra. It arises from the neck of the bladder and conducts urine to the outside of the body. In females, this tube is about 4 cm long and serves as a passage for urine only; while in males, it measures about 20 cm and functions as a common passage for urine and spermatogenic fluid. A muscular sphincter keeps the urethra closed except during voiding of urine.

*Micturition* is a process of the accumulation of formed urine in the urinary bladder and then elimination of the same from the bladder from time to time. It is controlled by the nervous mechanism. Micturition may be voluntarily inhibited for a prolonged interval until the bladder pressure rises too high. On the contrary, micturition may also be voluntarily initiated even before sufficient urine has collected in the bladder.

### **Accessory Excretory Organs:**

The urinary system is the main excretory organ. Apart from this, some other organs and tissues like the skin, lungs and liver function as accessory excretory organs.

### ***Excretory role of skin/integument:***

In aquatic animals, integument is more permeable to nitrogenous wastes than in terrestrial animals. Ammonia is mainly excreted out into the surrounding water by diffusion through the skin. Terrestrial animals can prevent the loss of water through skin mainly in deserts. Mammalian skin, including man, has two types of glands for secreting two fluids on its surface, viz. Sebum from sebaceous glands and sweat from sweat glands.

Sweat is an aqueous fluid contains sodium chloride, lactic acid, urea, amino acids and glucose. It excretes mainly water and sodium chloride, and small amounts of urea and lactic acid.

Sebum is a wax-like secretion, which eliminates some lipids such as waxes, sterols, other hydrocarbons and fatty acids on the skin.

### ***Excretory role of lungs:***

They help to eliminate the waste products of respiration-the carbon dioxide from the body. Along with carbon dioxide, some water in the form of vapour is also eliminated from the body.

### ***Excretory role of liver:***

The liver plays an important role in the excretion of cholesterol, bile pigments inactivated products of steroid hormones, some vitamins and drugs. The bile pigments are produced by the degradation of hemoglobin, some vitamins and drugs. The bile pigments are produced by the degradation of hemoglobin of the dead red blood cells in the liver. Through the bile ducts, the bile pigments are passed into the intestine and are eliminated along with the faecal matter.

### **Urinary elimination of waste Products in Man:**

Kidneys excrete nitrogenous waste products in the form urine. Hence kidneys secrete urine continuously in their nephrons.

***Nephrons:*** Nephrons are the functional units of kidneys. Each kidney is made up of numerous delicate uriniferous tubules or nephrons. Nephrons are held together by a little connective tissue in which blood vessels, nerves and lymph vessels are also present. There are about 1.2 million nephrons in each kidney of man. Each nephron consists of two main parts: (1) *Malphigian body or renal corpuscle* – it has a cup-shaped depression called *Bowman's capsule* into which tufts of capillaries called glomerulus are present. An afferent renal arteriole enters the capsule, divide into capillaries forming glomerulus and leaves as efferent renal arteriole enters the capsule, divide into capillaries forming glomerulus and leaves as efferent renal arteriole. Efferent renal arteriole then supplies blood to the remaining part of tubule and join to renal vein. Blood is filtered in the Malphigian body. (2) *Secretory tubule* starts after malphigian body and is divisible into three distinct regions: 1. *Proximal convoluted tubule*(PCT) starts immediately after bowman's capsule, makes a few coils in the cortex and proceed towards medulla of kidney; 2. *Loop of Henle-tubules* make a U-turn in the medulla forming loop of Henle (thus it has a descending and an ascending portion) ; and 3. *Distal convoluted tubule* (DCT) starts after loop of Henle and joins the collecting tubule. These collecting ducts unite with each other in the medulla to form the larger duct – the duct of Bellini. These run through the renal pyramids and open into renal pelvis. In these tubules, various substances from the nephric filtrate are reabsorbed back. There is a rich supply of blood vessels to the kidneys. It is estimated that total length of blood vessels in the kidneys of man is about 160 kilometres. A network of vessels paralleling the loop of Henle is known as vasa recta.

**Composition of Urine:** Urine is transparent, pale yellow in colour, aqueous fluid which is usually acidic in nature. The pale yellow colour of the urine is mainly dependent upon the presence of a pigment *urochrome*. This colour also varies with the quantity and concentration of the urine voided. In fever, it becomes dark-yellow or brownish in colour. Quantity of urine formed in 24 hours in an adult normal individual varies from 1000 ml to 1800 ml. Normally, it depends upon water intake, diet, environmental temperature, mental state and physiological state of the person.

During summer months, when the body is exposed to warmth, skin perspires freely because cutaneous blood vessels are dilated whereas the abdominal and renal blood vessels are constricted causing less volume of urine. During winter months, cutaneous blood vessels are constricted and elimination of water through perspiration is ceased but the abdominal and renal blood vessels are dilated resulting in the increased flow of urine. Thus perspiration has got inverse relation with the formation of urine.

Substances that increase the formation of urine are termed as diuretics. Tea, coffee and alcoholic beverages have got diuretic effects.

The normal specific gravity of urine varies between 1.003 and 1.040. The odour of the normal urine is slightly aromatic and is due to the presence of large number of volatile organic substances particularly the bad smelling substance – *urine*. When allowed to stand for some time, the urine smells of ammonia due to the bacterial decomposition of urea to ammonia.

Urea is the main nitrogenous constituent of human urine. Besides urea, it contains other nitrogenous substances like ammonia, uric acid, creatinine and hippuric acid. Sodium chloride is the principal mineral salt in urine. Small amount of inorganic salts like chlorides, sulphates and phosphates of potassium, calcium and magnesium are also present. Non-nitrogenous organic substances include small amounts of vitamin C, oxalic acid and phenolic substances. Glucose is normally negligible in amount. Proteins, bile salts, bile pigments, glucose and ketone bodies occur in urine in various pathological conditions.

### **Formation of Urine:**

Urine is formed in the nephron by the following three processes:

#### **1. Glomerular filtration or ultrafiltration:**

Glomerulus is a tuft of capillaries found in the Bowman's capsule of the nephron. In it there are fine filter pores (millipore filters) that separate the red blood cells from the plasma. The blood that enters into the glomerulus is under a very high pressure from the afferent renal arteriole. It has got urea, glucose, various salts and proteins of plasma and large quantities of water. The lining of Bowman's capsule has a single layer of flat epithelial cells through which blood is filtered into the lumen of the tubule. The filtrate formed in the tubule is known as glomerular or nephric filtrate and contains urea, large amounts of water, glucose, amino acids and various minerals. Ultrafiltration in the glomerulus is a passive process. Nephric filtrate does not have blood proteins as big-sized molecules are not filtered through the lining of the Bowman's capsule. It is estimated that the effective filtration pressure by which the blood is filtered is about 10 mm Hg and at this pressure, 125 ml of nephric filtrate is formed in the two kidneys after every minute. It is also estimated that about one fifth of the total volume of blood plasma flowing through the kidneys is filtered out as glomerular filtrate. The filtration occurs across the membrane made of the glomerular capillary wall and the inner membrane of the Bowman's capsule. The pores of this filtering membrane are impermeable to large molecules or particles.

Large particles like blood cells and protein macromolecules do not normally enter into the glomerular filtrate. But smaller molecules like glucose, urea, creatinine, amino-acids and mineral salts are filtered into the Bowman's capsule in concentrations more or less similar to their respective concentrations in the plasma. Therefore, the filtrate almost resembles the protein-free plasma in composition and osmotic pressure.

## **2. Tubular reabsorption:**

This occurs by two ways i.e., active and passive reabsorption. The important substances like glucose, amino acids are reabsorbed actively. This active reabsorption is rapid and continues even when the concentration of the substance is far lower in the glomerular filtrate than in the blood.

Some other substances are reabsorbed from the tubules slowly by the physical process of diffusion. This passive reabsorption occurs only when their concentrations in the glomerular filtrate exceed their respective concentrations in the blood. Hence, these substances can never be totally reabsorbed from the urine, e.g. urea, ammonia, creatinine and ketone bodies.

- In proximal portion of convoluted tubule (PCT) most of the water re-enters into the blood capillaries. About 80% of the water is reabsorbed here. Glucose, amino acids and vitamin C are also reabsorbed back here. But this is an active reabsorption; while the absorption of water is purely passive. About 70% of  $\text{Na}^+$  ions, 75% of  $\text{K}^+$  ions and large amounts of  $\text{Ca}^{++}$  ions are also reabsorbed here by the active transport mechanism.
- In descending loop of Henle about 5 per cent of water comes out due to osmosis because of high osmotic pressure of the medullary extracellular fluid. Sodium enters the tubules and it increases the hypertonicity of the nephric filtrate.
- In ascending loop of Henle sodium and potassium is reabsorbed actively and also some amounts of  $\text{Cl}^-$  ions. There is no reabsorption of water as its walls are thick and impermeable to water. So the filtrate now becomes hypotonic as compared to the plasma when it flows through this part of the nephron.
- In distal convoluted tubule (DCT) and collecting duct there is active reabsorption of sodium ions from the filtrate. The process of diffusion also reabsorbs some  $\text{Cl}^-$  ions. Large amounts of water are also reabsorbed. This makes the nephric filtrate isotonic. This isotonic fluid enters the collecting tubule and here it is more concentrated due to the further reabsorption of water.

## **3. Tubular secretion:**

In addition to reabsorption, the renal tubules also secrete into their lumen many substances like urea, creatinine, uric acid, para amino hippuric acid etc. Most of the  $\text{K}^+$  ions eliminated in the mammalian urine are secreted by the distal convoluted tubule (DCT) and the collecting ducts in exchange to the reabsorption of  $\text{Na}^+$  ions. These substances are then removed from the body along with urine. This tubular secretion is much significant in marine fishes and desert amphibians. Because these animals possess no glomerulus in their nephrons; they form urine by secreting solutes such as urea, creatinine and mineral ions into their tubules. Tubular secretion is of less importance in mammals.

Thus, urine is formed in the nephron by a combination of glomerular filtration, tubular reabsorption and tubular secretion.



### ***Osmoregulation by Kidney:***

The kidneys maintain the water and osmotic concentration of the blood. This phenomenon is known as osmoregulation. In aquatic animals like fresh water fishes, or when the animal is taking large amounts of water, the urine passed out of the body is more dilute than the plasma of blood even. Thus they eliminate hypotonic urine in order to get rid off excess of water. Most of the vertebrates including mammals can pass out hypotonic urine. In them, first the isotonic glomerular filtrate is formed in the Bowman's capsule and then from that filtrate some solutes are reabsorbed by the tubules of the nephron. Therefore, the urine passed out of the body becomes hypotonic. It helps to raise the osmoconcentration of the blood to normal.

In those animals living in scarcity of water, urine passed out of the body is hypertonic to the plasma of blood. This reduces the water loss from the body. Mammals and birds can excrete hypertonic urine, which is more concentrated than their blood plasma. In them first an isotonic glomerular filtrate is formed in the Bowman's capsule and then from that filtrate most of the water is reabsorbed by the tubules of nephron. However, some of the solutes are also reabsorbed but this is not proportionate to the amount of water reabsorbed. Therefore, the urine passed out of the body becomes hypertonic. It is a very effective mechanism to reduce the loss of urinary water.

Normally in summer months, when most of the water is lost from the body during perspiration, the urine passed out is hypertonic, and in winter months as there is no perspiration, the urine passed out is hypotonic. Largely the movement of  $\text{Na}^+$ ,  $\text{Cl}^-$  and water regulates the fluid volume and osmolarity at the kidney. When the protein-free fluid is filtered into the Bowman's capsule from the blood, it has the same osmo-concentration as the blood plasma of the capillaries surrounding uriniferous tubule. In PCT,  $\text{Na}^+$  gets actively reabsorbed, and  $\text{Cl}^-$  gets reabsorbed passively as it is attracted to the positive charge of  $\text{Na}^+$ .

The concentration of urine is mainly dependent upon two factors: (i) the loop of Henle – the greater the ability of an animal to excrete hypertonic urine, the longer are its loop of Henle; (ii) presence of vasa rectae in the kidneys – these vessels occur as loops surrounding the loop of Henle. The blood flows in opposite directions in the two limbs of each vasa recta, the blood flowing in descending limb comes close to the blood flowing in ascending limb. This is known as counter-current system and is mainly responsible for making the urine hypertonic.

The two limbs of loop of Henle also constitute the counter-current system. The nephric filtrate flows in opposite directions in the descending and ascending loops of Henle.  $\text{Na}^+$  and  $\text{Cl}^-$  are reabsorbed from the ascending limb into the surrounding vasa recta. Moreover, water cannot flow out of this limb as it is impermeable to water. Thus in ascending limb, urine becomes hypotonic. But the walls of descending limb are permeable to both water and salts. Thus the reabsorbed  $\text{Na}^+$  enters the descending limb and the water moves out. It makes the urine hypertonic.

### ***Role of ADH in forming hypertonic urine:***

*Antidiuretic hormone* (ADH) or *vasopression* is released from the posterior lobe of pituitary. It acts on the distal convoluted tubules (DCT) and collecting ducts of the nephron and increases their permeability to water. If the water contents in the body is more than needed, it inhibits the secretion of ADH. As a result, DCT and other collecting tubules remain less permeable to water. So water is not reabsorbed, but the active reabsorption of Na<sup>+</sup> continues from the filtrate. Thus the filtrate becomes more and more dilute and hypotonic urine passes out of the kidney.

If the water contents in the body is low, it stimulates the secretion of ADH that acts on the walls of DCT and other collecting tubules and make them more permeable to water. Further, the surrounding tissue is hypertonic due to active reabsorption of Na<sup>+</sup> into it and also due to the retention of Na<sup>+</sup> and urea by the counter current system of vasa recta. So water is progressively reabsorbed from the filtrate while flowing through DCT and collecting tubules. Hence the urine passing out becomes hypertonic.

Thus, the kidney helps in osmoregulation by eliminating either hypotonic or hypertonic urine, according to the need of the body.

### ***Functions of kidney:***

- It excretes waste products, specially formed due to protein metabolism. These waste products are ammonia, urea and uric acid.
- It helps to maintain water balance of the body and thereby plasma volume.
- It helps to maintain the normal pH of the blood and other fluids of the body.
- It helps to maintain the optimum concentration of certain constituents of blood by the process of selective reabsorption in the kidney tubules.
- It eliminates drugs and various toxic substances from the body.
- It helps to maintain the osmotic pressure in blood and tissues.

### **Disorders of the Excretory System:**

1. **Uremia:** Malfunctioning of kidneys due to accumulation of urea in blood. It is very harmful and leads to renal failure. For such kind of patients we go for Hemodialysis, where blood is drained from a convenient artery is pumped into a dialyzing unit after adding an anticoagulant like Heparin. **Hemodialysis** contains a coiled cellophane tube surrounded by a dialysing fluid having the same composition as that of plasma except the nitrogenous wastes. The porous cellophane membrane of the tube allows the passage of molecules based on concentration gradient. The cleared blood is pumped back to the body through a vein after adding anti-heparin to it.
2. **Renal failure:** a functioning kidney is used in transplantation from a donor of closely relative.
3. **Renal calculi:** Stone or insoluble mass of crystallized salts (oxalalates, etc)formed within the kidney.
4. **Glomerulonephritis:** Inflammation of glomeruli of kidney.

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## **CHAPTER - 20 : LOCOMOTION AND MOVEMENT**

All living organisms show a characteristic phenomenon of either moving their whole body from one place to another place (locomotion or locomotory movement), or only a part of the body while the whole body remains fixed to a place (movement or non-locomotory movement). Various acts of the body like walking, running, crawling, jumping, flying, swimming etc. are known as locomotory movements. The locomotion helps the organism to shift its entire body from one place to another. Generally, the animals show locomotory movements in search of food, mate and shelter. It also helps the animals to run from the adverse environmental conditions, and to move away from the predators.

Movements of limbs, appendages, head and trunk serve to change the posture of the body and maintain equilibrium against the gravity. For example, taking in of food involves the movements of tongue, jaws, snout, limbs in man; movements of external ear and eyeballs help to perceive the informations from the outside environments; movements of alimentary canal help to pass the food down; movements of heart circulate the blood in the body; lungs are ventilated by the movements of thoracic muscles and diaphragm etc.

Besides such locomotion and movements of the body, multicellular organisms can also move their individual cells like the movements seen in unicellular organisms. Some of the white blood cells and macrophages, which are phagocytic in nature, move through the tissues by amoeboid movements to reach the places of infection. Ciliary movements occur in the upper respiratory tract, fallopian tubes and vasa efferentia tubes of testes. A mammalian sperm moves into the female reproductive tract by the flagellar movements. In sponges, flagellar movements of some cells occur to maintain the water current in them.

Most of the multicellular animals have muscle fibres for locomotion, limb movements as well as movements of internal organs. In all higher animals (vertebrates) there are mainly two systems that bring about movement and locomotion of the body. These two systems are skeletal system and muscular system that work in coordination with each other. The force generated by muscle contraction is utilised to move bones of the skeleton like levers. This results in movements of limbs and appendages. So the muscles working with the skeletal system are called skeletal muscles.

### **Movements in some invertebrates:**

There are also many invertebrates like jellyfish, earthworm and leech, which are devoid of skeletons but possess muscles for their movements.

#### **Movements in Hydra:**

Hydra lacks a well-developed muscular system. They have two types of contractile cells on its body wall, viz. epitheliomuscular cells in the outer layer of the body wall and the nutritive muscular cells in the inner layer. Contractions and relaxations of these cells, respectively, shorten and elongate their processes. Various types of movements seen in Hydra are looping, somersaulting, climbing, shortening and elongation etc.

#### **Movements in Annelids:**

Earthworms and leeches have muscle fibres of the body wall that help these animals to crawl on land. These muscle fibres are of two types – longitudinal muscle fibres; and circular muscle fibres. In earthworms, the locomotion of the body is brought about by alternate contraction of circular and longitudinal muscles, causing waves of thinning and thickening to pass backwards. It involves partly a pushing of the anterior end and partly of the posterior end. The coelomic fluid gives turgidity as it acts as a hydraulic skeleton making the body wall tough. The worm moves at the rate of about 25 cm per minute.

#### **Movements in Starfish:**

Starfishes have got a water vascular system that help them in their locomotion. Each arm of the starfish has two rows of tube feet underneath. Water enters into these tube feet by the muscular contractions and this moves the animal over the surface of the substratum in water. Starfishes are bottom dwellers found in sea waters only.

#### **Movements in higher vertebrates:**

In higher animals, movements and locomotion depend on the association of skeletal muscles with the skeletal system. The skeletal system consists of a specialised rigid connective tissue called bones. This skeletal system consists of many parts, each made of one or more bones.

According to the shape and size, bones may be long (thigh bone and the upper arm bone); flat (breast bone and the shoulder girdle bone); or irregular (bones of the vertebral column). In all, the skeletal system consists of 206 bones in man. Some major parts of human skeleton consist of the following numbers of bone – skull or cranium (8), face (14), each forelimb (30), each hindlimb (30), vertebrae (24), sacrum (1), coccyx (1), sternum (1), ribs (24), pelvis (3), each shoulder girdle (2).

### Functions of skeletal system:

1. It provides a kind of framework for the body.
2. It provides shape and posture to the body.
3. It provides protection to some of the inner delicate organs like brain, spinal cord and lungs.
4. It gives rigid surface for the attachment of muscles with the help of tendons.
5. It helps in locomotion.
6. The bone marrow serves as the centre for the production of red blood cells and white blood cells.
7. The movements of ribs and sternum help in breathing.
8. In the ear, the sound vibrations are conveyed from the tympanum to the internal ear by a set of three bones as in man.
9. It helps the body to be an integrated unit.
10. It serves to store various ions like calcium and phosphate, which are then released into the body at the time of need. These minerals perform various functions of the body.

### Joints:

The junctions where two or more bones articulate with each other are known as joints. These joints allow the movement of bones in different ways. According to the mobility they are of the following types:

1. **Fixed or immovable or fibrous joints:** At these joints the bones are held firmly together and movements are not allowed in between them. At these joints a dense and tough inextensible white fibrous tissue is present. For example, sutures that join the various bones of the skull.
2. **Slightly movable or cartilaginous joints:** At these joints a dense disc of white fibrocartilage is present that joins the opposite surfaces of the articulating bones. It allows only a little movement like bending and rotation. These joints are seen in between the vertebrae.
3. **Freely movable or synovial joints:** In this type of joint there is a fluid filled synovial cavity in between the movably articulated bones. The fluid is called as synovial fluid. A synovial membrane covers this fluid filled synovial cavity forming the capsule. The articulating bones are provided with cartilage caps. Ligaments are also present to hold the bones. It is of the following types:
  - (i) **Ball and socket joint.** In this, one of the bones forms a globular head while the other forms a cup – like socket into which head fits in. It allows a free movement in all directions e.g., shoulder girdle and hip girdle joints. Such joints may stretch (extend), fold (flex) and rotate the limb of the body. This may allow the movement of the limb towards the body or away from the body.
  - (ii) **Hinge joint.** Here the two bones are fitted like the hinge of a door so as to allow to and fro movements in one direction only. These joints are provided with strong ligaments. It is seen in elbow joint, knee joint and joints between phalanges of fingers and toes.
  - (iii) **Pivot joint.** In this type of joint, one bone is fixed while the other moves freely over it. The movement is, therefore, confined to a rotation around a longitudinal axis through the centre of the pivot e.g., movement of the skull over the odontoid processes of the first neck vertebra.
  - (iv) **Gliding joint.** It is a biaxial joint, the articulating bones of which can glide one above the other. It is seen in wrist bones that can glide over forearm bones, in zygapophysis by which vertebrae can glide one above the other e.g., some of the bones in the palm or in the sole of foot.

- (v) *Ellipsoid joints.* They permit movements of articulating bones around two axes. Such joints are formed between the toe bones and some bones in the sole of foot.

Movements are produced at joints by contractions of skeletal muscles inserted into the articulating bones. Flexible connective tissue bonds called ligaments stabilise the joints by holding the articulating bones together.

### **Movements of Skeletal Muscles:**

The skeletal muscles are made of striated muscle fibres and are under voluntary control. According to the type of movements, skeletal muscles can be classified as under:

1. *Flexor.* A muscle that bends one part upon another (e.g., leg upon thigh)
2. *Extensor.* The muscles responsible for straightening out a part of the body are termed extensor muscles (e.g., muscles concerned with the extension of foot).
3. *Adductor.* The muscle that is concerned with the movement of a part of the body towards the midline of the body is called the adductor muscle.
4. *Abductor.* The muscle which moves a part of the body away from the midline of the body is termed as abductor muscle.
5. *Pronator.* A muscle that brings about the rotation of body parts. For example, the rotation of fore arm to turn the palm downward or backward.
6. *Supinator.* It helps to rotate the fore arm and thus make the palm face upward or forward.
- 7.

### **Antagonistic muscles:**

When the two muscles contract to bring out opposite movements at the same place, then they are called as antagonistic muscles. For example, biceps muscles present in the arm is a flexor for the elbow joint; and the triceps is its antagonistic muscle and acts as an extensor for that joints. During flexion movements the biceps contracts and triceps relaxes; while during extension movements biceps relaxes and triceps contracts.

### **Threshold stimulus:**

The skeletal muscle has got large number of muscle fibres. Each of these muscle fibres is supplied with a motor nerve fibre. When the muscle contracts or shortens in length, it is due to the shortening of the individual muscle fibres. A muscle always contracts in response to a given stimulus and then it relaxes back to its original position. The stimulus to the nerve supplying the muscle can be thermal, electrical, mechanical or chemical in nature. There should always be some minimum strength of stimulus that will make the muscle respond or contract. This is known as threshold value of the stimulus. If the given stimulus is less than this threshold limit, the muscle fibres will not respond at all. Further, on stimulation, each muscle fibre contracts to its full. If the strength of stimulus is below the threshold value, then the muscle fibres will not respond.

If we increase the strength of stimulus beyond the threshold value, the muscle fibres will contract but the level of contraction is same as that for the threshold value. That means if the strength of stimulus is increased, the level of muscle contraction for the individual muscle fibre will be the same. This shows that either the muscle will contract to a given stimulus or it will not contract at all. This is known as all-or-none law. However, this force of contraction may depend upon other factors like changes in temperature, pH, or slight stretching of the fibre. But under all such changed conditions, increasing the strength of stimulus cannot increase the force of contraction. This all-or-none law is also followed by smooth muscles, cardiac muscles and the nerve fibres.

### **Muscle twitch and Tetanus:**

When an electrical stimulus is given to a nerve supplying a muscle, the muscle fibres contract. This contraction of a single muscle fibre is known as *muscle twitch*. In this the muscle fibre contracts after an initial latent period, and then it relaxes back.

When a muscle is given series of stimuli continuously then it shows tetani. In this the second stimulus is given even before the muscle has relaxed from first, and the third stimulus is given even before the muscle has relaxed from the second and so on. Such a response of the muscle is known as *tetanus*.

### Mechanism of muscle contraction:

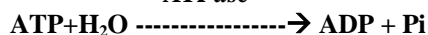
A voluntary muscle fibre consists of numerous myofibrils which have their units as sarcomeres. Each myofibril is covered by the cisternae and tubules of sarcoplasmic reticulum at the I band; and at the junction of A and I band by a T-tubule that communicates with the exterior of cell. A sarcomere consists of a half-light band and a half dark band i.e., the distance between two Z-membranes. It also has primary and secondary filaments. The primary filaments are made up of a protein called myosin while secondary filaments are of actin.

As the stimulus is given to the muscle, the secondary filaments slide over to the primary filaments thus shortening the length of the light band or I-band. It is important to note that the length of dark band or A-band does not change. The actual site where sliding of the filaments occur is known as cross bridges. Thus in response to a stimulus, the overall length of the sarcomere and the myofibril decreases. A muscle never expands to a stimulus but always contracts in its length.

### Chemical changes in muscle contraction:

ATP is the immediate source of energy for muscle contraction. Hence hydrolysis process occurs in the contracting muscle to convert ATP to ADP with the release of inorganic phosphate and energy by myosin ATPase:

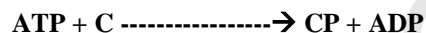
*ATPase*



This energy released is used up in muscular contraction. For restoration of ATP, body muscles have also got another compound called creatine phosphate (CP). This is also an energy rich compound. It helps in the conversion of ADP to ATP again immediately. This happens at the end of muscular contraction.



Creatine formed during muscular contraction is again reconverted to creatine phosphate by the utilisation of ATP generated by carbohydrate oxidation:



During muscle contraction, carbohydrates are metabolized through glycolysis in the muscle to produce ATP. This results in the formation of lactic acid from carbohydrates. During recovery after contraction, lactic acid is oxidized to carbon dioxide and water aerobically, giving more energy.

### Fatigue:

Under heavy strain of muscular work one feels fatigue. The muscular fatigue may be defined as inability of muscular contraction after the prolonged stimulation. The fatigue occurs due to depletion of glycogen, oxygen and ATP and accumulation of lactic acid. Under deficiency of oxygen, the lactic acid is not reconverted into glycogen and is not oxidised to form water and CO<sub>2</sub>, then this lactic acid gets accumulated. When we allow resting for some time, the fatigue is removed and the muscle can contract again.

### Distinguish between Red muscle fibres and White muscle fibres:

Birds and mammals consist of two types of skeletal or striated muscle fibres viz. red muscle fibres or slow fibres and white muscle fibres or fast fibres. A comparison of these two types of muscle fibres is given below:

Red muscle fibres	White muscle fibres
1. Thinner in size	Thicker in size
1. These are dark red in colour due to the presence of heme protein called as myoglobin. Myoglobin can bind with oxygen to form oxymyoglobin and thus stores oxygen. Oxymyoglobin can release oxygen during muscular contraction.	They are light red in colour due to the lack of myoglobin.
3. They have a slow rate of contraction.	They have a fast rate of contraction.
4. These muscle fibres are rich in mitochondria.	These muscle fibres are poor in mitochondria.
5. These fibres can carry out lot of aerobic metabolism and so aerobic contraction of the muscles without accumulating much of lactic acid. They can thus	These fibres mainly depend upon anaerobic metabolism (glycolysis only) and so anaerobic contraction of the muscles thus accumulating



contract for a longer time without muscular fatigue.  
6. These muscle fibres can do sustained but slower work for a long time.

Examples: Extensor muscles on the back of human body, flight muscles of some birds like kites etc.

lot of lactic acid leading to muscular fatigue.  
These muscle fibres can do fast work for a short period only.

Examples : Muscles of the eye ball, flight muscles of some birds like sparrow etc.

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## **CHAPTER – 21 : NEURAL CONTROL AND COORDINATION**

In man and other vertebrates, the physiological functions are coordinated by both the nervous and endocrine systems.

The system that receives the stimulus transmits it to other parts of the body and the corresponding effect shown is known as a Nervous System. The nervous system performs three basic functions; receives stimuli through sensory neurons from internal and external environment and passes to the brain; where the input stimuli is processed and then response is given back to the body parts through motor neurons.

### **Nervous system in Invertebrates:**

- In primitive invertebrates like Sponges lack neurons
- In Hydra, all neurons are linked to one another, forming a nerve net called plexus between the outer epidermis and inner gastrodermis.
- In Planaria, two nerve cords that converge to form a rudimentary brain.
- In Earthworm, has a single ventral nerve cord and paired segmental ganglia. The ganglia give rise to the segmental nerves to the tissues.

### **Nervous System of Cockroach:**

It consists of brain, the ventral nerve cord and ganglia and nerves which arise from ganglia. The brain or supraoesophageal ganglion is made of three fused ganglia of the head and present above the oesophagus. The ventral nerve cord is composed of ten ganglia. The First one lies just below the oesophagus and is known as Suboesophageal ganglion is connected with brain by a pair of Circumoesophageal (Circumpharyngeal) Commissures. The thoracic ganglia are three and six abdominal ganglia of which the last one is larger than the others.

### **Nervous System of Human:**

The human nervous system consists of the following two major parts;

1. **Central Nervous System (CNS):** It Comprises of Brain and Spinal cord. It is the site of information processing unit.
2. **Peripheral Nervous System (PNS):** The nerves which arise from the CNS (brain and spinal cord).
  - a) **Somatic Nervous System (Voluntary):** It consists of sensory / afferent neurons which transmit impulse from the receptors to the CNS; and the motor / efferent neurons, which transmit response from the CNS to the effector (skeletal muscles).
  - b) **Autonomic Nervous System (Involuntary):** It stimulates the glands and the other muscles of the body and responsible for the involuntary actions.
  - c) **Neuroendocrine System:** It consists of a net work of endocrine glands and their hormonal production is controlled by CNS.

**Nuclei:** The cluster / group of neurons in CNS.

**Ganglia:** The cluster / group of neurons in PNS.

**Nerve tracts:** The bundles of nerve fibres in CNS

**Nerves:** A bundles of nerve fibres in the PNS.

**A typical Nerve:**

A typical nerve has a tough outer covering called Epineurium. Inside the epineurium, axons of nerve cells form bundles called fascicle. Each fascicle is wrapped with a layer called perineurium.

Multipolar nerve cells have many short dendrites and one long axon, eg., in cerebral cortex. A bipolar nerve cell has a long axon extending on either side of the cell body, eg.in retina. Pseudounipolar nerve cells have cell body in a side branch of the main axon, eg.,cells of dorsal root ganglion.

**Conduction of Nerve impulse across neurons:**

a) Resting potential:

The permeability of plasma membrane to K<sup>+</sup> ions is greater than its permeability to Na<sup>+</sup> ions. So the surface of axon carries a positive charge relative to its interior; this electrical potential difference across the plasma membrane is called resting potential and it ranges from – 40 to – 90 mV.

b) Action potential:

When a threshold stimulus is applied on the axon membrane, depolarization is caused by a rapid change in membrane permeability. The membrane becomes more permeable to Na<sup>+</sup> than to K<sup>+</sup>. The interior becomes electropositive and the ECF becomes electronegative. The depolarization spreads, producing a local current, which induces the nearby passive Na<sup>+</sup> channels to open and to depolarize the nearby site.

c) Repolarisation:

After about 0.5 ms, permeability to K<sup>+</sup> ion increases because the build up of positive charge inside the cell opens the voltage gated K<sup>+</sup> channels. Movement of K<sup>+</sup> ions outward, down their concentration gradient, then reestablishes the charge differences that existed before the stimulus occurred. The exodus of K<sup>+</sup> ions lowers the number of positive ions within the cell and the potential falls back towards the resting potential.

**Synapse:**

The functional junction between two neurons, the axon of a neuron and the dendron/dendrite of another neuron.

### Types of synapse:

There are mainly two types of synapses based on the nature of transfer of information across the synapse; a) electrical and b) chemical synapses.

- a) In electrical synapses, the cells are separated by a gap of 0.2nm synaptic cleft, so an action potential can sufficiently depolarize the postsynaptic membrane.
- b) In chemical synapses, synaptic cleft gap is greater and neurotransmitter substance responsible for the transmission of nerve impulse across the synapse.

### Conduction of Nerve impulse across synapse:

In a synapse, there is a narrow fluid-filled gap of 10-20 nm, called synaptic cleft. The nerve terminal has a bulbous expansion called synaptic knob or synaptic button. In the cytoplasm of the synaptic knob, numerous tiny membrane-bound synaptic vesicles are present. These synaptic vesicles contain as many as 10,000 molecules of the neurotransmitter. When a nerve impulse reaches the presynaptic membrane, the voltage-gated calcium channels concentrated in the synapse, open. Calcium ions from the fluid in the synapse diffuse into the synaptic button and stimulate the vesicles to move to the terminal membrane, fuse with it and then rupture to release the neurotransmitter. The neurotransmitters quickly diffuse to the other side of the gap, combine with specific receptor molecules of the other nerve cell and cause sparking a second electrical current, passing its signal.

### Structure of Human Brain:

Human brain is covered by a tough tissue covering called meninges. The three layers of meninges are the outer most duramater, middle arachnoid membrane and inner pia mater. A deep cleft called longitudinal fissure divides the brain into two halves or the cerebrum into right and left hemispheres.

### Cerebral Cortex:

The outer surface of Cerebrum 2-6 mm thick and is known as Cerebral Cortex. It consists of Gray matter (spindle and satellite neurons cell bodies).

The surface area of cerebral cortex is increased by numerous infoldings/convolutions called *Sulci* (small groove), *Fissure* (large groove) and *Gyri* (swollen area between adjacent sulci/fissure). Two thirds of the surface of the cerebral cortex is hidden in the sulci and fissure.

Beneath the cerebral cortex a large number of myelinated axons of cerebral cortex neurons form White matter.

Cerebral cortex is the region of various activities and has 3 areas namely Sensory, Motor and Associative.

### **Cerebellum:**

It is the second largest part of brain. It is also known as “little cerebrum” and present below the cerebrum.

It is also made up of two cerebellar hemispheres and has gray matter outside as 3 layers.

Outer layer consists of cell bodies.

Middle layer consists of large flask-shaped complex neurons called Purkinje cells.

Three pairs of bundles of myelinated nerve fibres called Cerebellar Peduncles form the communication pathways between the Cerebellum and other parts of the CNS.

Superior Cerebellar peduncles – connect the cerebellum to the midbrain.

Middle Cerebellar peduncles – have connection with Pons of Hind brain.

Inferior Cerebellar peduncles – communicate with medulla oblongata and spinal cord.

Cerebellum is a large reflex centre and control involuntary actions and rapid muscular activities like running, talking, typing, etc., and maintains posture.

Nuclei : collection of different kinds of neurons in brain.

Basal ganglia : collection of subcortical nuclei in the forebrain (below the cortex)

Corpus striatum : It is the largest nucleus in the subcortical nuclei and planning and execution of stereotyped movements.

### **Thalamus:**

It is a region present at the centre of the forebrain and wrapped by cerebrum. All sensory informations first pass through the thalamus. So it receives, determines their source, evaluates their importance and interprets those sensory signals and then channels them to the appropriate cerebral cortex region.

### **Hypothalamus:**

It is present beneath the thalamus. It weighs around 4 gm and is highly vascularized. It contains the nerve centres for temperature regulation, hunger, thirst, heart beat and respiration regulation and emotions (like anger, love, cool, etc). It has connection with pituitary gland hence also controls growth and sexual behaviour.

### **Limbic system:**

It is a part, which connects cerebrum and the brain stem. It sends signals to brain and body parts to regulate our behaviour.

1. Amygdala:

It is located above the hypothalamus and influences behaviour and activities so that they are appropriate for meeting the body's internal needs. These include feeding, sexual interest, and emotional reactions such as anger. Hence it is responsible for controlling our moods.

2. Hippocampus:

It is the swollen lower lip of the limbic fork. It involves with learning, the recognition and memory. It also converts short term memory to long term memory; hence it plays a vital role in learning.

3. Septum:

It is a part of hypothalamus has centre for sexual arousal.

The midbrain contains 4 little lobes called Corpora Quadrigemina. It has a pair of Superior colliculi controls visual reflexes (to fix and focus on an object) and a pair of Inferior colliculi controls auditory reflexes (locates and detects the source of a sound).

**Brain Stem:**

The area between thalamus and spinal cord is known as brain stem and it forms the region of hind brain.

Pons:

It forms the floor of the brain stem and links cerebral cortex and cerebellum.

Medulla oblongata:

It is the posterior most part and connects the spinal cord and various parts of the brain. This medulla oblongata continues into the spinal cord. This brain stem controls various reflexes like breathing, salivation, chewing, coughing, sneezing, etc.

Reticular formation:

It connects thalamus with major nerves of spinal cord and is the gatekeeper of consciousness.

**Ventricles of the brain and cerebrospinal fluid:**

There are four cavities in the brain called the two lateral ventricles, the third ventricle and the fourth ventricle.

Cerebrospinal fluid (CSF) fills the ventricles and the subarachnoid space.



Cerebrospinal fluid has the following functions:

- a) it contributes to homeostasis.
- b) It protects the brain and spinal cord as a shock-absorbing medium.
- c) It gives buoyancy to the brain and reduces the pressure at the base.
- d) It helps in nutrition and excretion of the neurons.
- e) It transports the hormones to various areas of the brain.

**Spinal cord:**

42-45 cm long and 2 cm in thick (in mid thoracic region) and longer in larger in lower cervical and lumbar regions. It grows till 4-5 yrs. It acts like a link between brain and various parts of the body.

**Structure of Spinal cord:**

In a cross section, spinal cord consists of butterfly shaped gray matter in the centre which contains cell bodies and dendrites and synapse. This gray matter has dorsal, ventral and lateral horns. This gray matter is surrounded by the white matter made of myelinated axons.

**PERIPHERAL NERVOUS SYSTEM:**

**Cranial nerves:**

12 pairs – 10 pairs originate from brain stem. There are 3 types of CN sensory nerves (sensory fibres), mixed nerves (has both) and motor nerves (motor fibres).

I&II – sensory

III&IV – originate from mid brain.

1/3 originate (V-VIII) from pons.

V cranial nerve (Trigeminal nerve) is the largest and branches into 3 pairs (to jaw, scalp and face).

1/3 (IX-XII) originate from medulla.

X cranial nerve (Vagus) controls and regulates the functions of thoracic and abdominal organs.

**Spinal Nerves:**

All the spinal nerves are mixed nerves.

Each spinal nerve has two roots, a dorsal sensory and a ventral motor root.

At the middle of each dorsal root, is a swelling called dorsal root ganglion, which contains sensory neurons.

The motor neurons for the ventral root are present in the grey matter of spinal cord.

### **Autonomic Nervous System (ANS) :**

It functions independently and has two output systems, sympathetic and parasympathetic systems.

SI No.	Sympathetic nervous system	Parasympathetic nervous system
1.	The preganglionic axons arise from the thoracic and lumbar segments of spinal cord, hence called thoraco-lumbar outflow.	The preganglionic fibres arise from midbrain and sacral segments of spinal cord, hence called cranio-sacral outflow.
2.	The preganglionic fibres are short and the post ganglionic fibres are long.	The preganglionic fibres are long and the post ganglionic fibres are short.
3.	The autonomic ganglia are interconnected and occur as two lateral chains, one on either side of the spinal cord.	The autonomic ganglia occur individually in the visceral organs / tissues concerned.
4.	The post ganglionic fibres secrete nor-adrenaline at their synapses.	The post ganglionic fibres secrete acetylcholine at their synapse.

### **Reflex Action:**

Reflex actions are very rapid, involuntary automatic and stereotyped behaviour, in which some stimulus evokes a specific, short-lived response at the unconscious level. There are more than two hundred reflexes, which follow the sequence from stimulus to reflex, along a neural pathway called reflex arc.

### **Components and pathway of reflex arc:**

Receptor → Afferent neuron → Intermediate neuron → Efferent neuron → Effector

### **Sense Organs:**

#### **Structure of Human Eye:**

Each eye ball consists of three concentric layers, the outermost sclera, middle choroids and innermost retina. The sclera in the front forms the transparent cornea, with more curved surface to refract light towards the retina. The posterior part of the sclera is tough and elastic and contains collagen fibres.

The middle choroid is highly vascular and pigmented, that prevents internally reflected light within the eye. Just behind the junction between cornea and sclera, the choroid becomes thicker and has smooth muscles in it, forming the ciliary body. The iris extends from the ciliary body in front of the lens; it contains radial and circular muscles that control the dilation or constriction of pupil. The lens is suspended from the ciliary body, by suspensory ligaments; the lens and the suspensory ligaments divide the cavity of the eye ball into an anterior and a posterior chamber. The anterior chamber is filled with an aqueous clear fluid, aqueous humor and the posterior chamber has a gelatinous material, vitreous humor. The innermost layer of retina is composed of several layers of cells; the photoreceptor layer contains rods and cones, the intermediate layer has bipolar neurons, which synapse with retinal ganglion cells and their axons bundle to form optic nerve. A tiny circular area called yellow spot or macula lutea that acts as filter over fovea, where the vision is the sharpest. The place where the optic nerve emerges from the retina is the blind spot. The image produced by the lens of eye on the retina is inverted, but the brain interprets the image in the right way.

### **Structure of Human Ear:**

Human ear consists of three parts, the external ear, middle ear and internal ear. The external ear consists of a sound gathering trumpet, called auricle and the external auditory canal. The auditory canal is lined by a mesh of hair and sebaceous glands; the sebum and the hair prevent entry of unwanted particles and infection. The tympanic membrane separates the middle ear from the external ear. The middle ear is an air-filled chamber, which is connected to pharynx by Eustachian tube. The middle ear lodges three small bones, the ear-ossicles namely, the malleus, incus and stapes. They act as a lever system and increase the force of vibration to transmit it to the endolymph in the inner ear. The middle ear communicates with the internal ear through the oval window. The inner ear has bony labyrinth, inside which a membranous labyrinth is floating in the perilymph. The labyrinth has three parts, the semicircular canals, vestibule and cochlea. The cochlea, a shell-like part is composed of three fluid-filled canals (vestibular canal, median canal and tympanic canal) separated by two membranes, Reissner's membrane and the basilar membrane. Receptors for hearing are tiny sensory hair cells that line the basilar membrane; they are covered by tectorial membrane; these three constitute the organ of Corti. The sensory hair cells are stimulated by the vibrations of endolymph that set off nerve impulses to the auditory nerve. The vestibular system (semicircular canals, utricle and saccule) helps to maintain balance of the body, i.e., orientation, acceleration and rotation to this system.

### **Organ of Smell:**

Nose is the organ of smell sensation (olfaction) and contains olfactory epithelium. The olfactory epithelium has three types of cells; a) Olfactory bipolar neurons b) Supporting columnar epithelium and c) Bowman's glands. Each receptor cell bears twenty or so tiny sensory cilia, olfactory hair that extends to the mucus. The mucus absorbs the odoriferous substances that stimulate the receptors. Bundles of non-myelinated axons of the olfactory receptors unite to form olfactory nerve.

### **Organ of Taste:**

Tongue is the organ of taste sensation (gustation). There are four basic types of taste namely sweet, sour, salty and bitter, which are detected in distinct regions on the tongue. The tongue detects taste through tiny organs called taste buds; each contains about 50 gustatory receptor-cells. A single gustatory receptor cell is exposed to the external surface, through an opening called taste pore. Though each receptor is more responsive to a particular substance, a broad range of chemicals can stimulate it. The brain integrates the differential inputs from various taste buds into a complex flavors.

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## **CHAPTER - 22 : CHEMICAL COORDINATION AND INTEGRATION**

**Internal Environment of animal body is maintained in a steady state by**

1. Autonomic Nervous System
2. Endocrine System

### **What are glands?**

They are secretory organs.

### **Types of glands:**

Exocrine glands – **Duct glands - Enzymes**

Endocrine glands – **Ductless glands – Hormones**

### **What are Hormones?**

**Chemical regulators / messengers / information molecules**

### **Chemical nature of Hormones**

Organic substances of varying complexity fall into two major classes;

1. Steroid Hormone
2. Amino acid Hormone

### **Characteristics of Hormone:**

- Target organs / tissues
- Specific in their action
- Trace amount

### **Functions of Hormones**

- Metabolic activities
- Homeostasis
- Morphogenic activities
- Mental activities
- Growth, maturation and regeneration

- Secondary sexual characters and reproductive activities
- Control of other endocrine glands

### **Endocrine glands in man**

- Pituitary glands – In head
- Thyroid glands – In neck
- Parathyroid – embedded on thyroid gland
- Adrenals – upper end of kidney
- Thymus – on either side of trachea
- Gonads – In or below pelvic cavity
- Gastric – In the wall of stomach & intestine
- Pineal gland – dorsal side of brain
- The hypothalamus is a region of the brain that controls an immense number of bodily functions.
- The pituitary gland, also known as the *hypophysis*, is a roundish organ that lies immediately beneath the hypothalamus
- It composed of two distinctive parts:

The anterior pituitary (adenohypophysis) & the posterior pituitary (neurohypophysis).

### **Characteristics of hormones:**

- Hormones have more or less a specific role. The spectrum of action varies with the hormone. Some are highly selective, while others are more generalized.
- Hormones are produced from a tissue or an organ, and then they act on different tissues or organs i.e., they have a target organ to act or their activity is at a remote rate.
- Hormones can be easily transported via blood. They are poured into venous blood.
- They are active in minute concentrations, only a few picograms (10<sup>-12</sup> g) or a few microgram (10<sup>-6</sup> g). The number of hormone molecules per unit target tissue is definite.
- A hormone in its “primary action” affects one or a limited number of reactions and does not influence directly all other metabolic activities of the cell.

***Differentiate hormones and enzymes:***

Hormones	Enzymes
1. They are produced from glands without any ducts (endocrine glands)	They are produced from glands having ducts (exocrine glands).
2. Chemically, they can be either proteins, steroids, or biogenic amines.	Chemically, they are all protein polypeptides in nature
3. They are used up during a metabolic reaction.	They remain unchanged at the end of reaction (catalyst).
4. They are produced in an organ other than they perform their function i.e., they have a target organ.	They are produced in an organ where they perform their function.
5. They are easily transported through blood.	They are not transported through blood.

**Mammalian endocrine system:**

The mammalian endocrine system consists of the following organs and tissues : Hypothalamus pituitary, thyroid, four parathyroids, two adrenals, two testes (male) or two ovaries (female), thymus, pineal, islet tissue of pancreas, and hormonal tissues on gastrointestinal tract. The hypothalamus is a nervous system of the brain, which is also integrated with the endocrine system and secretes hormones.

**Hypothalamo-pituitary Axis:**

**Hypothalamus as an endocrine gland:**

Hypothalamus is a part of the brain and consists of several masses of grey matter called hypothalamic nuclei. In fact, it forms the floor of the third cerebral ventricle of the brain. Neurons of the hypothalamic nuclei control the activity of pituitary gland. The hypothalamus is connected to the anterior lobe of pituitary by hypophyseal portal vessels. The hypothalamic nuclei or neurosecretory cells secrete several hormones called neurohormones that reach the anterior pituitary by hypophyseal portal vessels. These neurohormones control the secretions of the hormones from the anterior pituitary. These neurohormones are given below:

Sl. No.	Hormones from Hypothalamus	Functions
1.	Growth Hormone Releasing Hormone (GHRH)	Stimulates the secretion of growth hormone
2.	Growth Hormone Inhibiting Hormone (GHIH)	Inhibits the secretion of Growth hormone.
3.	Thyrotrophic Releasing Hormone (TRH)	Stimulates release of thyroid stimulating hormone (TSH)
4.	Adrenocorticotrophic Releasing hormone (ACTH-RH)	Stimulates the secretion of adrenocorticotrophic Hormone (ACTH)
5.	Gonadotropin releasing Hormone (GnRH)	Stimulates the release of Follicle stimulating hormone (FSH) and Luteinizing Hormone (LH)
6.	Prolactin Releasing Hormone (PRH)	Stimulates the release of prolactin.
7.	Prolactin Inhibiting Hormone (PIH)	Inhibits the release of prolactin
8.	Melanocyte Stimulating Hormone Releasing Hormone (MRH)	Stimulates the secretion of melanocyte stimulating hormone (MSH)
9.	Melanocyte Stimulating Hormone Inhibiting hormone (MIH)	Inhibits the secretion of melanocyte stimulating hormone.



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### Pituitary as an endocrine gland :

Pituitary is a small body, about the size of a gram located on the ventral side of the diencephalon region of the brain. The pituitary hangs below the hypothalamus by a stalk called as infundibulum. The pituitary has three different parts viz. anterior lobe or adenohypophysis, intermediate lobe and posterior lobe or neurohypophysis. The adenohypophysis is compact and highly vascular. It is connected to the hypothalamus by hypophyseal portal vessels. The neurohypophysis is connected to the hypothalamus by nerve fibres. The anterior lobe of pituitary releases six hormones (all protein in nature) that control the activities of various other endocrine glands also. They are given below:

1. *Growth hormone or Somatotrophic hormone (GH or STH)*. It is secreted by the Somatotrophic cells of anterior pituitary and regulates general body growth; increases the length of bones; control carbohydrate, protein, and fat metabolism; muscles and viscera growth; may counteract insulin to raise blood glucose levels etc. Its deficiency causes dwarfism in youngs, and acromicria (rarely) in adults – hypoactivity; while its excessive secretion – hyperactivity causes gigantism in youngs, and acromegaly in adults.
2. *Adrenocortico-trophic hormone (ACTH)*. It is secreted by the Corticotrophic cells of anterior pituitary and controls the growth and secretion of adrenal cortex to release glucocorticoids – cortisol, cortisone etc. However, the secretion of mineralocorticoids by adrenal medulla is stimulated to a much less degree.
3. *Thyroid stimulating hormone (TSH)* or Thyrotrophic hormone or Thyrotropin. It is secreted by the Thyrotrophic cells of anterior pituitary and controls the growth and activity of the thyroid gland. It acts on thyroid to release its hormone – thyroxine.
4. *Follicle stimulating hormone (FSH)*. It is also secreted by Gonadotrophic cells of anterior pituitary and increases the number and size (maturation) of graffian follicles in the ovaries in females; and stimulates spermatogenesis in males.
5. *Luteinising hormone (LH) or interstitial cell stimulating hormone (ICSH)*. It is also secreted by Gonadotrophic cells. In females: (i) it completes the development of graffian follicles to its secretory stage and brings about ovulation along with FSH; (ii) it causes appearance, growth and maintenance of corpus luteum; (iii) it stimulates the secretion of progesterone from the ovaries. In males: it stimulates the development and functional activity of interstitial cells to produce testosterone.
6. *Prolactin or Lactogenic hormone or Luteotrophic hormone (LTH)*. It helps in the growth of mammary glands during pregnancy and initiates the secretion of milk after child birth.

The posterior lobe of pituitary releases the following two peptide hormones. Both these hormones are synthesized in the hypothalamus and are carried to the posterior pituitary along with nerve fibres where they are stored. From posterior pituitary, they are released into the blood.

1. *Vasopressin or Pitressin or Antidiuretic hormone (ADH)*. It is released from posterior pituitary in response to stress and dehydration. It increases the reabsorption of water in the distal convoluted tubules and the collecting tubules of kidney. So its deficiency in the body increases the urine flow causing **diabetes insipidus**. It also raises blood pressure by constricting the peripheral blood vessels.

### Deficiency of ADH

*Hypothalamic ("central") diabetes insipidus results from a deficiency in secretion of antidiuretic hormone from the posterior pituitary.*

*Nephrogenic diabetes insipidus occurs when the kidney is unable to respond to antidiuretic hormone*

*The major sign of either type of diabetes insipidus is excessive urine production.*

2. *Oxytocin or Pitocin.* It is an important uterus-contracting hormone at the time of child birth. It also acts on mammary glands and helps in the expulsion of milk at the time of suckling. It is, therefore, also known as 'milk-ejection hormone' and 'birth hormone'. It decreases the blood pressure by dilating the peripheral blood vessels (opposite to that of vasopressin).

### Feed back inhibition of hormones:

Hypothalamus produces thyrotropin releasing factor (TRF) that acts on anterior pituitary to release thyroid stimulating hormone (TSH). This TSH then acts on thyroid to release its hormone – thyroxine. Now if the level of thyroxine in the blood is more, it will inhibit the hypothalamus to produce TRF, hence less of TSH and thyroxine. And if thyroxine is less, more of TRF is produced. Hypothalamus may also be inhibited or activated by the levels of TSH. This is known as feed back inhibition.

### Thyroid Gland:

Thyroid hormones are derivatives of the amino acid tyrosine bound covalently to iodine.

The two principal thyroid hormones are: thyroxine (known affectionately as T<sub>4</sub> or L-3,5, 3',5'-tetraiodothyronine) triiodotyronine (T<sub>3</sub> or L-3,5,3'-triiodothyronine).

Thyroid epithelial cells - the cells responsible for synthesis of thyroid hormones – are arranged in spheres called *thyroid follicles*. Follicles are filled with *colloid*, a proteinaceous depot of thyroid hormone precursor.

Thyroid is found on the ventral side in the neck region of the body. At the base of larynx, it has two lateral lobes one on either side of trachea. Cells lining the thyroid follicles secrete two thyroid hormones, thyroxine and triiodothyronine. Both are iodinated forms of an amino-acid called thyronine and stored in the form of semifluid material (colloid) in the lumen of follicles. Whenever necessary, the hormones are released from the colloid to the blood.

### Functions:

- Thyroid hormones increase the metabolic rate of the body, enhance heat production and maintain BMR.
- They also promote growth of body tissues-both physical growth and development of mental faculties are stimulated.
- They stimulate tissue differentiation; hence promote metamorphosis of tadpoles into adult frogs.

### Disorders due to thyroid hormone imbalances:

- Excessive secretion of thyroid hormone (hyperthyroidism) results in exophthalmic goitre or Grave's disease. It is accompanied by the bulging of the eye ball. It is associated with high metabolic rate, heart beat and blood pressure rises, restlessness, tremors, nervousness, rise in body temperature, etc.
- Less secretion of thyroid hormone (hypothyroidism) results in Myxedema in adult and cretinism (feeble mindedness) in children. The patient of myxedema suffers from low metabolic rate, slow heart rate, low body temperature and reproductive failure. Administration of thyroid hormones cures the symptoms.
- For the synthesis of thyroid hormone (thyroxine), an important inorganic ion called iodine is needed in the body. Hence the dietary deficiency of iodine causes goitre in which thyroid gland enlarges in an effort to produce more thyroxine.
- Failure of thyroid hormone secretion in children slows body growth and mental development and reduces metabolic rate. The child becomes stunted and mentally retarded. The body temperature, heart rate and blood pressure are lower than normal. The patient is pot-bellied and pigeon chested and has a protruding tongue. This disease is known as cretinism.

### **Thyroid gland – Disorders**

#### **Hypothyroidism:**

##### Reasons:

- Failure of thyroid gland
- Hyposecretion of TRH, TSH or Both
- Inadequate dietary iodine

##### Symptoms:

- Low metabolic activity
- Poor tolerance of cold

#### **Hypothyroidism**

##### **Cretinism (in children):**

Poor skeleton growth – dwarfism – mentally retarded – dry skin – thick tongue – lethargy – respiratory problems – constipation – neonatal jaundice.

##### **Myxoedema (in adult):**

Edema – facial tissues to swell and look fluffy.

## **Hyperthyroidism**

### **Grave's disease (exophthalmic goitre):**

- An immune disease in which autoantibodies bind to and activate the thyroid-stimulating hormone receptor, leading to continual stimulation of thyroid hormone synthesis – edema behind eyes (exophthalmos) with – more often in females.

### **Parathyroids:**

They are four pea-sized organs, clinging to the rear surface of thyroid, but are independent of thyroid structurally and functionally. This gland secretes parathormone (PTH) whose functions are as follows:

- a) It regulates the calcium and phosphate balance between blood and other tissues.
- b) It inhibits synthesis of collagen by osteoblasts and bone resorption by osteoclasts.
- c) It helps in absorption of calcium from the intestine and reabsorption by kidneys.

### **Disorders:**

#### **a) Hypoparathyroidism:**

It leads to deficiency of plasma calcium. Nerve and muscle action potentials rise leading to muscle twitches, spasm, etc., and the condition is called hypocalcemia or parathyroid tetany.

#### **b) Hyperparathyroidism:**

It causes demineralization of bones leading to their easy fracture and deformation. It may lead to osteitis fibrosa cystica.

## **Adrenals or Suprarenals:**

There are two adrenal glands, one on the top of each kidney. Adrenal gland has an outer portion called adrenal cortex, and an inner portion called adrenal medulla. Both these parts differ in the nature of hormone produced and also with respect to their functions.

### **Adrenal cortex:**

This part of adrenal gland is very important for the animal and its removal or destruction will kill the animal. It produces mainly three groups of steroid hormones viz., (i) glucocorticoids; (ii) mineralocorticoids; and (iii) sex corticoids.

- (i) Glucocorticoids regulate the metabolism of carbohydrates, proteins and fats; they also increase the blood glucose level e.g., cortisone, cortisol and corticosterone. The secretion of glucocorticoid hormones is regulated by ACTH from anterior pituitary.
- (ii) Mineralocorticoids are produced from the outermost cellular layer of the adrenal cortex. The main hormone in mammals and birds is aldosterone that reduces the sodium loss from the body in urine, sweat, saliva etc. by its active reabsorption from those fluids. It also increases the excretion of potassium, in an exchange with the absorption of sodium; retain water in the body along with sodium. Thus it regulates the ionic and water balance of the body. The secretion of aldosterone is stimulated by three factors : (a) a fall in the sodium ions in the plasma of blood; (b) a rise in the potassium ions in the plasma of blood ; (c) a fall in the volume of blood itself.
- (iii) Gonadocorticoids: They stimulate the development of secondary sexual characters in males

### Adrenal medulla:

It helps the body to prepare for stress or any emergency conditions. This part of adrenal, unlike cortex, is not so vital for the survival of the organism and so its removal will not cause death.

It produces two hormones called as *adrenaline or epinephrine* and *nor-adrenaline or nor-epinephrine*. Both these hormones act on tissues and organs that are supplied by sympathetic fibres and produce similar effects. Thus adrenal medulla and sympathetic system function as a closed integrated unit and is known as *sympathetico-adrenal system*.

### Pancreas :

The pancreas comprises both exocrine and endocrine parts. The endocrine part of pancreas forms the islets of langerhans. They are small patches of cells present in the pancreas. They produce the following two hormones:

- The endocrine portion of the pancreas takes the form of many small clusters of cells called islets of Langerhans
- Pancreatic islets house three major cell types, each of which produces a different endocrine product:
- Alpha cells (A cells) secrete the hormone glucagon.
- Beta cells (B cells) produce insulin
- Delta cells (D cells) secrete the hormone somatostatin.

1. Insulin. It is protein hormone produced by Beta-cells of islets of langerhans. It regulates the amount of glucose in the blood by converting excess of glucose into glycogen (glycogenesis) which can be stored in the liver and muscles. Lack of insulin, therefore, results in excess glucose in blood (hyperglycemia) and it starts appearing in urine. This disease is known as diabetes mellitus.

### Functions of Insulin:

- It increases the utilization of glucose in the tissues and facilitates the storage of glucose as glycogen in the liver and muscles. As a consequence, insulin lowers the blood glucose level in the body.
  - It increases the synthesis of fats in the adipose tissues from fatty acids and also from glucose.
  - It reduces the break down and oxidation of fats.
  - It promotes protein synthesis from amino acids in the body tissues.
  - It also reduces the breakdown of proteins in the body. Thus, insulin can be regarded as an anabolic hormone.
2. Glucagon. It is also protein hormone produced by Alpha-cells of islets of langerhans. It also regulates the amount of glucose in the blood by converting glycogen back to glucose whenever required. Thus its effect is opposite to that of insulin.
  3. Somatostatin. It inhibits the secretion of glucagons and insulin.

## **Insulin Disorders**

### **Hyperglycaemia:**

High blood Glucose level – Breakdown of muscle tissue – loss of weight – tiredness.

### **Hypoglycaemia:**

Low blood Glucose level – Hunger – Sweating – Irritability – Double vision.

## **Pineal Gland**

**The pineal gland or epiphysis synthesizes and secretes melatonin**, a structurally simple hormone that communicates information about environmental lighting to various parts of the body. It is attached to the roof of third ventricle in the rear part of brain. It functions as a biological clock and a neurosensory transducer, converting the neural information.

### **Thymus:**

It secretes thymosin, thymic factor and thymopoietin. It stimulates the entire immune system and hence is called as ‘throne of immunity’. It stimulates the spleen and other organs, which have stopped functioning to function again. Its secretion decreases with advancing age and entirely ceases by about 50 years.

### **Endocrine functions of Gonads:**

The male gonad is testes and female gonad is ovary. Gonads produce reproductive cells and secrete hormones, which control reproductive organs. These hormones are called as sex hormones. They start to secrete from the age of puberty or sexual maturity.

#### **In female:**

- a) Ovarian follicle – Estrogen – Development of female sexual characteristics and regulate the menstrual cycle.
- b) Corpus luteum – Progesterone and Estrogen – help in implantation and maintaining pregnancy, lactation.  
Relaxin – relaxes pubic symphysis to dilate uterine cervix  
Inhibin / Actin – Inhibition / activation of FSH and GnRH production.

#### **Placenta:**

- a) Human Chorionic Gonadotropin – Stimulates progesterone release from the corpus luteum and maintains it.
- b) Human placental lactogen – stimulates mammary growth.

#### **In Male :**



- a) Testes – Testosterone – Development of male sexual characteristics and stimulation of spermatogenesis.
- b) Inhibin / actin – activation / inhibition of LH and FSH production.

### **Gonads – Disorders**

**In Male:** Hyposecretion:

**Eunuchoidism** : Prostate, seminal vesicles and penis remain small – infertility – no secondary sexual characters.

**Gynaecomastia**: Development of breast tissues in males – due to increased estrogen during pregnancy & puberty.

**In Females** : Infertility – poor development of secondary sexual characters.

### **Pineal Gland**

**The pineal gland or epiphysis synthesizes and secretes melatonin**, a structurally simple hormone that communicates information about environmental lighting to various parts of the body

### **Hormone from Heart:**

The atrial wall of our heart secretes atrial natriuretic factor (ANF), when the blood volume and pressure in the atria increase.

### **Hormone from Kidney:**

The cells of juxtaglomerular apparatus produce a peptide hormone called erythropoietin; it stimulates the formation of erythrocytes (RBC).

### **Hormones from Gastro-intestinal Tract:**

- a) Gastrin: It is secreted by the mucosa of pyloric stomach and duodenum. It controls the secretion of gastric juice by the gastric glands.
- b) Secretin: It acts on the exocrine region of pancreas and stimulates the secretion of water and bicarbonate ions.
- c) Cholecystokinin (CCK): It is secreted by the intestinal mucosa. It acts on pancreas to secrete pancreatic enzymes. It also acts on gall bladder to release bile juice into duodenum.
- d) Gastric Inhibitory Peptide (GIP): It is secreted by the mucosa of duodenum. It inhibits gastric secretion and mobility.

### **Molecular action of Hormone action**

**a) Steroid Hormones:**

The lipid soluble hormones can enter the cell through the bilayer of phospholipids and interact with intra cellular receptors to regulate gene expression.

b) Peptide Hormones:

The water soluble hormones interact with a surface receptor. For example, insulin hormone has a surface receptor, which is a hetero-tetrameric protein, consisting of four subunits. Of these two alpha subunits protrude from the surface of the cell and bind insulin and two beta subunits span the membrane and protrude into the cytoplasm. The following are the five steps in the hormone action:

- a) Binding to the receptor
  - b) Use of second messengers, the mediators
  - c) Amplification of signal
  - d) Antagonistic effect
  - e) Synergistic effect
-