ALAGAPPA UNIVERSITY

(Accredited with 'A+' Grade by NAAC (with CGPA: 3.64) in the Third Cycle and Graded as category - I University by MHRD-UGC)
(A State University Established by the Government of Tamilnadu)

KARAIKUDI – 630 003

DIRECTORATE OF DISTANCE EDUCATION

M.SC. (ZOOLOGY)

Second Year – Third Semester

35031 – ANIMAL PHYSIOLOGY

Author:
Dr. P. Thiruchenthil Nathan
Professor
Department Of Zoology
Periyar University
Salem- 636011

Reviewer:
Dr. J. Arockia John Paul
Assistant Professor in Zoology
Department of Zoology
Arumugam Pillai Seethai Ammal College
Thirupathur

Syllabus **Page No**

35031- ANIMAL PHYSIOLOGY

Contents **Page**

Contents **Page**

BLOCK – I

INTRODUCTION TO DIGESTIVE, RESPIRATORY AND EXCRETORY SYSTEM

UNIT – I INTRODUCTION TO ANIMAL PHYSIOLOGY

Structure

1.1 INTRODUCTION

Animal physiology is the scientific study of the life-supporting properties, functions and processes of animals or their parts. The discipline covers key homeostatic processes, such as the regulation of temperature, blood flow and hormones. Animal physiology is an interesting field in the branch of biology. In general, physiology is the subject which deals with functional study of an organism from sub-cellular level to the organism as a whole. It describes the interactions of organism with the surrounding environment and its physiological adaptations to the particular environment and linking them to physical and chemical principle. Animal physiology differs from typical physiology by focusing the physiological principles of all the animals rather than mainly concentrating on the human system. We could define life by the functions of the living system and that non living things do not perform. The living things organize themselves using energy from the raw materials, such as lipid, carbohydrate and protein from the surroundings and maintain integrity through homeostasis and reproduce. The field of animal physiology deals with all these things like how the animals get the food and digest and excrete. To study the respiratory system, sensory system and the reproduction of organism deal with the study of Animal Physiology. Physiology is a broad subject, which is integrative in nature and it employs a wider range of specific techniques than most of the other biological disciplines.

1.2 DEFINITIONS AND DIVISIONS OF PHYSIOLOGY

The physiology is defined as the studying the homeostasis and biological functions of organisms at many levels of organization. Based on these animal physiology is divided into many branches and each divisions itself stand out to be a major area of research. Even though there are multitudes of divisions and branches in physiology, we will see few important major divisions in physiology.

1. CELL AND MOLECULAR PHYSIOLOGY

Cell and molecular physiology deals with the physiological mechanism that occur at the cellular level and these affect the important consequences for the higher levels of organization. The cell and molecular physiologists study molecular genetics, signal transduction, metabolic biochemistry, or membrane biophysics.

2. SYSTEM PHYSIOLOGY

The physiology of the living organism can be divided into different systems such as respiratory system, digestive system, excretory system, nervous system etc. System physiologists concerns with the physiological functioning of specific system in the organism. So the respiratory physiologists study about the respiratory system, Neurophysiologist concern with the nervous system, and so on.

3. ORGANISMAL PHYSIOLOGY

Organismal physiology concern with the way an intact animal undertakes a specific process or behaviour. For example, the research of an organismal physiologist concerns with the changes in animal metabolic rate in response to stressor, such as temperature. The metabolic rate is the result of the interactions between multiple physiological systems in the body. Some organismal physiologists specialize in particular group of animals, such as mammalian physiologists, avian physiologists, fish physiologists etc.

4. ECOLOGICAL PHYSIOLOGY

Ecological physiology deals with how the physiological properties of an animal influence the distribution and abundance of a species or population. For example, an ecological physiologists study the influence of nutrient distribution in the environment on the growth rate of animal. Ecological physiologists are concern with how an interesting environment affects diverse animals within the environment.

5. COMPARATIVE PHYSIOLOGY

Comparative physiology studies about the functional aspects of an organ in different animals and, how the animal is adapted to the particular environment. The comparative physiology is also helpful to identify the evolutionary lineage of an organ system. For example, comparative hysiologist studies the respiratory system of vertebrates.

6. PATHOPHYSIOLOGY

Pathophysiology is one of the branches of biomedical science. It deals with the study of the disordered physiological processes that cause, result from, or are otherwise associated with a disease or injury. Pathophysiologist

seeks to explain the functional changes that are occurring within an individual due to a disease or pathologic state, and this may helpful for diagnosis and cure.

7. **DEVELOPMENTAL PHYSIOLOGY**

Developmental physiology deals with how structures and functions change as animals grow through the various stages of life from the embryo to adult, to senescence and death. These specific pathways are responsible for the conversion of unspecialized stem cells into multicellular tissues and systems.

8. **EVOLUTIONARY PHYSIOLOGY**

The evolutionary physiology deals with explaining how specific physiological traits arise within lineages over the course of multiple generations. The evolutionary physiologist is interested to study the origin of variations within the populations of a single species, or the closely related groups of animals.

1.3. RELATIONSHIP OF PHYSIOLOGY WITH OTHER SCIENCES

The field of physiology has relationship with other science fields like physics, chemistry and other branches and this leads to the new discoveries and inventions. Some of the activities like respiration, water intake and osmoregulation are physical phenomenon. Most of the biological instruments like X-ray, Microscope, and Ultrasound detector have physics application.

Physiology is related with number of subjects like biochemistry, biophysics, general physiology, and molecular biology and so on. Physiology has an important position among the functional sciences that are closely related to the field of medicine. Unsolved problems of physiology will require technical and research expertise from the people belonging to different fields like physics, chemistry, mathematics, engineering and so on. The concept of comparative biochemistry provided the foundations for a physiology of microorganisms that extended beyond the parasitic forms that are of medical importance and resulted in recognition of the fundamental roles of microorganisms in the world. Research in physiology also is aimed at the integration of the varied activities of cells, tissues, and organs at the level of the intact organism. Both analytical and integrative approaches uncover new problems that also must be solved. These solutions will be practical value in medicine or helps to improve the understanding of both human beings and other animals.

1.4. SIGNIFICANCE OF PHYSIOLOGY

The study of animal physiology gives the knowledge about how the animals work. The study of physiology has enormous practical applications and helpful for the understanding of health and disease. The study of physiology of other animals as models gives the knowledge about the understanding of human physiology. The effect of pollutants and heavy metals on the physiological system of give knowledge about the

deleterious role of these pollutants and to take a action for mitigation of these pollutants.

Physiology is also very important because it is one of the biology's most integrative disciplines. Physiologists study the level of organization of the animal body. This will help to understand how an organ works, for instance by student will get the working mechanism of nervous system, circulatory system and other organ systems of the body. Further, the students know about the control mechanism such as hormones and enzymes. So by studying physiology, students get the overall knowledge about the working mechanism of animal kingdom.

1.5. LET US SUM UP

Physiology is the interesting subject which deals with the functional study of an organism from sub cellular level to the organism as a whole. It is a broad subject which is integerative in nature with subjects like physics and chemistry. The field of physiology is divided into cell and molecular physiology, system physiology, organismal physiology, ecological physiology, comparative physiology, Pathophysiology and various other sub fields. Physiology is closely related with other fields such as physics, chemistry, engineering and so on. The study of physiology gives knowledge about how the animals work and helpful for understanding the healthy and diseased conditions of animals. So by studying physiology students get the knowledge about the working mechanism of animal kingdom.

1.6 . UNIT END EXERCISE

1. The branch of biology deals with studying the functional mechanism of animals is called

   a. Anatomy b. Physiology c. Biology d. Ecology

2. Physiological mechanism of animals at the cellular level is studied by

   a. Ecophyiology b. Neurophysiology c. Organismal physiology d. Cell and molecular physiology

3. Studying respiratory or digestive system as whole is called as

   a. System physiology b. Molecular physiology c. Ecotoxicology d. Ecology

4. Disorders in the physiological system is studied through

   a. Comparative physiology, b. Pathophysiology, c. Toxicology, d. None of the above.

1.7. ANSWER TO CHECK YOUR PROGRESS

1. b, 2. d, 3.a, 4.b

1.8. SUGGESTED READINGS

Hill, R.W., G. A. Wyse, M. Anderson (2016) Animal Physiology, Sinauer, 4th Edition, USA

Moyes, C.D., P.M. Schulte (2016) Principles of Animal Physiology, Pearson Education India, 2nd Edition, India.

Campbell, A.M., C. J. Paradise (2016) Animal Physiology, Momentum Press, USA.

Sherwood, L., Klandrof, H., P. Yancy (2012) Animal Physiology: From genes to organisms, Cengage learning, USA

UNIT II - DIGESTIVE SYSTEM IN MAN

Structure

2.1. INTRODUCTION TO DIGESTIVE SYSTEM

Humans are heterotrophs and omnivore. They depend on external sources as raw materials for the production of energy which is needed for growth, maintenance and functioning. The major component of food materials are carbohydrates, fats, proteins, minerals, vitamins and water. The main function of the digestive system is to transfer food and water from external environment to internal environment and breakdown in to smaller components for subsequent distribution to the cells of the body through the circulatory system. Because most of the food consumed are made up of complex substances which cannot pass through the cell membrane. Digestive system makes the complex and insoluble food substances into simpler forms which are suitable for absorption. This break down process of the food is called digestion and the digestion is performed by the digestive enzymes present in the alimentary canal.

2. 2. PHYSIOLOGY OF DIGESTION

Digestion is a process by which food substances are altered physically and chemically, so that they are reduced to simple assimilable or absorbable forms. The process is divided into two main parts:

A. MECHANICAL DIGESTION

The mechanical digestion comprises liquefying of food by the digestive juices, mastication, swallowing and after that food enter into the stomach by peristalsis movement. It is a special method of muscular contraction by which the food bolus is carried down from the oesophagous to the stomach.

Peristalsis may be defined as a wave of muscular contraction preceded by a wave of relaxation which causes the contents of a hollow tube to be passed onwards. The circular muscles of the digestive tube immediately behind the bolus contract and those directly in front of it relax. This results in the bolus being forced into the relaxed portion. The contraction of muscles follows closely behind the bolus and further relaxation occurs in front, thus the bolus of food passes steadily forwards.

B. CHEMICAL DIGESTION

Chemical digestion is effected by the chemical substances or the enzymes present in various digestive juices with which food comes in contact at different level of alimentary tract. These enzymes cleave the native proteins to amino acids; starches to monosaccharides and fats to glycerol and fatty acids. In the course of these digestive reactions, the minerals and vitamins of the foodstuffs are also made assimilable by the body system

The digestive juices, secreted in the various parts of the alimentary tract, are as follows: Saliva in the mouth, Gastric juice in the stomach, bile in the duodenum, Pancreatic juice in the duodenum, Intestinal juice in the small intestine.

2.2. 1. HUMAN DIGESTIVE SYSTEM

1. ORAL CAVITY

In humans, digestion begins in the oral cavity where food is chewed. Saliva is secreted in large amounts (1-1.5 liters/day) by three pairs of exocrine salivary glands (**Parotid, Submandibular**, and **Sublingual**) in the oral cavity, and is mixed with the chewed food by the tongue. There are two types of saliva. One is a thin, watery secretion, and its purpose is to wet the food. The other is a thick, mucous secretion, and it acts as a lubricant and causes food particles to stick together and form a bolus. The saliva serves to clean the oral cavity and moisten the food, and contains digestive enzymes such as **salivary amylase**, which aids in the chemical breakdown of polysaccharides such as starch into disaccharides such as maltose. It also contains mucous, a glycoprotein which helps soften the food into a bolus. Swallowing transports the chewed food into the esophagus, passing through the pharynx.

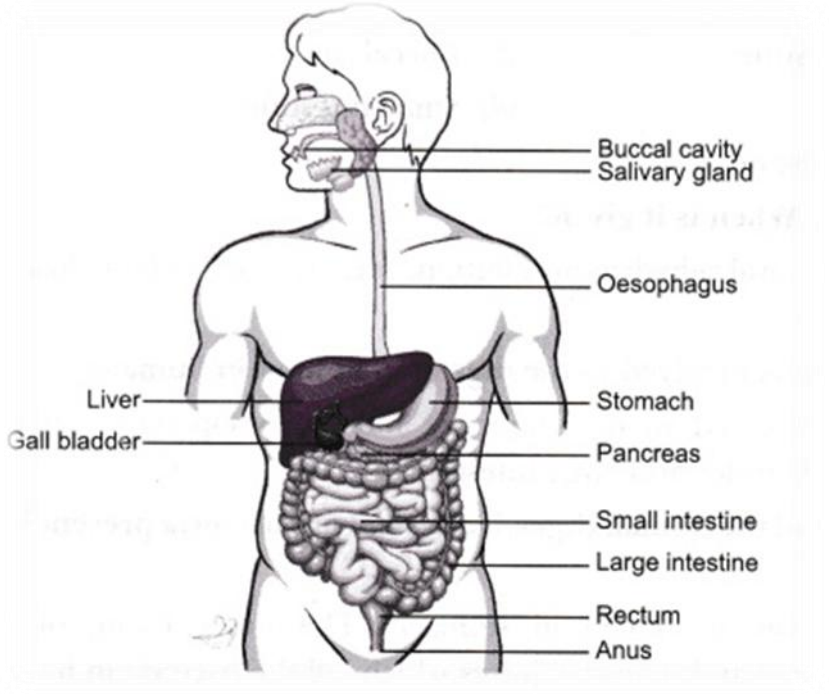


Figure.1. Human digestive system

NOTES

2. PHARYNX

The pharynx is the part of the neck and throat situated immediately posterior to (behind) the mouth and nasal cavity, and cranial, or superior, to the esophagus. It is part of the digestive system and respiratory system. Because both food and air pass through the pharynx, a flap of connective tissue, the epiglottis closes over the trachea when food is swallowed to prevent choking or asphyxiation.

3. ESOPHAGUS

The esophagus is a narrow muscular tube about 25 centimeters long which starts at pharynx at the back of the mouth, passes through the thoracic diaphragm, and ends at the cardiac orifice of the stomach. The wall of the esophagus is made up of two layers of smooth muscles, which form a continuous layer from the esophagus to the open and contract slowly, over long periods of time. The inner layer of muscles is arranged circularly in a series of descending rings, while the outer layer is arranged longitudinally. At the top of the esophagus, is a flap of tissue called the epiglottis that closes during swallowing to prevent food from entering the trachea (windpipe). The chewed food is pushed down the esophagus to the stomach through **peristaltic contraction** of these muscles. It takes only about seven seconds for food to pass through the esophagus and no digestion takes place.

4. STOMACH

The stomach is a small,'J'-shaped pouch with walls made of thick, elastic muscles, which stores and helps break down food. Food which has been reduced to very small particles is more likely to be fully digested in the small intestine, and stomach churning has the effect of assisting the physical disassembly begun in the mouth.

Food enters the stomach through the cardiac orifice where it is further broken apart and thoroughly mixed with **gastric acid** which contains **hydrochloric acid** (H Cl), which make the medium into acidic and helps the reaction of digestive enzymes. Further harmful microorganism present in the food is also get killed by the gastric acid. It can also denature proteins. This is the process of reducing polypeptide bonds and disrupting salt bridges which in turn causes a loss of secondary, tertiary or quaternary protein structure. The enzymes **Pepsin** and **Renin** present in the stomach break down the proteins. Pepsin is present in the proenzyme form pepsinogen which is activated by gastric juice. The parietal cells of the stomach also secrete a glycoprotein called intrinsic factor which enables the absorption of vitamin B-12. Other small molecules such as alcohol are absorbed in the stomach, passing through the membrane of the stomach and entering the circulatory system directly. Food in the stomach is in semi-liquid form, which upon completion is known as chyme. The mucus lubricates the food and also prevents hydrochloric acid from acting on the walls of the stomach.

5. SMALL INTESTINE

After being processed in the stomach, food is passed to the small intestine via the pyloric sphincter. The majority of digestion and absorption occurs here after the milky chyme enters the duodenum. Here it is further mixed with three different liquids:

- Bile, which emulsifies fats to allow absorption, neutralizes the chyme and is used to excrete waste products such as bilin and **bile acids**. Bile is produced by the liver and then stored in the gallbladder. The bile in the **gallbladder** is much more concentrated.
- **Pancreatic juice** made by the **pancreas**.
- Intestinal enzymes of the alkaline mucosal membranes. The enzymes include **maltase**, **lactase** and **sucrase** (all three of which process only sugars), **trypsin** and **chymotrypsin** which act on proteins are secreted by the pancreas.

As the pH level changes in the small intestines and gradually becomes basic, more enzymes are activated further that chemically break down various nutrients into smaller molecules to allow absorption into the circulatory or lymphatic systems. Small, finger-like structures called villi, each of which is covered with even smaller hair-like structures called microvilli improve the absorption of nutrients by increasing the surface area of the intestine and enhancing speed at which nutrients are absorbed. Blood containing the absorbed nutrients is carried away from the small intestine via the hepatic portal vein and goes to the liver for filtering, removal of toxins, and nutrient processing.

The small intestine and remainder of the digestive tract undergoes peristalsis to transport food from the stomach to the rectum and allow food to be mixed with the digestive juices and absorbed. The circular muscles and longitudinal muscles are antagonistic muscles, with one contracting as the other relaxes. When the circular muscles contract, the lumen becomes narrower and longer and the food is squeezed and pushed forward. When the longitudinal muscles contract, the circular muscles relax and the gut dilates to become wider and shorter to allow food to enter.

6. LARGE INTESTINE

After the food has been passed through the small intestine, the food enters the large intestine. Within it, digestion is retained long enough to allow fermentation due to the action of gut bacteria, which breaks down some of the substances which remain after processing in the small intestine; some of the breakdown products are absorbed. In humans, these include most complex saccharides (at most three disaccharides are digestible in humans). In addition, in many vertebrates, the large intestine reabsorbs fluid; in a few, with desert lifestyles, this resorption makes continued existence possible.

In humans, the large intestine is roughly 1.5 meters long, with three parts: the cecum at the junction with the small intestine, the colon, and the rectum. The colon itself has four parts: the ascending colon, the transverse

NOTES

colon, the descending colon, and the sigmoid colon. The large intestine absorbs water from the bolus and stores feces until it can be egested. Food products that cannot go through the villi, such as cellulose (dietary fiber), are mixed with other waste products from the body and become hard and concentrated feces. The feces is stored in the rectum for a certain period and then the stored feces is eliminated from the body due to the contraction and relaxation through the anus. The exit of this waste material is regulated by the anal sphincter.

2.2.2 DIGESTION OF CARBOHYDRATES:

Carbohydrate is a prominent component of the food consumed by humans and about 63 to 83% contains carbohydrates. They provide the main bulk of energy for the organism. The breakdown of complex carbohydrates into monosaccharide is called carbohydrate digestion. The carbohydrate digestion occurs in buccal cavity, stomach and intestine and the important glands involved are 1. Salivary gland, 2. Pancreas, 3. Gastric glands and 4. Intestinal glands.

A. ENZYMES INVOLVED IN CARBOHYDRATE DIGESTION:

The break down of carbohydrate is brought about by the set of enzymes called carbohydrases. They are 1. buccal and pancreatic amylase, 2. Maltase, 3. Lactase, and 4. Sucrase

B. DIGESTION OF STARCH:

Starch is digested by salivary amylase or **ptyalin** and converts it into maltose. First of all in the buccal cavity starch is converted into soluble starch. Then the soluble starch is converted into erythrodextrin, which in turn splits into achrodextrin. Finally achrodextrin is converted into maltose.

$$\text{Starch} \xrightarrow{\text{Ptyalin}} \text{Maltose}$$

C. DIGESTION OF MALTOSE:

Maltose is digested by the enzyme maltase. It is secreted by salivary glands and gastric glands. Maltase splits maltose into two molecules of glucose.

$$\text{Maltose} \xrightarrow{\text{Maltase}} \text{Glucose + Sucrose}$$

D. DIGESTION OF SUCROSE:

Sucrose is digested by sucrase. Sucrase is secreted by gastric glands. Sucrose splits sucrose into glucose and fructose.

$$\text{Sucrose} \xrightarrow{\text{Sucrase}} \text{Glucose + Fructose}$$

E. DIGESTION OF LACTOSE

Lactose is digested by lactase secreted by gastric glands. Lactase splits lactose into glucose and galactose.

$$\text{Lactose} \xrightarrow{\text{Lactase}} \text{Glucose + Galactose}$$

2.2.3 DIGESTION OF PROTEINS:

An essential macronutrient, protein is used by the body to build and repair cells, to regulate a huge number of body functions. For example, almost 50 percent of the dietary protein we consume each day goes into making enzymes, the specialized proteins that help to digest food, assemble or divide molecules to make new cells and other chemical substances. In the process of digestion proteins are split into amino acids and subsequently absorbed.

Digestion of protein occurs in stomach and intestine. It does not occurs in buccal cavity. The protein digestion is helped by the following digestive glands: 1. Pancreas, 2. Gastric glands and 3. Intestinal glands.

A. ENZYMES INVOLVED IN PROTEIN DIGESTION:

The enzymes responsible for the digestion of proteins are called proteases or peptidases or proteolytic enzymes. The following are proteases: 1. Pepsin, 2. Tripsin, 3.Chymotripsin, 4. Carboxypeptidase, 5. Aminopeptidase, 6.Dipeptidase and 7. Renin.

B. STEPS IN PROTEIN DIGESTION

During digestion proteins are split into amino acids step by step. First of all, proteins are split into proteoses. The proteoses are split into peptones. Then the peptones are split into polypeptides. The polypeptides are split into dipeptides. Finally dipeptides are split into aminoacids.

C. ROLE OF PEPSIN:

Pepsin is a proteolytic enzyme secreted by the gastric glands. It is secreted in an inactive from called pepsinogen. The hydrochloric acid activates this enzyme into pepsin. Pepsin acts on native proteins and milk and convert them into proteoses, peptones and polypeptides.

Native protein $\xrightarrow{\text{Pepsin}}$ Proteoses + Peptones + Polypeptides

Calcium + Casein (milk) $\xrightarrow{\text{Pepsin}}$ Calcium paracasein (curd) + Proteose

Calcium paracaesin $\xrightarrow{\text{Pepsin}}$ Proteoses, peptones, polypeptides

D. ROLE OF TRYPSIN

Trypsin is a proteolytic enzyme secreted by the pancreas. It is secreted in an inactive form called trypsinogen. It is activated by another enzyme called enterokinase. It converts proteins, proteoses and peptones into polypeptides and dipeptides.

Native protein $\xrightarrow{\text{Trypisn}}$ Proteoses + Peptones + Polypeptides

E. ROLE OF CHYMOTRYPSIN:

It is a proteolytic enzyme secreted by the pancreas. It is secreted in an inactive form called chymotrypsinogen. It is activated by trypsin. It acts on native proteins, proteoses and peptones and gives polypeptides and dipeptides. Chymotrypsin also acts on milk.

NOTES

F. ROLE OF CARBOXYPEPTIDASE:

It is a proteolytic enzyme secreted by pancreas. It can not act on proteins. But it acts on proteoses, peptones and polypeptides and converting them into dipeptides and aminoacids.

G. ROLE OF AMINOPEPTIDASE

It is a proteolytic enzyme secreted by the pancreas. Its action is similar to that of carboxypeptidase. It acts on proteoses, peptones, polypeptides converting them into dipeptides and aminoacids.

H. ROLE OF DIPEPTIDASE

It is a pancreatic enzyme. It acts on dipeptides and splits them into aminoacids

Dipeptide $\xrightarrow{Dipeptidase}$ Aminoacid + Aminoacid

I. DIGESTION OF MILK

Milk is digested by rennin and chymotrypsin. Renin is secreted by gastric glands and chymotrypsin is secreted by pancreas. These enzymes bring about the coagulation of milk. This process is called curdling of milk.

Renin acts on the casein of milk and converts it into paracaesin. Paracaesin combines with calcium to form calcium paracaeseinate. Calcium paracaesinate separates out as curd and acted upon by pepsin.

Caesin $\xrightarrow{Renin}$ Paracaesin

Paracaesin + Ca $\xrightarrow{Renin}$ Calcium paracasenate

2.2.4. DIGESTION OF LIPIDS:

Lipids are the second major source of energy for animals. The dietary lipids include neutral fats, phospholipids, cholesterides, free cholesterol, fatty acids and glycerol. During digestion lipids are split into fatty acids and glycerol.

Lipids $\longrightarrow$ Fatty acids + Glycerol

The digestion of lipid occurs in the stomach and intestine. It does not occur in the buccal cavity. Lipid digestion is helped by the following digestive glands: 1. Gastric gland, 2. Liver and 3.Pancreas

ENZYMES INVOLVED IN LIPID DIGESTION:

The breakdown of the lipids is brought about by a set of enzymes called lipases. The following are lipases: 1. Gastric lipase, 2.Pancreatic lipase, 3.Phospholipase, 4. Phospho diesterase, 5. Phosphatase and 6. Cholesterol esterase.

A. EMULSIFICATION:

Emulsification is a process by which the insoluble lipids are converted into a soluble milky liquid containing drops of oil and fat. Emulsification is the first step in the digestion of fat. It occurs in the stomach.

Emulsification is brought about by the bile secreted by the liver. Only after emulsification, the proteases and lipases begin their digestive function on lipids.

B. DIGESTION OF NEUTRAL FATS:

Neutral fats are acted by gastric lipase and are split into fatty acids and glycerol in a series of steps.

First of all, hydrolysis of neutral fats leads to the formation of one molecule of fatty acid and another molecule of diglyceride. The diglyceride is then split into one molecule of fatty acid and another molecule of monoglyceride. The monoglyceride is then hydrolysed into one molecule of fatty acid and another molecule of glycerol.

Thus each molecule of neutral fat produces three molecules of fatty acids and one molecule of glycerol.

Neutral fat ⟶ Diglyceride + Fatty acid

Diglyceride ⟶ Monoglyceride + Fatty acid

Monoglyceride ⟶ Glycerol + Fatty acid

C. DIGESTION OF LECETHIN AND CEPHALIN

The pancreatic enzyme phospholipase acts on lecithin and cephalin and removes one fatty acid. This leads to the formation of substances called lysolecithins and lysocephalins.

Lecithin $\xrightarrow{\textit{Phospholipase}}$ Lysolecithin + Fatty acid

Cephalin $\xrightarrow{\textit{Phospholipase}}$ Lysocephalin + Fatty acid

These are hydrolysed further and the second fatty acid is removed. This leads to the formation of glycerol phosphorylcholine and other similar compounds.

Glycerol is split off by phosphodiesterases. Choline and sphingosine are freed by the action of phosphatases. Cholesterol is freed from cholesterides by cholesterol estrase. Lipid digestion is completed in the intestine by an intestinal enzyme called intestinal lipase.

NOTES

2.3. ABSORPTION AND ASSIMILATION

Ingestion and digestion are the first two phases of the processes occurring in the alimentary tract. The third phase is that of absorption.

1) **ABSORPTION FROM THE MOUTH**

Normally, there is no absorption from the mouth, but a few drugs may be absorbed into the blood thorugh the mucous membranes, if allowed to dissolve under the tongue, e.g. isoprenaline, glyceryl trinitrate.

2) **ABSORPTION FROM THE STOMACH**

In the stomach, absorption takes place to a limited degree. The only substances normally absorbed from the stomach are some water, glucose and considerable amounts of alcohol. These substances are absorbed through the walls of the stomach into the venous circulation. Although iron absorption takes place in the small intestine, it is dissolved out of foods most effectively in the stomach in the place of HCl.

3) ABSORPTION FROM THE SMALL INTESTINE

The small intestine is the main absorptive organ. About 90% of the ingested food-stuffs are absorbed in the course of passage through the small intestine. The surface area of the intestine trough which absorption can take place is vastly increased by the circular folds of the mucous membrane and by the large number of villi. The intestinal wall appears very much like a Turkish towel. Surface area of the intestine is further increased by the microscopic folds, the microvilli, protruding out from the surface of the intestinal epithelial cells. The villi are small fingerlike projections of mucus membrane. Each villus contains an arteriol which is connected to a venule through a net-work of capillaries. The venule ultimately empties in the portal vein. There is also blind lymph vessel in each villus called the lacteal. During absorption the villi are in a constant movement controlled by the plexus of Meissiner and a hormone known as villikinin.

There are two general pathways for the transport of materials absorbed by the intestine; the veins of the hepatic portal system which lead directly to he liver and the lymphatic vessels of the intestinal area, which eventually lead to the blood by way of the lymphatic system and the thoracic duct.

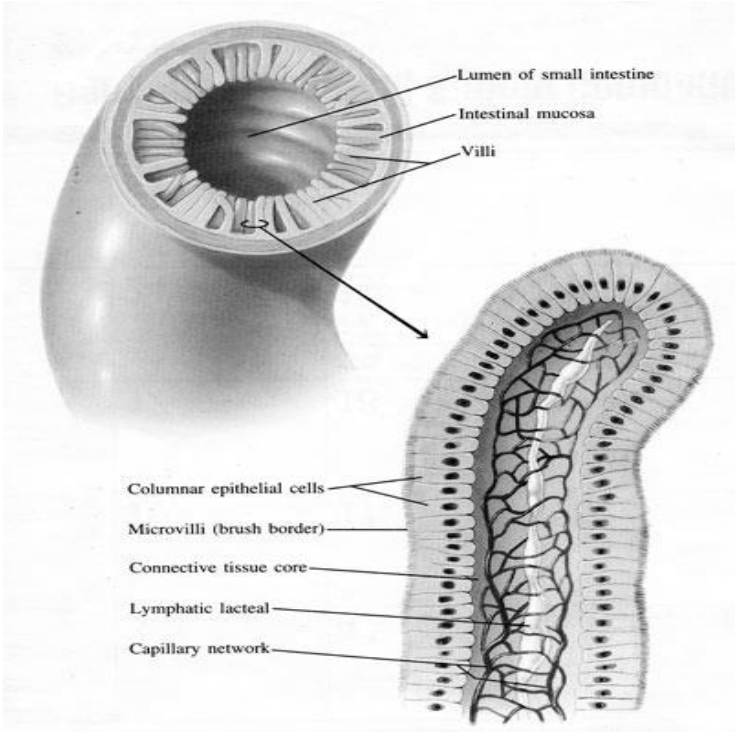


Fig. 3.2. Micorvilli in small intestine helps absorption of digested food

(I) ABSORPTION OF CARBOHYDRATES:

Carbohydrates are absorbed mainly in the form of a monosaccharides like galactose, laevulose, mannose, xylose, arabinose, etc. are also absorbed. The mechanism of absorption of sugars is a chemical process. Sugars undergo phosphorylation during absorption. This leads to the formation of hexose phosphates.

The formation of hexose phosphates occurs in the outer portion facing the lumen of epithelial cells. As a result, the concentration of free sugars remains lesser in the cells. This facilitates rapid absorption of sugars into the epithelial cells. This facilitates rapid absorption of sugars into the epithelial cells.

On the other side of the epithelial cells a reversible reaction called dephosphorylation occurs. During dephosphorylation, hexose phosphates are split into phosphates and sugars. Phosphates remain in the cells for further phosphorylation of sugars. The sugars freed from phosphates enter the blood stream. The phosphorylation reaction is catalysed by phoosphokinase.

The carbohydrate absorption is controlled by the following factors:

1. Complete digestion of carbohydrates
2. Presence of phosphoric acid and phosphokinase
3. Adrenal cortex
4. Anterior pituitary
5. Insulin and
6. B-complex vitamins like thiamine, pantothenic acid and pyridoxine

NOTES

(II)ABSORPTION OF PROTEINS

Proteins are absorbed mainly in the form of aminoacids. Rarely proteins are absorbed in the form of peptides. Absorption is an active or passive process. They are absorbed by the blood capillary and transported by portal system.

(II)ABSORPTION OF FATS

Fats are absorbed in the form of fatty acids and glycerol. Most of the fats are absorbed in the small intestine. Fats are absorbed after emulsification by bile salts. Fatty acids and monoglycerides are absorbed in the duodenum and jejunum; conjugated bile salts are absorbed in the terminal ileum.

Fatty acids are absorbed and are transported by lymphatic system. They enter the blood stream from thoracic duct.

The products of fat digestion enter the mucosa cells in two forms. They are:

1. Some of the fatty acids and monoglycerides aggregate to form water soluble particles called micelles. The micelles diffuse into the epithelial cells.
2. They are absorbed in the form of bile salts.

(III) ABSORPTION OF VITAMINS

Water soluble vitamins like members of B complex and vitamin C readily diffuse across the walls of the intestine into the blood. To move vitamin B_{12} across the wall of the ileum, a special system is required. In the atomach, the vitamin combines with a special protein secreted by gastric glands, known as the intrinsic factor. During the absorption process in the ileum, Vitamin B_{12} is released from the intrinsic factor and enters the blood. The fat soluble vitamins A, A, E and K are isssolved in micelles which enter the mucosal cells of the intestine by simple diffusion. The absorption of these fat-soluble vitamins is markedly decreased in the absence of bile.

2.4 GASTROINTESTINAL HORMONES AND THEIR CONTROL IN DIGESTION

The gastrointestinal hormones play an important role in digestion and they work in association with the gut's extensive nervous system called enteric nervous system and play a co-ordinating role in the control of appetite, the digestion of food, the regulation of energy balance and the maintenance of blood glucose levels. The gut continuously sends information to the brain regarding the quality and quantity of the food that is consumed.

Some of the important gastrointestinal hormones are as follows 1. Gastrin 2.Secretin 3. Cholecystokinin 4. Enterogastrone 5. Villikinin 6 Somatostatin.

1. **GASTRIN**

This hormone is secreted by gastrin cells (= G-cells) in the pyloric region of the stomach. It stimulates gastric glands to secrete and release the gastric juice. It also stimulates gastric mobility. This hormone release is

stimulated by the presence of protein in the stomach and inhibited by the accumulation of acid in stomach. It increases secretion of HCl and pepsinogen in stomach. Enhances gastric motility, stimulates ileal motility, relaxes ileocecal sphincter, induces mass movements in colon and helpful of the maintenance of well-developed, functionally viable digestive tract lining.

2. **Secretin**

Secretin was the first gastrointestinal hormone discovered by scientists. It is secreted by the epithelium of duodenum. It releases bicarbonates in the pancreatic juice. It increases secretion of bile. It decreases gastric secretion and motility. The presence of acid in the duodenum stimulates the release of this hormone. It inhibits gastric emptying in order to prevent further acid from entering duodenum until, acid already present is neutralized and prevent gastric secretion to reduce amount of acid being produced. This hormone stimulates pancreatic duct cells to produce large volume of aqueous NaHCO3 secretion. It also stimulates liver to secrete NaCO3 rich bile which assists in neutralization process along with Cholecystokinin.

3. **CHOLECYSTOKININ**

This hormone is secreted by the epithelium of entire small intestine. It stimulates the gall bladder to release bile and pancreas to secrete and release digestive enzymes in the pancreatic juice. This hormone act as a important regulator of food intake.

4. **ENTEROGASTRONE**

This hormone is also called as Gastric inhibitory peptide (GIP). It is secreted by the duodenal epithelium. It inhibits gastric secretion and motility. It slows gastric contraction.

5. VILIKININ

It is secreted by the epithelium of entire small intestine. It accelerates movement of villi.

6. SOMATOSTATIN

Somatostatin is secreted by the Delta cells of islets of Langerhans of the pancreas inhibits the secretion of glucagon by aplha cells and insulin by beta cells Somatostatin produced by argentaffin cells of gastric and intestinal glands suppresses the release of hormones from the digestive tract.

2.5 LET US SUM UP

Digestion starts in the mouth by grinding and mixing the food with saliva. The salivary amylase and maltase in the saliva act on the carbohydrate. Then the food passes from mouth to stomach through pharynx by peristaltic movement of the muscle. Once the food enter into the stomach, the hydrochloric acid secreted y the stomach make the food acidic and activate the enzymes and kill the microbes present in it. The enzyme pepsin and rennin act on proteins and lipase acts on lipids. After that the food entered into the small intestine. The front part of the small intestine is called as duodenum, where the secretion from the bile makes the food alkaline and activates the enzymes present in the pancreatic juice. In the

end the carbohydrate is converted into glucose, protein into amino acids and lipid into fatty acid and glycerol. Then the food is absorbed by intestinal villi present in the small intestine. These activities are facilitated by the secretion of the gastrointestinal hormones like gastrin, secretin, cholecystokinin etc. Then the food is passed into the large intestine. In the large intestine the water is reabsorbed, some microorganisms present in the large intestine give some vitamins and minerals to the body. Finally the waste material is egested out as feces.

2.6 UNIT-END EXERCISES

UNIT- END EXERCISE

Notes: a) Write your answers in the space given below.

b) Compare your answer with those given at the end of the unit.

i) Fill in the blanks:

a) There are three pairs of salivary gland in mouth, they are _____

b) The inactive pepsinogen is activated to pepsin by _____

c) The absorption of digested food material is done by _____

ii) Describe the enzymes involved in the digestion of proteins

---

2.7 ANSWER TO CHECK YOUR PROGRESS

i, Fill in the Blanks

a, Parotid, Sub lingual & sub mandibular glands

b, Hydrochloric acid

c. Intestinal Villi

ii, Pepsin, Renin, Amino peptidase, Corboxy peptidase, Tripsin and Dipeptidase

2.8. SUGGESTED READINGS

Berry, A.K & K.Berry (2008) A text book of animal physiology, Emkay publications, New Delhi.

Randall, D., Burggren, W. & K. French (2002) Eckert Animal Physiology, W. H. Freeman and Company, New York.

Reznikova, Z. (2007) Animal intelligence: From individual to Cognition, Cambridge university press, Cambridge.

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

UNIT III- RESPIRATORY SYSTEM IN MAN

Structure

3.1INTRODUCTION TO RESPIRATORY SYSTEM

Respiration is the important function of any animal for its survival. If an animal not respire it will expire. Respiration is defined as the process of receiving Oxygen and releasing of CO2 to the surrounding environment. All living organism organisms require a continuous and adequate supply of oxygen for cellular metabolic activity and during that process Carbon dioxide released as metabolic waste, which need to be removed. So the respiration consist of all the physiological process that contribute to the uptake of Oxygen and the elimination of Carbon dioxide.

3.2 TYPES AND MECHANISM OF RESPIRATION

In general human respiratory mechanism is divided to two types. They are external respiration and internal respiration.

1. EXTERNAL RESPIRATION

External respiration is otherwise called as lung respiration or breathing. This type of respiration is carried out by lungs and its accessory structures. External respiration is also called "breathing", which includes two phases, namely inspiration and expiration. Inspiration is called intake of air or breathing in and expiration is called as the release of air or breathing out. During external respiration pulmonary gas exchange takes place between alveoli and the blood.

It is the common available process in most of the higher animal groups. In some lower organisms, such as jelly fishes, earthworms, etc. skin plays an important role in respiration. In amphibians the purpose is served by the skin.

2. INTERNAL RESPIRATION

The second type is called internal respiration or cellular respiration. During internal respiration, the gaseous exchange between the blood or other circulating fluid and the active cells of the organism takes place. Since it this happens at cellular level it is called cellular respiration. In this second phasese, blood distributes O_2 to the cells and recives CO_2 from them

NOTES

through the tissue fluid. The internal respiration is chiefly concerned with the uptake of O_2, release of energy and the production of CO_2 by the cells.

3.2.1. PROCESS OF PULMONARY RESPIRATION

Respiration includes several processes which are listed below

i) **VENTILATION** is the breathing of air with more oxygen into the lungs (inspiration), it is followed by expulsion of air with more carbon-di-oxide (expiration).

ii) **DIFFUSION** of oxygen from the alveoli into the blood inside surrounding capillaries.

iii) **TRANSPORT** of oxygen by the blood to the heart through the pulmonary vein.

iv) **DISTRIBUTION** of oxygen by various arteries and their capillary network to all cells of the body. As the blood passes through tissue capillaries, it gives up oxygen (and nutrients such as glucose) to the body tissues and pick up the waste products of cellular respiration (Carbon dioxide and water).

v) **EXCHANGE** of the oxygen and carbon dioxide between blood and body cells. Within body cells glucose and oxygen take part in a complex series of reactions which provide energy to power the cells. During this cellular respiration glucose is converted to carbon dioxide and water (Enzymatic oxidation).

vi) **TRANSPORTING** blood with carbon dioxide. Carbon dioxide is carried back in the blood to the heart then to the lungs where it diffuses into the alveoli and is breathed out of the body (External respiration)

vii) **EXCHANGING** of carbon dioxide with oxygen at the alveolar surface.

viii) **EXPIRATION** of air with carbon dioxide from the lungs.

3.2.2. MECHANISM OF BREATHING

A. INHALATION

Inhalation is initiated by the diaphragm and supported by the external intercostal muscles. Normal resting respirations are 10 to 18 breaths per minute, with a time period of 2 seconds. Under normal conditions, the diaphragm is the primary driver of inhalation. When the diaphragm contracts, the ribcage expands and the contents of the abdomen are moved downward (Fig. 2a & 2b). This results in a larger thoracic volume and negative (suction) pressure (with respect to atmospheric pressure) inside the thorax. As the pressure in the chest falls, air moves into the conducting zone. Here, the air is filtered, warmed, and humidified as it flows to the lungs. During forced inhalation, as when taking a deep breath, the external intercostal muscles and accessory muscles aid in further expanding the thoracic cavity.

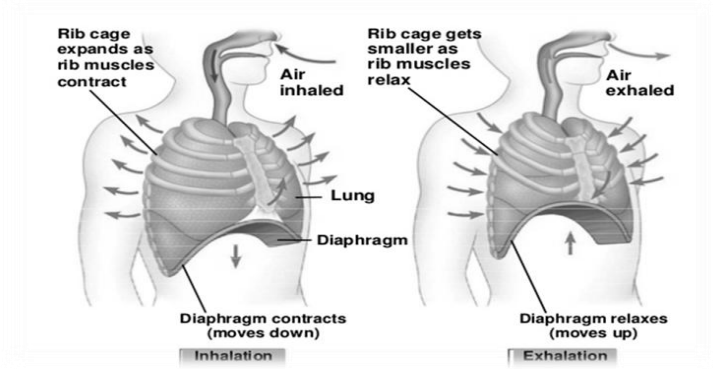


Fig. 2a. Process of ribcage expansion and relaxation during respiration

B. EXHALATION

Exhalation is generally a passive process; however, active or forced exhalation is achieved by the abdominal and the internal intercostal muscles. During this process air is forced or exhaled out. The lungs have a natural elasticity: as they recoil from the stretch of inhalation, air flows back out until the pressures in the chest and the atmosphere reach equilibrium. During exhalation ribcage muscles relax and the diaphragm moves up and relaxed (Fig. 2a & 2b).

During forced exhalation, as when blowing out a candle, expiratory muscles including the abdominal muscles and internal intercostal muscles generate abdominal and thoracic pressure, which forces air out of the lungs.

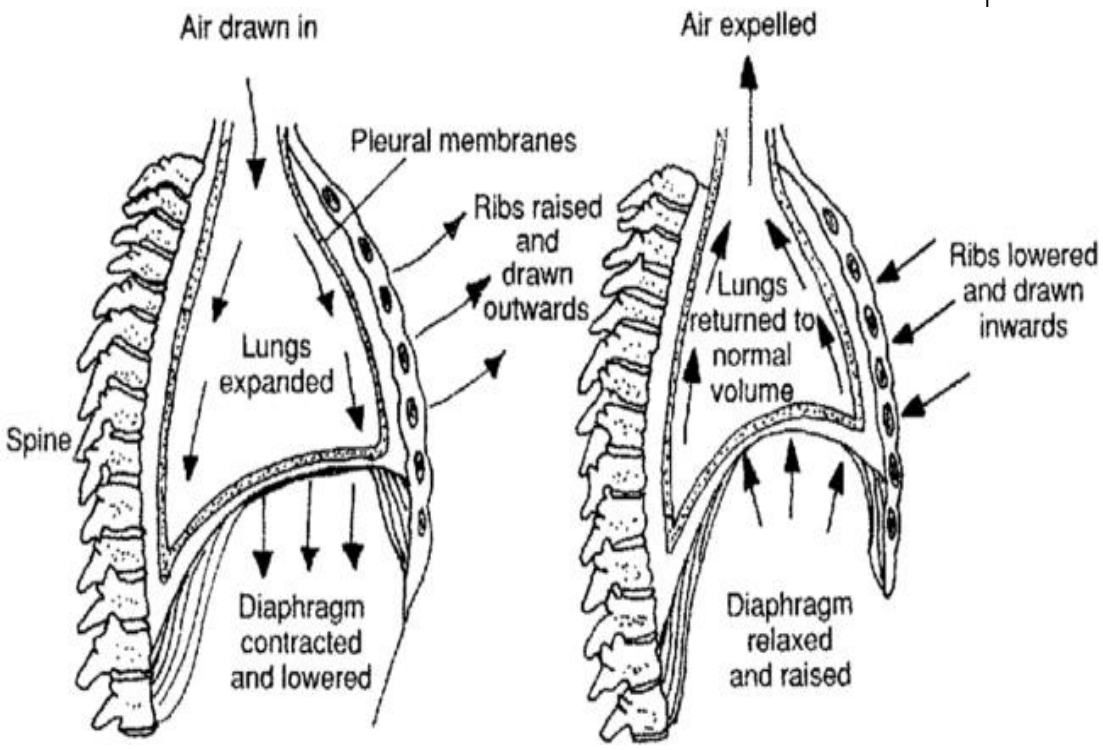


Fig.2.b. Contraction of diaphragm during inhalation and relaxation during exhalation

NOTES

3.3. TRANSPORT OF GASES

A. GAS EXCHANGE IN THE LUNGS

The major function of the respiratory system is gas exchange between the external environment and an organism's circulatory system. In humans and mammals, this exchange facilitates oxygenation of the blood with a concomitant removal of carbon dioxide and other gaseous metabolic wastes from the circulation. As gas exchange occurs, the acid-base balance of the body is maintained as part of homeostasis. If proper ventilation is not maintained, two opposing conditions could occur: respiratory acidosis, a life threatening condition, and respiratory alkalosis.

Upon inhalation, gas exchange occurs at the alveoli, the tiny sacs which are the basic functional component of the lungs. The alveolar walls are extremely thin (approx. 0.2 micrometres). These walls are composed of a single layer of epithelial cells (type I and type II epithelial cells) in close proximity to the pulmonary capillaries which are composed of a single layer of endothelial cells. The close proximity of these two cell types allows permeability to gases and, hence, gas exchange (Fig. 3). This whole mechanism of gas exchange is carried by the simple phenomenon of pressure difference. When the atmospheric pressure is low outside, the air from lungs flow out. When the air pressure is low inside, then the vice versa.

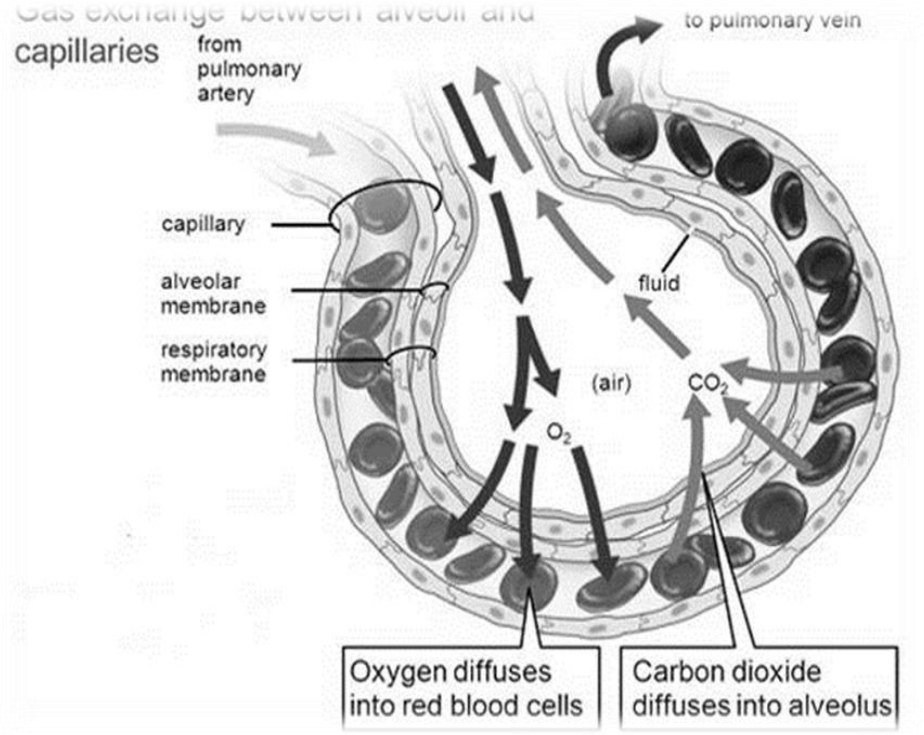


Fig. 3. Exchange of gases (O2 and CO2) between alveoli and capillaries

Gas exchange takes place at a respiratory surface—a boundary between the external environment and the interior of the organism. For unicellular

organisms the respiratory surface is governed by Fick's law, which determines that respiratory surfaces must have:

- a large surface area
- a thin permeable surface
- a moist exchange surface.

Many also have a mechanism to maximize the diffusion gradient by replenishing the source and/or sink.

B. RESPIRATORY PIGMENTS:

A respiratory pigment is a molecule, such as hemoglobin in humans, that increases the oxygen-carrying capacity of the blood. The four most common invertebrate respiratory pigments are hemoglobin, haemocyanin, haemerythrin and chlorocruorin. Hemoglobin is bright red when oxygenated, and dark red when deoxygenated, oxygenated haemocyanin is blue in color, deoxygenated is almost colorless. Oxygenated chlorocruarin turns green where oxygenated haemeryhrtin is a violet to pink colour, and colorless when deoxygenated. All vertebrates use the hemoglobin respiratory pigment.

Respiratory pigments such as hemoglobin and hemocyanin reversibly bind oxygen in the blood of many animals. This binding facilitates the transport of oxygen from the respiratory surfaces to the inner tissues. The oxygen binding properties of respiratory pigments are dependent upon both the partial pressure of oxygen and the pH of the blood. At equilibrium, the proportion of oxygenated to deoxygenated respiratory pigment has a sigmoid relation to the partial pressure of oxygen (PO2). When all of the respiratory pigment is combined with oxygen, the respiratory pigment is said to be saturated. Shifts in blood pH can affect this equilibrium, causing more or less O_2 to bind to the pigment at any given PO_2. It is the changing nature of these binding properties that facilitates the uptake of environmental oxygen at the respiratory surfaces and its subsequent release in the inner tissues.

C. FUNCTIONS OF RESPIRATION:

I) EXCHANGE OF GASES

Between the process of inspiration and expiration the interchange of respiratory gases occurs. This interchange takes place between the blood in the capillary network which surrounds the alveoli, and the air in the alveoli of the lungs. In external as well as internal respiration, gases always tend to diffuse from a high partial pressure to a lower partial pressure, i.e., down the concentration gradient. The atmospheric pressure at sea level is 760 mm Hg. In this partial pressure of oxygen is 159.2 mm Hg and carbon dioxide is 0.3 mm Hg.

The gas pressure in the blood are usually expressed as gas “tensions”, for example, the CO_2 “tension” (PCO_2) is the pressure of the dry gas (mm HG) with which the dissolved carbonic acid in the blood is in equilibrium; similarly PO_2 (oxygen tension) is the pressure of the dry gas with which the dissolved oxygen in the blood is in equilibrium.

The gases diffuse down the concentration gradient, oxygen diffuses from the alveoli into the blood in the venous capillaries of lungs and carbon dioxide from the blood to the alveoli. The exchange takes place during external respiration as follows,

1. Oxygen tension in alveolar air = 107 mm Hg

   Oxygen tension in venous blood = 40 mm Hg

A pressure difference of 6o mm Hg serves to drive oxygen from the alveoli of the lung into the blood.

2. CO_2 tension in alveolar air = 40 mm Hg

   CO_2 tension in venous blood = 46mm Hg

A relatively small difference of 6mm Hg is sufficient to drive CO_2 from the blood into the lung. This small difference in pressure is adequate because of the rapidity of the diffusion of CO_2 through the alveolar membrane.

By this mechanism carbon dioxide is excreted from the body and oxygen is absorbed and transported round the body in combination with haemoglobin in the erythrocytes. The blood, therefore, now becomes arterial. It has an oxygen tension of about 100 mm Hg and CO_2 tension of 40mm Hg. These gases are dissolved in the blood in simple physical solution. Exchange of gases between the blood and tissue cells during internal respiration takes place again in accordance with the usual physical laws of diffusion. Here, the concentration of O_2 is higher in the blood than in the tissue cells and concentration of CO_2 is greater in the tissue cells than in the blood. Oxygen, therefore, diffuses from the blood into the tissues and CO_2 from tissue cells into blood, at the same time through the intestinal fluid. Oxygen, thus received by tissue cells is utilized in oxidative metabolism producing energy and CO_2. This phenomenon maintains oxygen gradient between the blood and tissue cells and the CO_2 gradient between tissue cells and the blood.

2) THE TRANSPORT OF OXYGEN BY THE BLOOD

Oxygen is transported in the blood by respiratory pigment haemoglobin, which is a conjugated protein, the chromoprotein. Haemoglobin consists of a large protein molecule, the globin consisting of 4 polypeptide chains (two α and two β chains), to each of which is attached a prosthetic heam group.

Haem is based on a structure known as a prophyrin ring which includes 4 pyrrole groups around a central ferrous iron, Fe^{2+}. The iron is joined by four of its coordination bonds to N atoms of the porphyrin and the two bonds to imidazole N contained in histidine residues within the protein globin.

Transport of oxygen by the blood from the lungs to the tissues is due mainly to the ability of haemoglobin to combine reversible with oxygen. When haemoglobin is oxygenated, one of the immidazole N bonds is reversible displaced by O_2. The reaction is thus a reversible oxygenation and not an oxidation. Similarly, reduction is not involved when O_2 is given up.

In one molecule of haemoglobin has 4 haem groups, and each of them is capable of taking up one molecule of O_2; therefore, a mammalian haemoglobin should be depicted as Hb_4O_8.

$$Hb + 4O_2 \longleftrightarrow Hb_4O_8$$

(Deoxygenated or (Oxyhaemoglobin) reduced haemoglobin)

Haemoglobin is dark red, whereas oxyhaemoglobin is bright red in colour.

(i) Formation of oxyhaemoglobin in lungs. This takes place due to three factors:

a. Normal pH of the blood, i,e., 7.4.

b. comparatively lower temperature than other parts of the body.

c. High O_2, low CO_2 concentration (tension)

(ii) Dissociation of oxyhaemoglobin in tissues. Three factors account for this process.

a. Slightly acidic pH due to increase in H^+ concentration:

CO_2 produced in the course of metabolism enters the blood where it hydrated to form carbonic acid, which ionizes to form H^+ and HCO_{3-}

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_{3-}$$

b. Rise in temperature.

c. High CO_2, low O_2 tension.

3, MAXIMUM AMOUNT OF O_2 THAT CAN COMBINE WITH THE HAEMOGLOBIN OF BLOOD

The blood of a normal person contains about 15 gm of Hb in each 100 ml of blood. One gm of Hb binds to 1.34 ml of O_2 when fully saturated. Thus 100 ml of pre blood can combine with 20 ml of O_2, when Hb is 100% saturated.

On passing through tissue capillaries, this amount is reduced to 14.4 ml. Thus 5ml of O_2 is transported from the lungs to the tissue by each 100 ml of blood.

4, OXYGEN-HAEMOGLOBIN DISSOCIATION CURVE

The oxygen haemoglobin dissociation curve demonstrates a progressive increase in the percentage of haemoglobin bound with oxygen as the blood PO_2 increases, which is called the percent saturation of the haemoglobin. As the blood leaving the lungs and enterin g the systemic arteries usually has a PO_2 of about 95mm Hg, it can be observed from the dissociation curve that the usual oxygen saturation of systemic arterial blood is about 97 percent. On the other hand, in normal venous blood returning from the peripheral tissues, the PO_2 is about 40 mm Hg, and the saturation of the haemoglobin is about 75 percent. Haemoglobin in the blood automatically

NOTES

delivers O_2 to the tissues at a pressure that is held tightly between about 15 and 45 mm Hg. The curve drawn with CO_2 at a tension of 40 mm Hg is considered as representative of the normal physiologic condition.

5, FACTORS THAT SHIFT THE OXYGEN-HAEMOGLOBIN DISSOCIATION CURVE

A number of factors can displace the dissociation curve in one direction or the other. When the blood becomes slightly acidic, with the pH decreasing from the normal value of 7.4 to 7.2, the oxygen-haemoglobin dissociation curve shifts, on average about 15 percent to the right. Conversely, an increase in the pH from the normal 7.4 to 7.6 shifts the curve similar amount to the left.

In addition to pH changes, several other factors are known to shift the curve. Three of these, all of which shift the curve to the right, are (1) increased carbon dioxide concentration, (2) increased blood pressure, and (3) increased 2,3-diphosphoglycerate (DPG), a metabolically important phosphate compound present in the blood but in different concentration under different metabolic conditions.

Increased delivery of oxygen to the tissues when carbon dioxide and hydrogen ions shift the oxygen-haemoglobin dissociation curve- **The Bohr Effect.** A shift of the oxygen haemoglobin dissociation curve in response to changes in the blood carbon dioxide and hydrogen ions has a significant effect in enhancing oxygenation of the blood in the lungs and then again in enhancing release of oxygen from blood in the tissues. This is called Bohr Effect. This can be explained as follows:

As the blood passes through the lungs, carbon dioxide diffuses from the blood into the alveoli. This reduces the blood PCO_2 and decreases the hydrogen ion concentration because of the resulting decrease in blood carbonic acid. Both these effects shift the oxygen-haemoglobin dissociation curve to the left and upward. Therefore, the quantity of oxygen that binds with the haemoglobin at any given alveolar PO_2 now becomes considerably increased, thus allowing greater oxygen transport to the tissues.

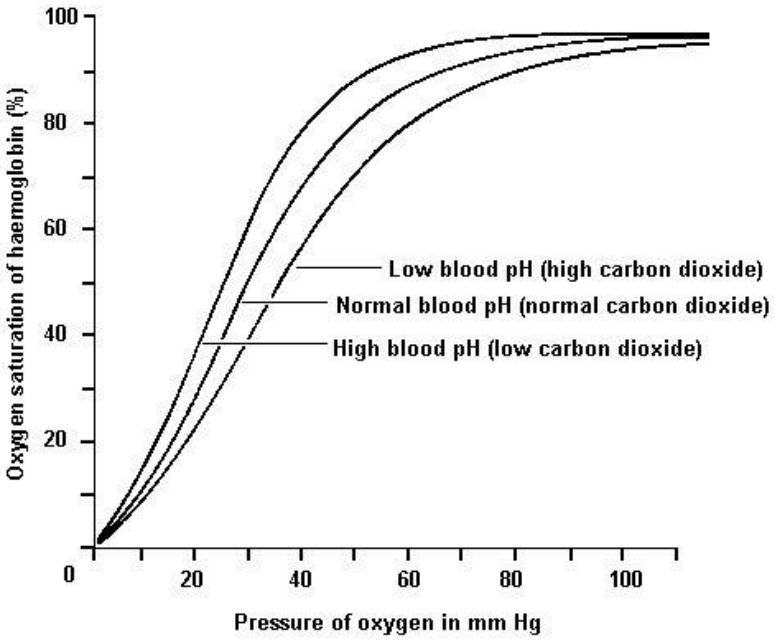


Fig. 4. Shift of Oxygen-haemoglobin dissociation curve to the left by high pH and low carbon dioxide.

3.4. CONTROL OF RESPIRATION

Oxygen must be supplied continuously and the amount of Oxygen present in the lungs, tissues and blood is only 1200ml which is enough for only 5 minutes. Oxygen deprivation causes loss of consciousness within 20 seconds and irreversible brain damage within about 4 minutes.

Respiration of lungs is under the control of the autonomic nervous system from parts of the brain stem, the medulla oblongata and the pons. This area of the brain forms the respiration regulatory center, a series of interconnected brain cells within the lower and middle brain stem which coordinate respiratory movements. The sections are the pneumotaxic center, the apneaustic center, and the dorsal and ventral respiratory groups. The activity of the respiration centre is modified by the chemical composition of its fluid environment, as well as by the nervous influences.

Control of respiration is due to rhythmical breathing generated by the phrenic nerve in order to stimulate contraction and relaxation of the diaphragm during inspiration and expiration. Ventilation is controlled by partial pressures of oxygen and carbon dioxide and the concentration of hydrogen ions. The control of respiration can vary in certain circumstances such as during exercise.

3.5 LET US SUM UP

Respiration is the process of receiving oxygen and releasing carbon dioxide to the surrounding environment. This can be classified into external respiration and internal respiration. External respiration is carried out by the lungs and its accessory structures. The internal respiration is called as cellular respiration carried out by the blood and the cells of the tissues. The normal breathing consist of inhalation and exhalation. The

intercostal muscles, diaphragm and ribcage assist the inhalation and exhalation. The gas exchange takes place in the moist surface of alveoli. The respiratory pigments in the RBC helps to carry oxygenated blood to the tissues. The respiration is controlled by the autonomic nervous system which is located in the brain stem, medulla oblongata and the pons.

3.6. UNIT-END EXERCISES

1. The process of removing carbon dioxide from the body occurs during

a. Inhalation b. exhalation c. absorption d. assimilation

2. In higher elevation more haemoglobin is needed to carry Oxygen because

a. More carbon dioxide present b. More oxygen present c. low partial pressure of oxygen d. none of the above

3. During inhalation the diaphragm ----------

a. Contracts b. Expands c. No change d. Relax

4. The Oxygen dissociation curve is inversely related to pH and carbon dioxide concentration is called----------

a. pH effect b. Carbon effect c. Chloride shift d. Bohr's effect

3.7. ANSWERS TO CHECK YOUR PROGRESS

1. b, 2. c, 3. a, 4. d

3.8 SUGGESTED READINGS

Hall, J. E. 2015. Guyton and Hall Text book of Medical Physiology, 13th Edition, Relx India Pvt. Ltd.

Verma, P.S., B.S. Tyagi, V. K. Agarwal, 2000. Animal Physiology, S. Chand & Co. India.

Rastogi, S. L. 1997. Essential of Animal Physiology, New Age International Publishers, India.

UNIT IV- EXCRETARY SYSTEM OF HUMAN

Structure

4.1 INTRODUCTION TO EXCRETORY SYSTEM

Excretion may be defined as the separation and elimination of the nitrogenous metabolic wastes from the body. The wastes eliminated are called excretory products. Metabolism produces a great variety of substances in addition to energy. Some of these metabolic by products and end products are reutilized for metabolic activities. But certain byproducts and end products of metabolism are toxic and they will poison the body tissues if retained. Hence these substances are eliminated from the body through excretion. The organs concerned with excretion are called excretory organs.

The organs involved in excretion are the kidneys, lungs, skin, and also liver, gastrointestinal tract and salivary glands. Among them kidneys are the chief excretory organs. The remove the waste products like nonvolatile fixed acids, nitrogenous wastes and sulfur containing products produced by metabolism. They maintain the water balance and osmotic equilibrium in the body.

4.1.1. KIDNEY AND ITS ROLE IN EXCRETION

The **kidneys** are paired organs with several functions. They are an essential part of the urinary system and also serve homeostatic functions such as the regulation of electrolytes, maintenance of acid-base balance, and regulation of blood pressure. They serve the body as a natural filter of the blood, and remove wastes which are diverted to the urinary bladder. In producing urine, the kidneys excrete wastes such as urea and ammonium; the kidneys also are responsible for the reabsorption of water, glucose, and amino acids. The kidneys also produce hormones including calcitriol and erythropoietin.

A, LOCATION

In humans, the kidneys are located in the abdominal cavity, in a space called the retroperitoneum. There are two, one on each side of the spine; they are approximately at the vertebral level T12 to L3. The right kidney sits just below the diaphragm and posterior to the liver, the left below the diaphragm and posterior to the spleen. Resting on top of each kidney is an adrenal gland. The asymmetry within the abdominal cavity caused by the

liver typically results in the right kidney being slightly lower than the left, and left kidney being located slightly more medial than the right. The upper (cranial) parts of the kidneys are partially protected by the eleventh and twelfth ribs, and each whole kidney and adrenal gland are surrounded by two layers of fat (the perirenal and pararenal fat) and the renal fascia. Each adult kidney weighs between 125 and 170 grams in males and between 115 and 155 grams in females. The left kidney is typically slightly larger than the right.

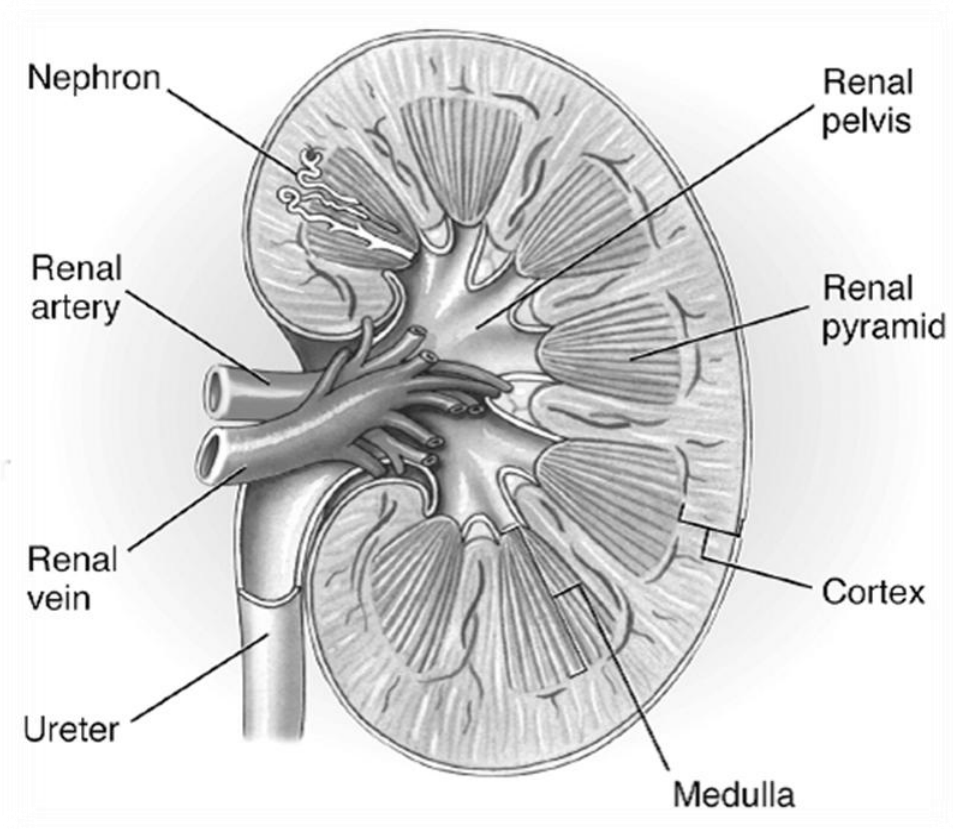


Fig. 5. Structure of a human kidney

B, STRUCTURE

The kidney has a bean-shaped structure, each kidney has concave and convex surfaces. The concave surface, the renal hilum, is the point at which the renal artery enters the organ, and the renal vein and ureter leave (Fig. 5). The kidney is surrounded by tough fibrous tissue, the renal capsule, which is itself surrounded by perinephric fat, renal fascia (of Gerota) and paranephric fat.

The kidney is approximately 11–14 cm in length, 6 cm wide and 3 cm thick. The substance, or parenchyma, of the kidney is divided into two major structures: superficial is the renal cortex and deep is the renal medulla. Grossly, these structures take the shape of 8 to 18 cone-shaped renal lobes, each containing renal cortex surrounding a portion of medulla called a renal pyramid (of Malpighi). Between the renal pyramids are projections of cortex called renal columns. Nephrons, the urine-producing functional structures of the kidney, span the cortex and medulla. The initial filtering portion of a nephron is the renal corpuscle, located in the cortex,

which is followed by a renal tubule that passes from the cortex deep into the medullary pyramids. Part of the renal cortex, a medullary ray is a collection of renal tubules that drain into a single collecting duct.

C, FUNCTIONS

The kidney participates in whole-body homeostasis, regulating acid-base balance, electrolyte concentrations, extracellular fluid volume, and regulation of blood pressure. The kidney accomplishes these homeostatic functions both independently and in concert with other organs, particularly those of the endocrine system. Various endocrine hormones coordinate these endocrine functions; these include renin, angiotensin II, aldosterone, antidiuretic hormone, and atrial natriuretic peptide, among others.

Many of the kidney's functions are accomplished by relatively simple mechanisms of filtration, reabsorption, and secretion, which take place in the nephron. Filtration, which takes place at the renal corpuscle, is the process by which cells and large proteins are filtered from the blood to make an ultrafiltrate that will eventually become urine. The kidney generates 180 liters of filtrate a day, while reabsorbing a large percentage, allowing for only the generation of approximately 2 liters of urine. Reabsorption is the transport of molecules from this ultrafiltrate and into the blood. Secretion is the reverse process, in which molecules are transported in the opposite direction, from the blood into the urine.

4.2. STRUCTURE AND FUNCTION OF NEPHRON

Nephron is the structural and functional unit of kidney. It is also called uriniferous tubule. Each kidney of man is formed of about 1.3million Nephrons. Each Nephron has the length of 4cm. Total length of all the Nephron will be about 65km. In human kidney the nephrons are present in the cortex region. Based on their position they are divided into two types they are 1. Cortical nephrons, which are found on the outer cortex of kidney. 85% of the nephrons are this type. 2. Justamudullary nephrons are the nephrons located in the inner cortex near medulla.

Each Nephron is made up of two components called Malpighian corpuscle and renal tubule. The **Malphigian corpuscle** is divided into the glomerular capillaries or **glomerulus** and the **Bowman's capsule**. It is in the renal corpuscle that the blood is filtered at high pressure. The arteriole that brings blood into the glomerulus is called the afferent arteriole whereas the artery that takes blood away from the glomerulus is known as the efferent arteriole.

Between these arterioles forms, a network of capillaries called the glomerular capillaries or the glomerulus. The Bowman's capsule is a cup-shaped structure in which this glomerulus is located. The glomerulus along with the Bowman's capsule achieve the filtration of blood to form urine (Fig. 6).

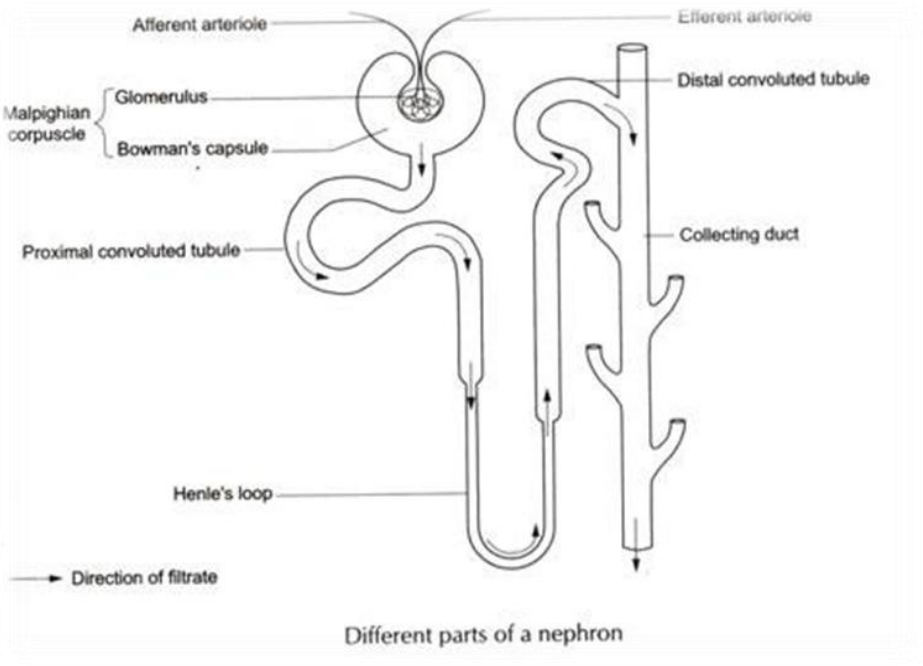


Fig. 6. The diagram illustrating the structure of Nephron

The renal tubule is formed of three components. They are 1. Proximal convoluted tubule, 2. Henle's loop and 3. Distal convoluted tubule.

4.2.1 PARTS OF NEPHRON

A, MALPHIGHIAN CORPUSCLE

The Malphighian corpuscle is a flattened spheroidal structure consisting of glomerulus and Bowman's capsule. It helps the filtration of blood, which is the first step in the formation of urine. The Malphighian corpuscle is also called as renal corpuscle (Fig. 6)

B, GLOMERULUS

The glomerulus is formed by a tuft of capillaries arising from the afferent arteriole. The glomerular capillaries join to form the efferent arteriole. The filtrate is formed from the blood passing through the glomerular capillaries with the help of the filtration membrane.

C, BOWMAN'S CAPSULE

Bowman's capsule is the blind end of the Nephron, which is funnel shaped. It encloses the glomerulus. It has an inner visceral layer covering the glomerulus and an outer parietal layer. The parietal layer is made up of simple squamous epithelial cells. The inner visceral layer covering the glomerulus has highly modified, branching epithelial cells called podocytes, podocites terminate in the foot process. The slit pores or filtration slits present between the foot processes of podocytes provide passage for the flow of plasma into Bowman's space.

D, PROXIMAL CONVOLUTED TUBULE (PCT)

The proximal convoluted tubule is the continuation of Bowman's capsule measuring about 15 mm. It is made up of proximal convoluted portion

called pars convolute and a straight portion called pars recta. The pars recta forms the first part of the descending limb of the loop of Henle.

The PCT is lined by a single layer of epitheial cells that are columnar in pars convolute and cuboidal in pars recta. The luminal surfaces of the lining cells have microvilli that give a brush-border appearance. The microvili increase the surface area of the cells. The cytoplasm of the cells is granular and the nucleus is situated toward the base. Functionally useful substances are absorbed from the part of the Nephron.

E, LOOP OF HENLE

The loop of Henle is the continuation of PCT. It is short in cortical nephrons and long in justamedullary nephrons. The loop of Henle has three parts, they are descending loop, hair pin loop and ascending loop.

The descending loop is thin walled and permeable to water. It is the continuation of pars recta of the PCT. The thin descending loop is variable in length and turns back to form thin ascending loop. The thin descending and short asending loops are lined by squamous epithelium. The thick ascending loop is the continuation of the thin ascending loop of Henle. The thick ascending loop is thick walled and impermeable to water. It is lined with columnar epithelium with few microvilli.

F. DISTAL CONVOLUTED TUBULE

Distal convoluted tubule (DCT) is the distal coiled part of the Nephron measuring about 5mm. It is lined by cuboidal cells. The cells lining the DCT resemble the cells of the thick ascending limb with few microvilli and mitochondira.

G. COLLECTING DUCT

The DCT continues as the collecting duct are made up of principal cells and intercalated cells. These cells contain an enzyme called carbonic anhydrase. In addition, the collecting duct has simple columnar cells. The collecting ducts receive the filtrate from the DCT and open into the renal pelvis. Two hormones, namely, ADH and aldosterone, act on this part of the Nephron.

4.3 URINE FORMATION AND REGULATION

4.3.1 FORMATION OF URINE

The formation of urine consist of three process. 1. The filtration of plasma in the glomerulus, 2. The selective reabsorption of substances such as salts, water, simple sugars and amino acids which are necessary to maintain internal environment, and 3. Secretion of waste product in the form of urine.

1. FILTRATION

The first step in the urine formation is filtration of the blood plasma. A large volume of blood, approximately 1 litre/ minute flows through the kidneys at rest. Filtration takes place through the semipermiable walls of the Glomerulus and the Bowman's capsule. Each glomerulus receives blood from the afferent arteriole and discharges the blood into the efferent

NOTES

arteriole. The molecular weight of the substance present in the blood determines whether it is possible for it to pass through the filter.

Substances of the low molecular weight filter from the blood into Bowman's capsule due to effective filtration pressure. These include water, amino acids, salts, fatty acids, glucose, urea, uric acid, creatinine etc. The constituent of the blood which are of high molecular weight such as the red blood corpuscles, white blood cells and plasma proteins do not leave the glomerulus as they are unable to pass through this semipermeable membrane.

2. **SELECTIVE REABSORPTION**

The glomerular filtrate contains many substances necessary for the normal metabolism, such as water, glucose, amino acids and electrolytes as well as substances to be excreted and removed such as urea, creatinine, and uric acid., Selective reabsorption is the process by which the essential constituents of the glomirular filtrate are reabsorbed in to the body during the passage through the nephrons. It is also significant in the fluid and electrolyte maintenance and the maintain the alkaline pH of the blood (pH 7.4).

In the proximal convoluted tubule sodium chloride, glucose, aminoacids and water first diffuse passively into the epithelial cell from the tubular lumen. Sodium, glucose and amino acids are then actively transported into the intercellular space. Chloride moves passively by diffusion with the electrochemical gradient. About 65% if the water in the nephric filtrate is reabsorbed by the proximal tubules. This fraction is referred as obligatory water reaabsorption.

3. SECRETION

Secretion is the release of waste materials in the blood to the urinary bladder through the Nephron. The secretary products contain aminohippuric acid, Potassium, ammonia, creatinine, phosphates and Urea. These waste materials are excreted by mammals as urine.

4.3.2 REGULATION OF URINE FORMATION

The cortex of the kidney produce one proteolytic enzyme called rennin, which is secreted into the blood through renal vein. In the blood rennin acts on a globulin called Angiosteninogen and split it into Angiostenin I and Angiostenin II. Angiostenin II increases the heart beat force and raises the blood pressure. It also acted upon the adrenal cortex and stimulate the release of the electrolyte regulating hormone Aldosterone. Aldosterone, by causing the retention of sodium and water by kidney tubules, tends to increase the blood volume, which in turn, raises the blood pressure and reduces the rennin production.

Another Pituitary hormone called Antidiuretic hormone (ADH) regulates water reabsorption in the distal tubules and collecting ducts aided by the osmoreceptors located in the anterior hypothalamic region of the brain. If the osmotic pressure of the blood is raised , the osmoreceptors in the hypothalamus are stimulated and there is an increase in the output of ADH by Pituitary gland. In turn, ADH increases the permeability of distal and collecting ducts to water, leading to the production of scanty concentrated urine. On the other hand, if the osmotic pressure of the blood is reduced as

by the ingestion of large amounts of water, the osmo-receptors are depressed and inhibit pituitary secretion of ADH. The resultant suppression of ADH then permits excretion of more water in the distal and collecting ducts by impairing water reabsorption, thus, a large volume of dilute urine results.

4.4. LET US SUM UP

Excretion is the process of elimination of nitrogenous waste products produced in the body during metabolic activities. The important organ involved in the excretion is kidney. Kidney is involved in the homeostatic functions such as regulation of electrolytes, maintenance of acid base balance and the regulation of blood pressure. All vertebrates have pair of kidney, which is a bean shaped structure. Many of the kidney's functions are accomplished by the relatively simple mechanism of filtration, resorbtion and secretion, which is taken place in the Nephron, the structural and functional unit of kidney. Nephron is made up of two components called the malphigian corpuscle and renal tubule. The Malphigian corpuscle is made up of glomerulus and Bowman's capsule. The renal tubule is made up of three compartments, the proximal convoluted tubule, Henle's loop and distal convoluted tubule. The formation of urine consist of filtration, selective resorption and secretion of waste product in the form of urine. The urine formation is regulated by Aldosterone and Antidiuretic hormones.

4.5 UNIT-END EXERCISES

1. In humans the nitrogenous waste product removed in the form of

   a. ammonia b. Uric acid c. Urea d. Carbon dioxide

2. Each kidney is made up of large number of excretory units called

   a. Bowman's capsule b. Glomerulus c. blood capillaries d. Nephron

3. Which vessel carry blood to the kidneys

   a. Renal artery b. Renal vein c. Aorta b. Radial artery

4. This is not present in the Nephron

   a. Bowman's capsule, b. Flame cell c. Glomerulus d. Henle's loop

4.6. ANSWER TO CHECK YOUR PROGRESS

1. c, 2. d, 3. a, 4.b

4.7 SUGGESTED READINGS

Hall, J. E. 2015. Guyton and Hall Text book of Medical Physiology, 13th Edition, Relx India Pvt. Ltd.

Verma, P.S., B.S. Tyagi, V. K. Agarwal, 2000. Animal Physiology, S. Chand & Co. India.

Randall, D., Burggren, W. & K. French. 2002. Eckert Animal Physiology, W. H. Freeman and Company, New York.

BLOCK II

CARDIOVASCULAR SYSTEM AND NERVOUS SYSTEM

NOTES

UNIT - V BLOOD

Structure

5.1 INTRODUCTION TO BLOOD

Blood is a fluid connective tissue circulating in the body. It provides one of the methods of communication between the cells of different parts of the body. The blood carries oxygen and nutrients to the tissues and carbon dioxide and waste products from the tissues to the excretory organs. In addition it conveys antibodies to the site of injury or disease and hormones or chemical messengers from the endocrine glands to various target organs. The blood is the medium of transportation to all these substances.

The average human adult has more than 5 liters of blood in his or her body. Blood carries oxygen and nutrients to living cells and takes away their waste products. It also delivers immune cells to fight infections and contains platelets that can form a plug in a damaged blood vessel to prevent blood loss. Through the circulatory system, blood adapts to the body's needs. When you are exercising, your heart pumps harder and faster to provide more blood and hence oxygen to your muscles. During an infection, the blood delivers more immune cells to the site of infection, where they accumulate to ward off harmful invaders.

5.2. BLOOD COMPOSITION

The blood is composed of faintly yellow transparent fluid known as plasma and numerous cells or corpuscles of different kinds floating in this liquid medium. The fluid plasma constitutes about 55% and the remaining 45% are occupied by corpuscles in the blood. The three main components of the blood are erythrocytes or red blood cells, leucocytes or white blood cells and blood platelets.

5.2.1 ERYTHROCYTES OR RED BLOOD CORPUSCLES

In humans red blood cells lacks the nucleus. However, absence of nucleus increases the respiratory efficiency of the red blood corpuscles. All the vertebrates other than mammals have nucleated red cells. The red blood cells are biconcave non nucleated cells. The central part of the corpuscle is much thinner than the circumference, thus the term biconcave. In edge view the outline is like that of a dumb bell. This shape favours the flexibility and the absorbing and releasing of gases quickly.

The red corpuscles are soft and flexible. They withstand much bending, squeezing and deformation as they are pushed through the narrow capillaries. The respiratory pigment of red corpuscle is haemoglobin. It is a complex protein having iron as one of the main constituents. In adults red blood cells are mostly produced in the red bone marrow and this process is called erythropoiesis. This also controlled by a feed back mechanism. Deficiency of Oxygen following haemorrhage or if an individual lives at higher elevation where the Oxygen pressure in the atmosphere is low, more RBC are produced. Other than that a hormone secreted by the kidney called erythropoietin also increase the production of erythrocytes.

The normal erythrocyte count is usually higher in men compared to women and having 5 to 5.5 million per cubic millimeter of blood. The number varies with different pathological and pathological conditions. An abnormal raise in RBC count is called polycythemia.

The life span of human erythrocytes is approximately 120 days. After that, these cells break down in the spleen. The protein part of the erythrocyte is converted into biliveridin, which is converted into a yellow pigment called bilirubin. This is carried by spleanic and portal veins to the liver, where it is again changed into conjugated form and excreted in the bile as bile pigment.

5.2.2. LEUCOCYTES OR WHITE BLOOD CELLS

Unlike RBC the white blood cells or leucocytes contain a nucleus. The leucocytes resembles the amoeba cells. They vary in size from 8 to 15 µ. The average number of WBC is between 6,000 to 10,000 numbers per cubic millimeter of blood. In pathogenic condition there is the variation from the normal number. An increase in the number of white blood cells is called leucocytosis. A decrease below 6,000 is called leucophenia as in typhoid fever.

The WBCs are divided as granular polymorphonuclear leucocytes and agranular or Mononuclear leucocytes.

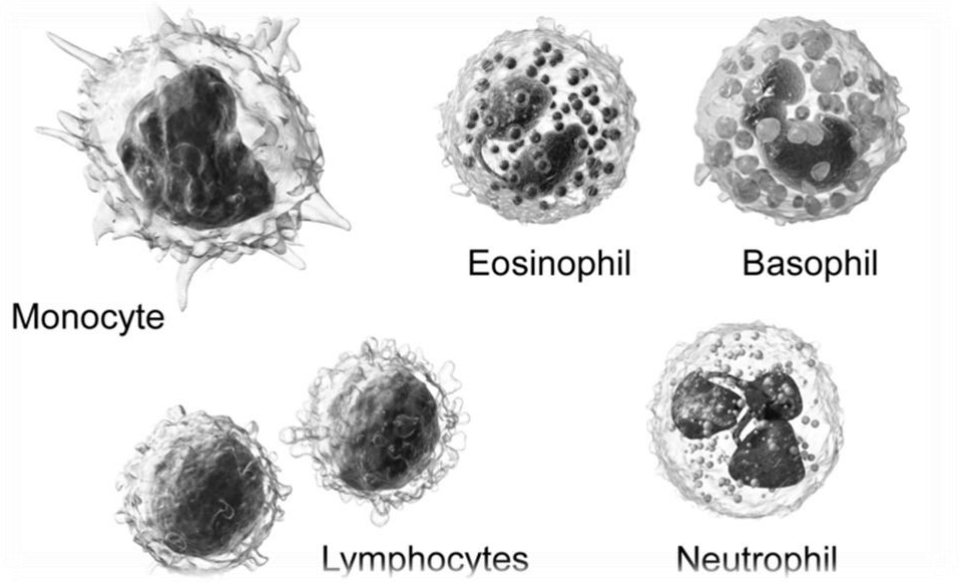


Fig. 7. White blood corpuscles

1. GRANULAR LEUCOCYTES

These cells are developed from the red bone marrow. The granulocytes constitute about 75% of the total white blood cells. Among them Neutrophils constitute approximately 70% followed by Eosnophils (4%) and Basophils (1%) (Fig. 7)

(A) NEUTROPHILS

The cytoplasm of Neurtophils are closely packed with fine, inconspicuous granules that absorb both acidic and alkaline dyes, thus producing neutral purple colour. The nucleus has three to five lobes connected by thin chromatin strands. Fewer lobe indicate less mature cells. About three percent of nuetrophils from a female show the sex chromosome attached to one end of the nuclear lobe by a thin stalk forming the so called "drumstick chromosome.

Neutrophils protect the body against the invasions of bacteria. They are attached in large numbers to any area of the body which has been invaded micro-organism. Neutrophils leave the blood by squeezing themselves out through the walls of the capillaries in the infected area. This process is known as diapedisis. Thereafter they kill the organisms by digesting them by means of various enzymes, a process known as phagocytosis. The pus which may exude from an infected area consists of destroyed tissue, live micro organisms and dead neutrophils which have ingested more microorganisms than they could diget. The life span of neutrophils which remain in blood vessels is about 30 hours. After migrating from the blood capillaries into the inflamed tissue, they play a defensive role there and soon die.

B) EOSINOPHILS

The diameter of the cell is nearly twice that of the red blood corpuscle. The cytoplasm is packed with coarse round granules which absorb acid dye such as eosin which is red. The nucleus is bilobed with a connecting isthmus. Eosnophils engulf the particles which are formed when antigens

and antibodies react with each other. In allergic conditions such as asthma and parasitic infections of the digestive tract they are increased in numbers.

C) BASOPHILS

The cytoplasmic granules absorb an alkaline or basic dye such as methylene blue and are stain dark blue or purple in colour. The granules The granules are not as numerous as in eosnophils but they are large, spherical and almost cover the nucleus which is generally, S. shaped. Basophils are actively amoeboid and ingest small particles like carbon.

2. AGRANULAR LEUCOCYTES

They have few non-specific or no granules in the cytoplasm and the nucleus is spherical to kidney shaped. They comprise about 25% of the leucocytes.

A) LYMPHOCYTES

There are two types of lymphocytes and they are classified as small and large lymphocytes. Small lymphocytes are mostly found in the blood. It has a large nucleus surrounded by narrow rim of basophilic cytoplasm. The nucleus is dense and dark because of heavy chromatin masses. Large lymphocytes are primitive cells residing in the lymph nodes that give rise to the active small lymphocytes. The nucleus is largely kidney shaped.

B) MONOCYTES

Monocytes are largest of leucocytes and are relatively few in number. The nucleus varies from oval, round or indented to kidney shape and stains lightly than that of the lymphocytes. The abundant cytoplasm is slightly basophilic. Their function is closely resembled that of the neutrophils in that that they are actively mobile, phagocytic in action and will leave blood capillaries to ingest microorganisms and other foreign particles that may introduced into the tissue.

5.2.3 BLOOD PLATELETS

Platelets arise from the megakaryocytes. They are 2-3 µ in diameter. There are approximately 300,000 platelets in the cubic millimeter of blood. The platelets are associated with blood clotting, both inside and outside of the blood vessals.

5.2.4. BLOOD PLASMA

Blood plasma contains 90 to 92% water. Other constituents include blood proteins. They are serum albumin, which is derived from liver, serum globulin derived from lymphocytes, fibrinogen, which is derived from liver helpful for blood clotting and prothrombin, which served as factor II in the blood clotting which is also derived from liver. The blood plasma gives viscosity to the blood and also helpful to maintain the blood pressure. The plasma also contains minerals such as sodium chloride, sodium carbonate, potassium, magnesium etc which involve in the physiological process. Nutrient materials such as carbohydrate, protein and fats to maintain the body functions. Other than hormones, enzymes, antibodies and gasses are also present in the blood plasma.

NOTES

5.3 HAEMOPOIESIS

Haemopoiesis is derived from the Greek words for 'blood' and 'tomake'. The bone marrow is the chief source of blood cells in children and adults. Cells are derived from the progressive differentiation of primitive haemopoietic stem cells, in the presence of soluble and cellular signals, and expression of key transcription factors. All skeletal bones are active sites of haemopoiesis in children, whereas in adults this is limited to a few sites such as the skull, vertebrae, ribs and scapulae. Haemopoietic tissue occupies most of the bone marrow in children, whereas this declines progressively in adults.

Haemopoiesis takes place in the honeycomb spaces of trabecular bone, interspersed with fat cells that increase in number with age. The bone marrow microenvironment forms a stem cell niche around self-renewing haemopoietic progenitor cells and is important for controlling appropriate blood cell production. Haemopoiesis is considered to be clonal. A single multipotent stem cell is capable of repopulating the entire haemopoietic system, forming blood and immune cells. A multipotent haemopoietic stem cell can self-renew or differentiate into a multipotent progenitor (MPP). MPP differentiation produces common myeloid progenitors and common lymphoid progenitors.

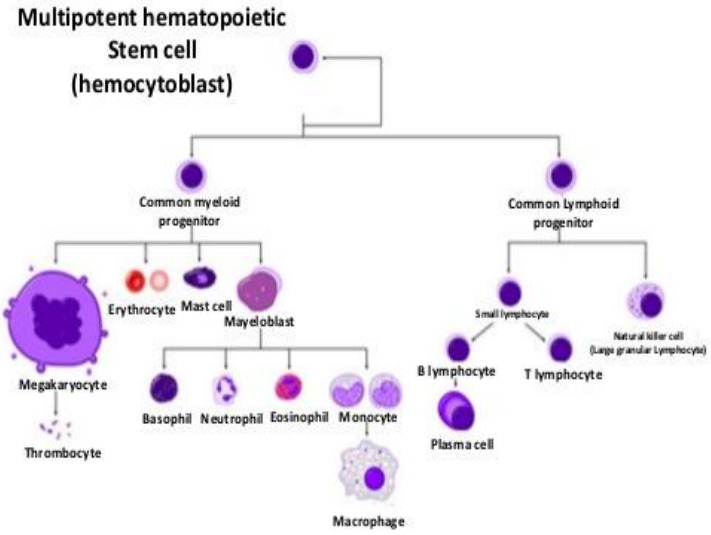


Fig. 8. Haematopoiesis from pluripotent stem cell

Haemopoietic stem cells differentiate into MPPs, then Common myeloid progenitors CMPs, then megakaryocyte erythroid progenitors (MEPs), then megakaryocytes and finally platelets (Fig. 8). Thrombopoietin (TPO), interleukin (IL)-6 and other cytokines and soluble growth factors stimulate maturation of megakaryocytes, where rounds of DNA replication occur without intervening cell divisions; this forms polypoid cells that have up to 64N. The resulting abundant cytoplasm facilitates the maturation of platelets. Megakaryocytes release platelets by

crashing into sinusoids, so nuclei enter the circulation, being cleared by pulmonary macrophages.

Erythropoietin (Epo) is chiefly produced by renal peritubular interstitial cells (and to some extent hepatocytes) in response to tissue hypoxia, through up-regulation of hypoxia-inducible factor 1 (HIF1). The von HippeleLindau tumour suppressor gene (VHL) negatively regulates HIF1 via an E3 ubiquitin ligase. Epo is necessary for the differentiation of all stages of red cell development from the erythroid colony-forming unit phase onwards. This phase is preceded by the erythroid burst-forming unit stage. Red cell formation often occurs around a macrophage, which contains iron stores.

In summary, form the haemotopoietic stem cells, lymphoid progenitor and the myeloid progenitors are formed. From the lymphoid progenetors, the lymphocytes and natural killer cells are formed. The Myaloid progenitor is divided into Megakaryocyte progenitor which produce platelets, erythroid progenitor which produce the red blood cells and Myaloblasts, which produce macropages (Fig. 8)

5.4 FORMED ELEMENTS

The formed elements are cells and cell fragments suspended in the plasma. The three classes of formed elements are the erythrocytes (red blood cells), leukocytes (white blood cells), and the thrombocytes (platelets).

Erythrocytes, or red blood cells, are the most numerous of the formed elements. Erythrocytes are tiny biconcave disks, thin in the middle and thicker around the periphery. The shape provides a combination of flexibility for moving through tiny capillaries with a maximum surface area for the diffusion of gases. The primary function of erythrocytes is to transport oxygen and, to a lesser extent, carbon dioxide.

Leukocytes, or white blood cells, are generally larger than erythrocytes, but they are fewer in number. Even though they are considered to be blood cells, leukocytes do most of their work in the tissues. They use the blood as a transport medium. Some are phagocytic, others produce antibodies; some secrete histamine and heparin, and others neutralize histamine. Leukocytes are able to move through the capillary walls into the tissue spaces, a process called diapedesis. In the tissue spaces they provide a defense against organisms that cause disease and either promote or inhibit inflammatory responses. There are two main groups of leukocytes in the blood. The cells that develop granules in the cytoplasm are called granulocytes and those that do not have granules are called agranulocytes. Neutrophils, eosinophils, and basophils are granulocytes. Monocytes and lymphocytes are agranulocytes.

Neutrophils, the most numerous leukocytes, are phagocytic and have light-colored granules. Eosinophils have granules and help counteract the effects of histamine. Basophils secrete histomine and heparin and have blue granules. In the tissues, they are called mast cells. Lymphocytes are agranulocytes that have a special role in immune processes. Some attack bacteria directly; others produce antibodies.

Thrombocytes, or platelets, are not complete cells, but are small fragments of very large cells called megakaryocytes. Megakaryocytes develop from hemocytoblasts in the red bone marrow. Thrombocytes become sticky and clump together to form platelet plugs that close breaks and tears in blood vessels. They also initiate the formation of blood clots.

5. 5. BLOOD VOLUME AND ITS REGULATION

Blood volume refers to the total amount of fluid circulating within the arteries, capillaries, veins, venules, and chambers of the heart at any time. The components that add volume to blood include red blood cells (erythrocytes), white blood cells (leukocytes), platelets, and plasma. Plasma accounts for about 60% of total blood volume while erythrocytes make up roughly 40% along with leukocytes and platelets. he amount of blood circulating within an individual depends on their size and weight, but the average human adult has nearly 5 liters of circulating blood. Women tend to have a lower blood volume than men. However, a woman's blood volume increases by roughly 50% during pregnancy. Blood volume is tightly regulated and related to multiple organ systems. Furthermore, it is closely associated with sodium content and hydration status. The maintenance of blood volume is crucial to normal function as it is necessary for the constant perfusion of body tissues. Blood volume can be increased or decreased by systemic dysfunction. Changes in blood volume can result in various clinical scenarios such as hypovolemic shock or edema.

5.5.1. ORGANS INVOLVED IN BLOOD VOLUME REGULATION

Multiple organ systems are involved in producing blood and regulating blood volume. These systems communicate with one another to optimally control blood volume. The renal system, and more specifically the kidney, is primarily responsible for regulating blood volume. The kidney's primary function is to modify the solutes and water content of the blood through filtration, reabsorption, and secretion. As blood passes through the glomerulus of the kidney, solutes and water are filtered out depending on a variety of signaling molecules. Then, as the filtrate passes through the tubules, some of the filtrates are reabsorbed along with water. The amount of water and solute reabsorbed is what primarily regulates blood volume. If blood volume is too low, more filtrate reabsorbs; if blood volume is too high, less filtrate reabsorbs. The kidney is also responsible for the secretion of erythropoietin. Erythropoietin is the protein that signals the bone marrow to produce red blood cells. Therefore, the kidney is responsible for both the regulation and partial production of blood volume.

The cardiovascular system maintains arterial pressure for the adequate perfusion of all bodily tissues. This system detects changes in blood volume and reflects it through increasing or decreasing arterial pressure. Reduced blood volume leads to collapsing vessels, reduced pressure, and subsequently reduced perfusion pressure. The cardiovascular system combats low blood volume by constricting blood vessels until the body reaches a blood pressure that restores proper perfusion pressure. Blood volume and blood pressure are interconnected through the renal and circulatory system, specifically the renin-angiotensin-aldosterone system (RAAS).

As mentioned earlier, the skeletal system is responsible for the production of blood cells which make up blood volume. When signaled by erythropoietin, the bone marrow creates erythrocytes which are eventually released into circulation. Leukocytes, which form a small portion of total blood volume, are also produced by the bone marrow when stimulated by colony stimulating factors released from mature leukocytes. Lastly, the nervous system aids in regulating blood volume by interacting with all three other systems. It is responsible for some of the stimulus at the level of the glomerulus as well as the constriction of blood vessels through sympathetic nerve activity.

5.5.2 IMPORTANCE OF BLOOD VOLUME REGULATION

Blood volume is necessary to maintain adequate perfusion to all of the tissues in the body. Nearly all cells in the body require replenishment of nutrients and a removal system for waste, both of which the blood provides. When a tissue loses its blood supply, ischemia occurs which may lead to an infarct after some time. Depending on the location of this tissue, an infarct could have a fatal effect. An infarct of the heart is a myocardial infarction; an infarct of cerebral tissue is a stroke.

Blood volume also functions in the maintenance of body osmolality. Osmolality refers to the balance of solutes and water within a solution, in this case, the blood. A properly functioning system maintains an osmolality of 275 to 295 mOsm/kg of water through water and sodium manipulation primarily at the kidney. When one of these two varies from the standard range, plasma osmolality changes and may increase or decrease plasma volume. Changing plasma osmolality results in an imbalance between intracellular and extracellular compartments. This imbalance can cause water entry or exit from cells. Overall, it may greatly increase or decrease blood volume. Increased blood volume is called hypervolemia and decreased blood volume is called hypovolemia.

5.6 HAEMOSTASIS

The term haemostasis means the prevention of blood loss, whenever is a blood vessel is severed or ruptured. It is the innate response for the body to stop bleeding and loss of blood. During hemostasis three steps occur in a rapid sequence. Vascular spasm is the first response as the blood vessels constrict to allow less blood to be lost. In the second step, platelet plug formation, platelets stick together to form a temporary seal to cover the break in the vessel wall. The third and last step is called coagulation or blood clotting. Coagulation reinforces the platelet plug with fibrin threads that act as a "molecular glue".

Platelets are a large factor in the hemostatic process. They allow for the creation of the "platelet plug" that forms almost directly after a blood vessel has been ruptured. Within seconds of a blood vessel's epithelial wall being disrupted platelets begin to adhere to the sub-endothelium surface. It takes approximately sixty seconds until the first fibrin strands begin to intersperse among the wound. After several minutes the platelet plug is completely formed by fibrin. Hemostasis is maintained in the body via three mechanisms:

1. **VASOCONSTRICTION -** Vasoconstriction is produced by vascular smooth muscle cells, and is the blood vessel's first response to injury. The smooth muscle cells are controlled by vascular endothelium, which releases intravascular signals to control the contracting properties. When a blood vessel is damaged, there is an immediate reflex, initiated by local sympathetic pain receptors, which helps promote vasoconstriction. The damaged vessels will constrict (vasoconstrict) which reduces the amount of blood flow through the area and limits the amount of blood loss. Collagen is exposed at the site of injury, the collagen promotes platelets to adhere to the injury site. Platelets release cytoplasmic granules which contain serotonin, ADP and thromboxane A2, all of which increase the effect of vasoconstriction. The spasm response becomes more effective as the amount of damage is increased. Vascular spasm is much more effective in smaller blood vessels.[5][6]
2. **PLATELET PLUG FORMATION-** Platelets adhere to damaged endothelium to form a platelet plug (*primary hemostasis*) and then degranulate. This process is regulated through thromboregulation. Plug formation is activated by a glycoprotein called Von Willebrand factor (vWF), which is found in plasma. Platelets play one of major roles in the hemostatic process. When platelets come across the injured endothelium cells, they change shape, release granules and ultimately become 'sticky'. Platelets express certain receptors, some of which are used for the adhesion of platelets to collagen. When platelets are activated, they express glycoprotein receptors that interact with other platelets, producing aggregation and adhesion. Platelets release cytoplasmic granules such as adenosine diphosphate (ADP), serotonin and thromboxane A2. Adenosine diphosphate (ADP) attracts more platelets to the affected area, serotonin is a vasoconstrictor and thromboxane A2 assists in platelet aggregation, vasoconstriction and degranulation. As more chemicals are released more platelets stick and release their chemicals; creating a platelet plug and continuing the process in a positive feedback loop. Platelets alone are responsible for stopping the bleeding of unnoticed wear and tear of our skin on a daily basis. This is referred to as primary hemostasis.

3. **CLOT FORMATION -** Once the platelet plug has been formed by the platelets, the clotting factors (a dozen proteins that travel along the blood plasma in an inactive state) are activated in a sequence of events known as 'coagulation cascade' which leads to the formation of Fibrin from inactive fibrinogen plasma protein. Thus, a Fibrin mesh is produced all around the platelet plug to hold it in place; this step is called "Secondary Hemostasis". During this process some red and white blood cells are trapped in the mesh which causes the primary hemostasis plug to become harder: the resultant plug is called as 'thrombus' or 'Clot'. Therefore 'blood clot' contains secondary hemostasis plug with blood cells trapped in it. Though this is often a good step for wound healing, it has the ability to cause severe health problems if the thrombus becomes detached

from the vessel wall and travels through the circulatory system; If it reaches the brain, heart or lungs it could lead to stroke, heart attack, or pulmonary embolism respectively. However, without this process the healing of a wound would not be possible.

HAEMOSTASIS METHODS IN MEDICINE

Some main types of hemostasis used in emergency medicine include:

- **Chemical/topical**- This is a topical agent often used in surgery settings to stop bleeding. Microfibrillar collagen is the most popular choice among surgeons because it attracts the patient's natural platelets and starts the blood clotting process when it comes in contact with the platelets. This topical agent requires the normal hemostatic pathway to be properly functional.
- **Direct pressure or pressure dressing**- This type of hemostasis approach is most commonly used in situations where proper medical attention is not available. Putting pressure and/or dressing to a bleeding wound slows the process of blood loss, allowing for more time to get to an emergency medical setting. Soldiers use this skill during combat when someone has been injured because this process allows for blood loss to be decreased, giving the system time to start coagulation.
- **Sutures and ties**- Sutures are often used to close an open wound, allowing for the injured area to stay free of pathogens and other unwanted debris to enter the site; however, it is also essential to the process of hemostasis. Sutures and ties allow for skin to be joined back together allowing for platelets to start the process of hemostasis at a quicker pace. Using sutures results in a quicker recovery period because the surface area of the wound has been decreased.
- **Physical agents (gelatin sponge)**- Gelatin sponges have been indicated as great hemostatic devices. Once applied to a bleeding area, a gelatin sponge quickly stops or reduces the amount of bleeding present. These physical agents are mostly used in surgical settings as well as after surgery treatments. These sponges absorb blood, allow for coagulation to occur faster, and give off chemical responses that decrease the time it takes for the hemostasis pathway to start.

5.7 LET US SUM UP

Blood is the liquid connective tissue circulating throughout the body. The blood carries Oxygen and nutrients to the tissues and carbon dioxide and waste products from the tissues to the excretory organs. The average human has about 5 litres of blood. The blood is composed of blood plasma, erythrocytes, leucocytes and blood platelets. The blood plasma contains 92% water and the remaining contains serum albumin, serum globulin and fibrinogen. Fibrinogens along with platelets are helpful for the blood clotting. The blood platelets are

produced by megakaryocytes. In humans the red blood cells lack nucleus in order to carry maximum oxygen. The life span of human erythrocyte is 120 days, after that they breakdown at the spleen. The white blood cells are classified as granular leucocytes and agranular leucocytes. They are involved in the defense of body from the foreign organisms. All blood cells are derived from haemotopoietic stem cells present in the bone marrow. Multiple organ system are involved in the regulation of blood volume. They are renal system, cardiovascular system, bone marrow and hormones. The haematostaic mechanism helps to prevent the blood loss.

5.8 UNIT-END EXERCISES

1. The RBC are break down at ----------

    a. Thymus b. Spleen c. Liver d. Pancreas

2. ---------- among the WBC found in maximum numbers

    a. Neutrophils b. Eosnophils c. Basophils d. Monocytes

3. Platelets are formed from ----------

    a. WBC b. RBC c. Megakaryocytes d. Lymphocytes

4. The blood loss in the body is prevent through

    a. Haemostasis b. Haematopoisis c. RBC d. WBC

5. 9. ANSWER TO CHECK YOUR PROGRESS

1. b, 2. a, 3. c, 4. a

5. 10 SUGGESTED READING

Harminder singh, Ltika singh, M. Yadav (2018) Fundamentals of medical physiology, Elsevier, Relx India Pvt. Ltd. India

Moyes, C.D., P.M. Schulte (2016) Principles of Animal Physiology, Pearson Education India, 2nd Edition, India.

Campbell, A.M., C. J. Paradise (2016) Animal Physiology, Momentum Press, USA.

Sherwood, L., Klandrof, H., P. Yancy (2012) Animal Physiology: From genes to organisms, Cengage learning , USA

UNIT VI CIRCULATORY SYSTEM

Structure

6.1 INTRODUCTION

The **circulatory system** is a network consisting of blood, blood vessels, and the heart. This network supplies tissues in the body with oxygen and other nutrients, transports hormones, and removes unnecessary waste products. The **circulatory system**, also called the **cardiovascular system** or the **vascular system**, is an organ system that permits blood to circulate and transport nutrients (such as amino acids and electrolytes), oxygen, carbon dioxide, hormones, and blood cells to and from the cells in the body to provide nourishment and help in fighting diseases, stabilize temperature and pH, and maintain homeostasis.

6.2. TYPES OF HEARTS

In general heart is an organ that pumps the blood to the tissues and organs to supply nutrients to them and then takes the waste material and removes it through the respiratory system in terms of oxygen exchange and through the excretory system in terms of removal of nitrogenous wastes. Bases on the pumping mechanism, they are divided as **neurogenic** and **myogenic** hearts.

6.2.1 NEUROGENIC HEART

In general the circulatory system of animals are divided into open and closed circulatory system. The Open Circulatory System is a system in which fluid (called haemolymph) in a cavity called the haemocoel bathes the organs directly with oxygen and nutrients and there is no distinction between blood and interstitial fluid; this combined fluid is called hemolymph or haemolymph. Muscular movements by the animal during locomotion can facilitate hemolymph movement, but diverting flow from one area to another is limited. When the heart relaxes, blood is drawn back toward the heart through open-ended pores (ostia). In most of the suction pump hearts the beating rhythm is set through nerve impulses. Such hearts are known as **Neurogenic hearts** (Fig. 9)

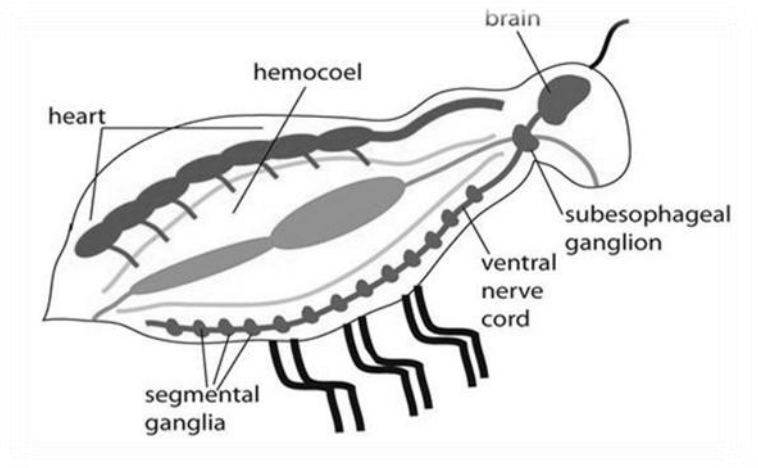


Fig. 9. Neurogenic heart of invertebrates

This type of circulatory system is called open type circulatory system. The open circulatory system is common to molluscs and arthropods. Open circulatory systems (evolved in crustaceans, insects, mollusks and other invertebrates) pump blood into a haemocoel with the blood diffusing back to the circulatory system between cells. Blood is pumped by a heart into the body cavities, where tissues are surrounded by the blood.

6.2.2 MYOGENIC HEART

A myogenic heart is capable of generating cardiac contraction independent of nervous input. In higher animals with closed ciruclatory system 2, 3 or 4 chambered hearts are seen with muscular ventricles which pumps the blood in the body with pressure and hence heart are known as pressure pumps. In pressure pump heart the rhythm is set in specialized muscle cells within the heart. They are known as **Myogenic hearts**. Vertebrates, and a few invertebrates, have a closed circulatory system. Closed circulatory systems have the blood closed at all times within vessels of different size and wall thickness. In this type of system, blood is pumped by a heart through vessels, and does not normally fill body cavities.

The cardiovascular systems of humans are closed, meaning that the blood never leaves the network of blood vessels. In contrast, oxygen and nutrients diffuse across the blood vessel layers and enters interstitial fluid, which carries oxygen and nutrients to the target cells, and carbon dioxide and wastes in the opposite direction. The other component of the circulatory system, the lymphatic system, is not closed. The heart is located in the center of the body between the two lungs. The reason that the heart beat is felt on the left side is because the left ventricle is pumping harder.

The heart is said to be myogenic, this means it is able to generate its own impulses. These impulses begin at the sinoatrial node (SA node), often referred to as the hearts pacemaker. When the SA node initiates an electrical impulse this starts the conduction system of the heart. The SA node is a small mass of specialised muscle tissue found in the right atrial wall. The SA node sets the hearts rhythm and when an electrical impulse is initiated it sends a wave of excitation through the atria, spreading through

the atria like a Mexican wave, causing atrial systole. Systole refers to the contraction phase of the heart. The impulse eventually reaches the atrioventricular node (AV node), another specialised mass of tissue that electrically connects the right atrium and right ventricle. There is a slight delay as the impulse passes through the AV node to allow time for the atria to fully contract and fill the ventricles before the ventricles can then contract.

The impulse is then passed from the AV node down the septum, the muscular wall that separates the right and left sides of the heart. The bundle of his, specialised bundles of nerve tissue, conduct the impulse through the septum to the tip of the ventricles. The impulse is then passed onto smaller branches that spread through the wall of the ventricles. The impulse eventually reaches the Purkinje fibres which conduct the impulse to the ventricles causing ventricular systole (Fig. 10).

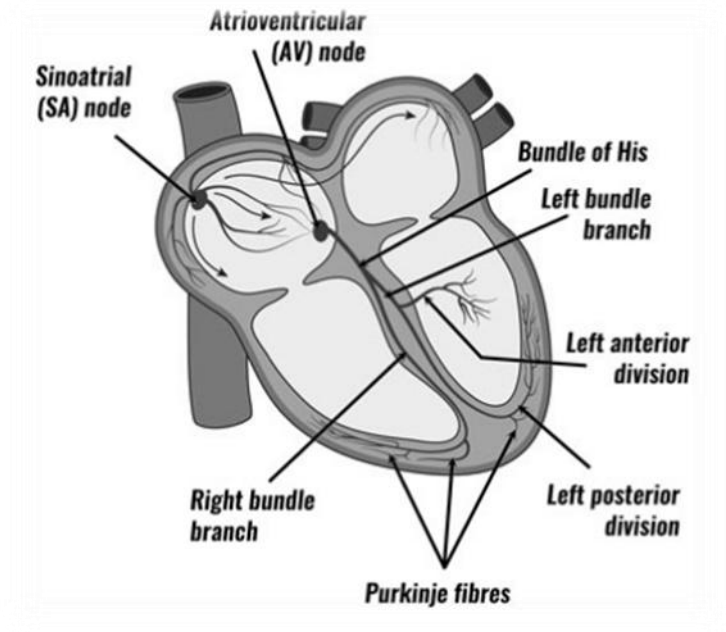


Fig. 10. Myogenic heart of vertebrates

6.3 STRUCTURE OF HUMAN HEART

The human heart is a four-chambered muscular pump located inside the chest. The heart is mesodermal derivative. The adult human heart is roughly about the size of a closed fist. It is a myogenic heart. The heart is covered by a fibrous sac called pericardium. The wall of the heart is primarily made up of cardiac muscles called myocardium. The heart is formed of four chambers, namely two auricles and two ventricles. The auricles are named as right and left auricles. The ventricles are named as right and left ventricles.

The right auricle opens into right ventricle by a right auriculo ventricular aperture. Similarly, the left auricle opens into the left ventricle by a left auriculo ventricular aperture. The right auricle receives deoxygenated blood through three veins, namely inferior vena cava, superior vena cava and coronary veins.Two main blood vessels carry blood from the

NOTES

ventricles. One large aortic arch carries blood from the left ventricle to the various parts of the body except the lungs. The pulmonary aorta carries blood from the right ventricle to the lungs.

The heart contains three types of valves. They are bicuspid valves, tricuspid valves and semilunar valves. The left auriculoventricular aperture is guarded by bicuspid valve. It has two flaps and hence the name 'bicuspid'. The right auriculoventrivular aperture is guarded by tricuspid valve containing three flaps. The openings of the aortic arch and pulmonary aorta are guarded by semilunar valves. Each semilunar valve is made up of three half moon cusps, attached to the wall of the aorta by one border, with the curved edge free inside the lumen of the aorta. They open during ventricular systole and close during ventricular diastole. They allow only the blood flow from aortae to the ventricles and reverse flow is prevented (Fig. 11).

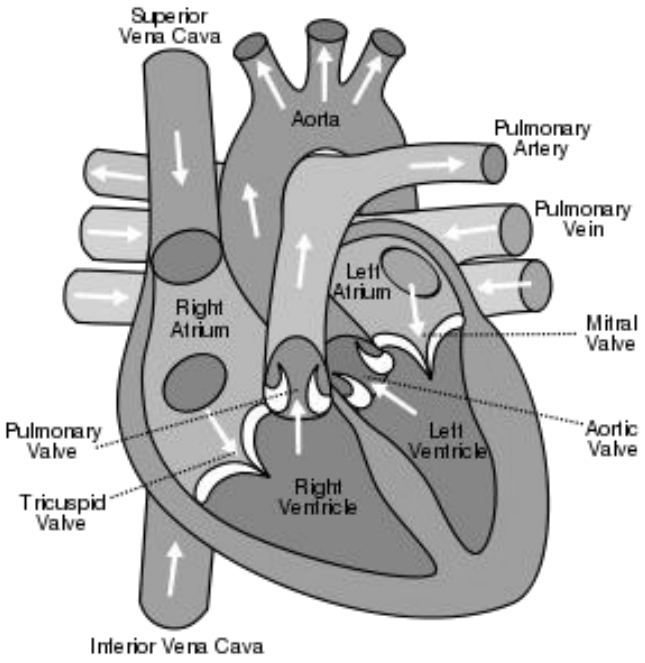


Fig. 11. Structure of human heart

6.4 HEART BEAT AND CARDIAC CYCLE

The cardiac cycle is the sequence of events that occurs when the heart beats. As the heart beats, it circulates blood through pulmonary and systemic circuits of the body. There are two phases of the cardiac cycle. In the diastole phase, the heart ventricles are relaxed and the heart fills with blood. In the systole phase, the ventricles contract and pump blood out of the heart and to arteries. One cardiac cycle is completed when the heart chambers fill with blood and blood is then pumped out of the heart. We can divide it into four parts

1. FIRST DIASTOLE

During the first diastole period, the atria and ventricles are relaxed and the atrioventricular valves are open. Oxygen-depleted blood returning to the heart from the body passes through the superior and inferior vena cavae and flows to the right atrium. The open atrioventricular valves (tricuspid and mitral valves) allow blood to pass through the atria to the ventricles. Impulses from the sinoatrial (SA) node travel to the atrioventricular (AV) node and the AV node send signals that trigger both atria to contract. As a result of the contraction, the right atrium empties its contents into the right ventricle. The tricuspid valve, located between the right atrium and right ventricle, prevents blood from flowing back into the right atrium.

2. FIRST SYSTOLE

At the beginning of the first systole period, the right ventricle is filled with blood passed on from the right atrium. The ventricles receive impulses from fiber branches (Purkinje fibers), which carry electrical impulses to the ventricles causing them to contract. As this occurs, the atrioventricular valves close and the semilunar valves (pulmonary and aortic valves) open. Ventricular contraction causes oxygen-depleted blood from the right ventricle to be pumped to the pulmonary artery. The pulmonary valve prevents blood from flowing back into the right ventricle. The pulmonary artery carries oxygen-depleted blood along the pulmonary circuit to the lungs. There, blood picks up oxygen and is returned to the left atrium of the heart by the pulmonary veins.

3. SECOND DIASTOLE

In the second diastole period, the semilunar valves close and the atrioventricular valves open. Oxygenated blood from the pulmonary veins fills the left atrium (blood from the venae cavae is also filling the right atrium at this time). The SA node contracts again triggering both atria to contract. Atrial contraction causes the left atrium to empty its contents into the left ventricle (the right atrium is also emptying blood into the right ventricle at this time). The mitral valve**,** located between the left atrium and left ventricle, prevents oxygenated blood from flowing back into the left atrium.

4. SECOND SYSTOLE

During the second systole period, the atrioventricular valves close and the semilunar valves open. The ventricles receive impulses and contract. Oxygenated blood in the left ventricle is pumped to the aorta and the aortic valve prevents the oxygenated blood from flowing back into the left ventricle (oxygen-depleted blood is also being pumped from the right ventricle to the pulmonary artery at this time). The aorta branches out to provide oxygenated blood to all parts of the body through systemic circulation. After its tour through the body, oxygen-depleted blood is returned to the heart via the venae cavae.

NOTES

6.5. BLOOD PRESSURE

Blood pressure is defined as the pressure which the blood exerts on the walls of the artery. The arterial blood pressure is the result of the discharge of the blood from the left ventricle in to the aorta. The blood pressure is measured by an instrument called **Sphygmomanometer** in terms of height in millimeters of a column of mercury. When left ventricle contracts and pushes blood into the aorta the pressure produced is known as systolic blood pressure which is found in an adult to be 120 mm Hg. When complete cardiac diastole occurs the heart is resting with no ejection of blood, the pressure within the blood vessels is termed as diastolic blood pressure. In an adult it is found to be 80 mm Hg. The blood pressure is usually expressed as 120/80 mm Hg.

6.6 ECG AND ITS APPLICATIONS

A record of the electrical events occurring during a cardiac cycle, made on a graph paper in a wave form is called electrocardiogram. The electric events include depolarization and repolarisation of the auricles and ventricles bringing about their contraction and relaxation. The machine by which the electrogram is recorded is known as electrocardiograph.

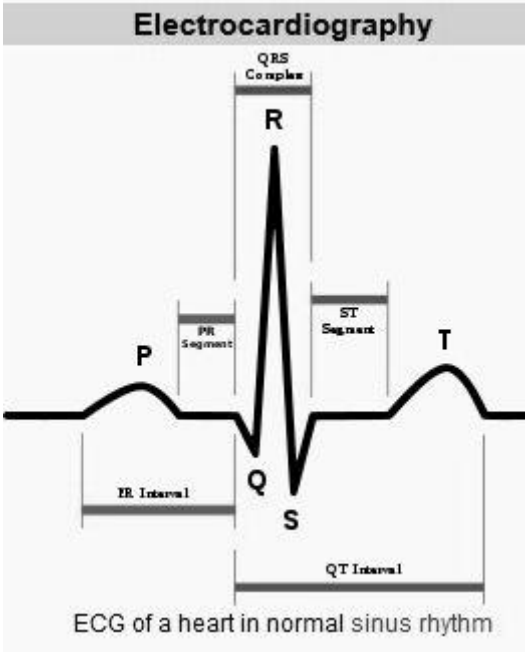


Fig. 12 Electrocardiogram

The ECG tracing shows five waves which by convention, have been named P, Q, R, S and T. The P, R and T waves are above the zero base line of ECG and are called positive waves while Q and S waves are below the base line and are termed as negative waves. Any abnormality in the working of the heart changes the wave pattern of ECG and can be interpreted by the trained physician. So ECG is helpful to find out the abnormality of the heart and its treatment.

6.7 LET US SUM UP

The circulatory system is a network consist of blood vessels and heart. The circulatory system is also called as cardiovascular system. On the basis of pumping mechanism the heart is divided as myogenic and neurogenic heart. The neurogenic heart is found in invertebrates which have open circulatory system. The myogenic heart is found in animals which have closed circulatory system. Human heart is myogenic and able to generate its own impulses. The heart impulses start at sinuarterial node, which is often referred as pace maker of the heart. Then it passed to auriculoventricular node and with the help of Purkenje fibers passed to whole of the heart. This facilitate the pumping of heart. The human heart is four chambered. The deoxygenated blood from the body enter into right cuticle then pass to right ventricle. From the right ventricle the pulmonary artery carry the blood to the lungs. The oxygenated blood from the lungs enter into left auricle and then into left ventricle. From the left ventricle the blood pass throughout the body through the aorta. The blood pressure can be studied through Spigmomanometer an the normal blood pressure is 120/80 mmHg. The normal heart functioning can be identified through ECG.

6.8 UNIT END EXERCISES

1. In mammals ---------- type of heart is present

a. Myogenic b. Neurogenic, c. Autocrine d. None of the above

2. Spigmomanometer measures the ------

a. Blood volume, b. Blood pressure, c. Blood type, d. None of these

3.Pacemaker of heart is ----------

a. Purkenjee fibers b. Bundle of His c. AV node, d. SA node

4. Human heart is --------

a. 2 chambered b. 3 chambered c. 4 chambered d. open type

5. The impure blood in the body is carried to the lungs through

a. Aorta, b. Pulmonary artery c. Pulmonary vein d. Superior venocava

6.9 ANSWER TO CHECK YOUR PROGRESS

1. a, 2. b 3.d 4. c 5.b

6.10 SUGGESTED READINGS

Campbell, A.M., C. J. Paradise (2016) Animal Physiology, Momentum Press, USA.

Sherwood, L., Klandrof, H., P. Yancy (2012) Animal Physiology: From genes to organisms, Cengage learning , USA

Berry, A.K & K.Berry (2008) A text book of animal physiology, Emkay publications,

New Delhi.

UNIT VII NERVOUS SYSTEM

NOTES

Structure

7.1 INTRODUCTION

The nervous system provides the most important and rapid means of communication between different parts of the body. It provides the means by which the various activities of the body are integrated and coordinated, and by which the organism is made aware of the changes in the environment and enables it to react appropriately to the changes. In the lower forms of life, the nervous system is rudimentary, but in higher forms it is more complex and made up of central nervous system (CNS) comprising brain and spinal cord and the peripheral nervous system. The peripheral nervous system is made up of 12 pairs of cranial nerves arising from the brain stem and 31 pairs of spinal nerves from the spinal cord.

The nervous system can be functionally divided into three parts, the afferent, the central and the efferent systems. The afferent system consists of the sensory receptors and the sensory nerves which conduct the impulses towards the centre. The efferent system conducts the impulses outward from the centres. The effector organs are usually muscles and glands and they contract or secrete in response to the impulses received by them.

7.2 TYPES AND FUNCTIONS OF NEURON

The neuron comprises a cell body (soma) and two types of processes, the dendrites and axons. Several dentrites usually arise from a single nerve cell. They are characterized by their repeated branching, short course, and irregular number. From each neuron, usually there arises a single axon from a a conical expansion of the cell known as axon hillock. The length of axon varies in different cells. Most of the cells have long axon which, either naked or along with their enclosed sheaths are called as nerve fibers. The length of axon varies considerably in different cells. Most of the cells have long axon which, either naked or along with their enclosed sheath, are called nerve fibers.

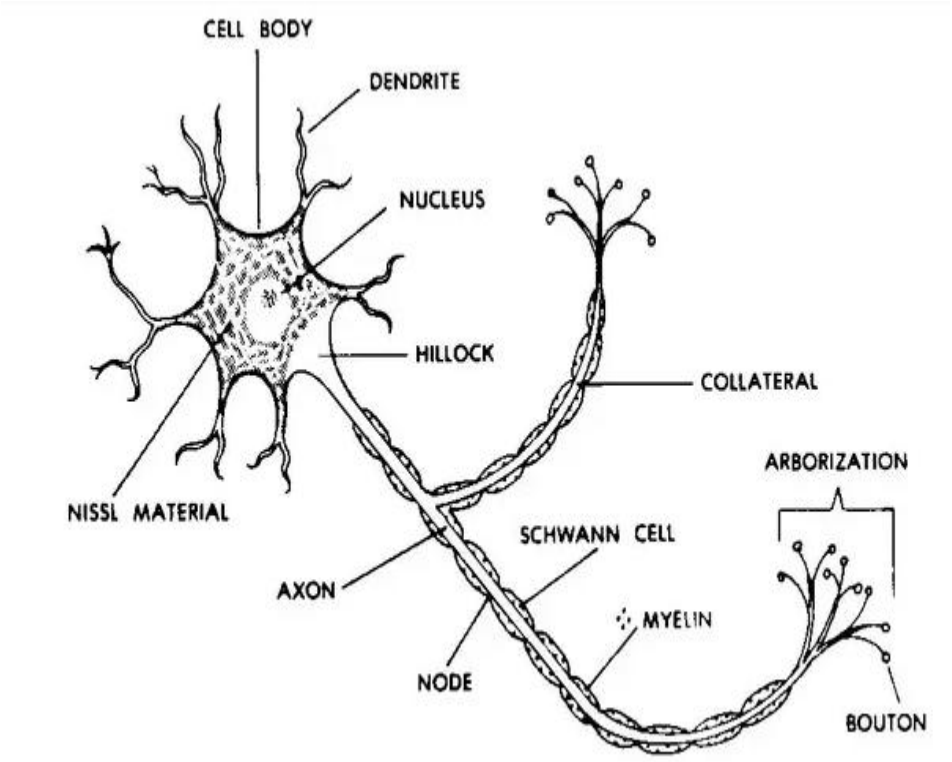
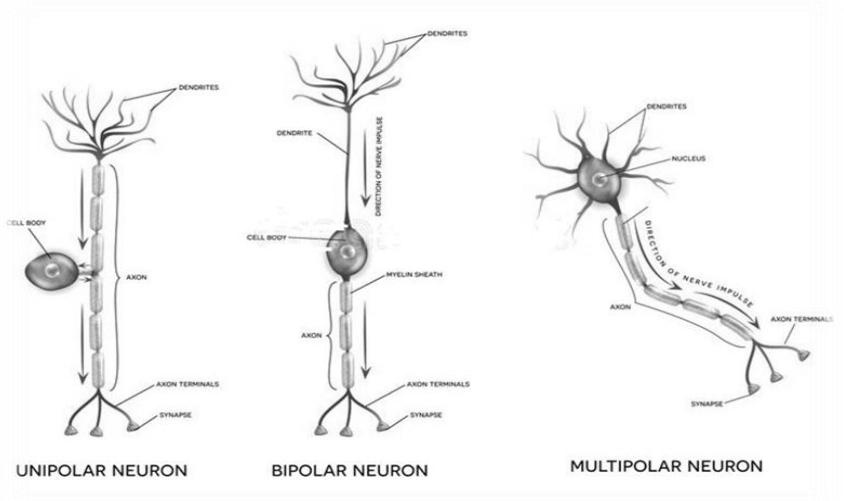


Figure 13. Structure of nerve cell

The axons may give off collateral branches alsong their course but ultimately they break up into a number of terminal branches ending in knobs or buttons. As a general rule the dendrites convey impulses towards the cell body, and axons away from the cell body.

7.2.1. TYPES OF NEURON

Neurons can also be classified as unipolar, bipolar or multipolar based on the different types of cell processes emerge from the cell body.



NOTES

Fig. 14 . Types of Neuron

The **Unipolar neurons** have only one axon often with dendrites or collateral process, takes is origin from the cell body. Unipolar neurons are mostly found within the posterior roosts of spinal nerves and in the roosts of certain cranial nerves such as the trigeminal, glossophryngeal and the vegus nerves.

In the **bipolar neurons** two processes take their origin from the cell body, one on either side of the cell body. Out of the two processes one may be Dendron and the other may be axon.

The multipolar neurons have large number of cell processes and among them at least one of them is an axon. Bipolar and **multipolar neurons** may be isopolar or heteropolar. Isopolar neurons usually have two or more somewhat similar processes whereas the heteropolar neurons usually have distinct axon that is long and smooth and one or more irregularly branched dendrites.

7.2.2 CONDUCTION OF NERVE IMPULSE

The important function of neuron is conduction of nerve impulse. Nerve impulse is an overall physiological changes that occur in a neuron due mechanical, chemical or electrical disturbance created by a stimulus. It propagation through axon, synapse and neuromuscular junction is called Nerve Impulse conduction. The transmission of nerve impulse along the nerve fiber is described in three steps. They are polarization (Resting potential), depolarization (action potential) and repolarization.

A. POLARIZATION OR RESTING POTENTIAL

A neuron at resting is electrically charged but not conducting. The Axoplasm or plasma membrane of a resting neuron is negatively charged as compared to the interstitial fluid. The potential difference measured at this stage is called **resting potential** which is about **-70mV**. The interstitial fluid has high concentration of Na+ ion which is about 16 times higher outside the neuron than inside neuron. Similarly, the axoplasm has high concentration of K+ ion which is about 25 times higher inside than in outer interstitial fluids. Due to difference in concentration of ions, Na+ ion tends to diffuse into the axoplasm and K+ ion tends to diffuse outside the axoplasm. The membrane of neuron at resting is more permeable to K+ ion than Na+ ion. So, K+ leaves the neuron faster than Na+ enter the neuron. The difference in permeability results in accumulation of high concentration of cation (+ve charged ion) outside the neuron compared to the concentration of cation inside. This state of resting neuron is called **Polarized state** and it is electro-negatively charged (Fig. 15 a)

B. DEPOLARIZATION OR ACTION POTENTIAL

Any stimulus beyond the threshold can initiate an impulse. When such stimulus is applied in the resting neuron, it opens the sodium channel. Now the permeability of Na+ ion suddenly increases at the point of stimulus causing depolarization. The diffusion of Na+ ion increases by 10 times from outside to inside. As a result the axoplasm become positively charges, which is exact opposite to polarized state, so called as **depolarized state** or **reverse polarized state.** The depolarization of the membrane stimulates

the adjacent voltage channel, so the action potential passes as a wave along the length of neuron (Fig. 15. B).

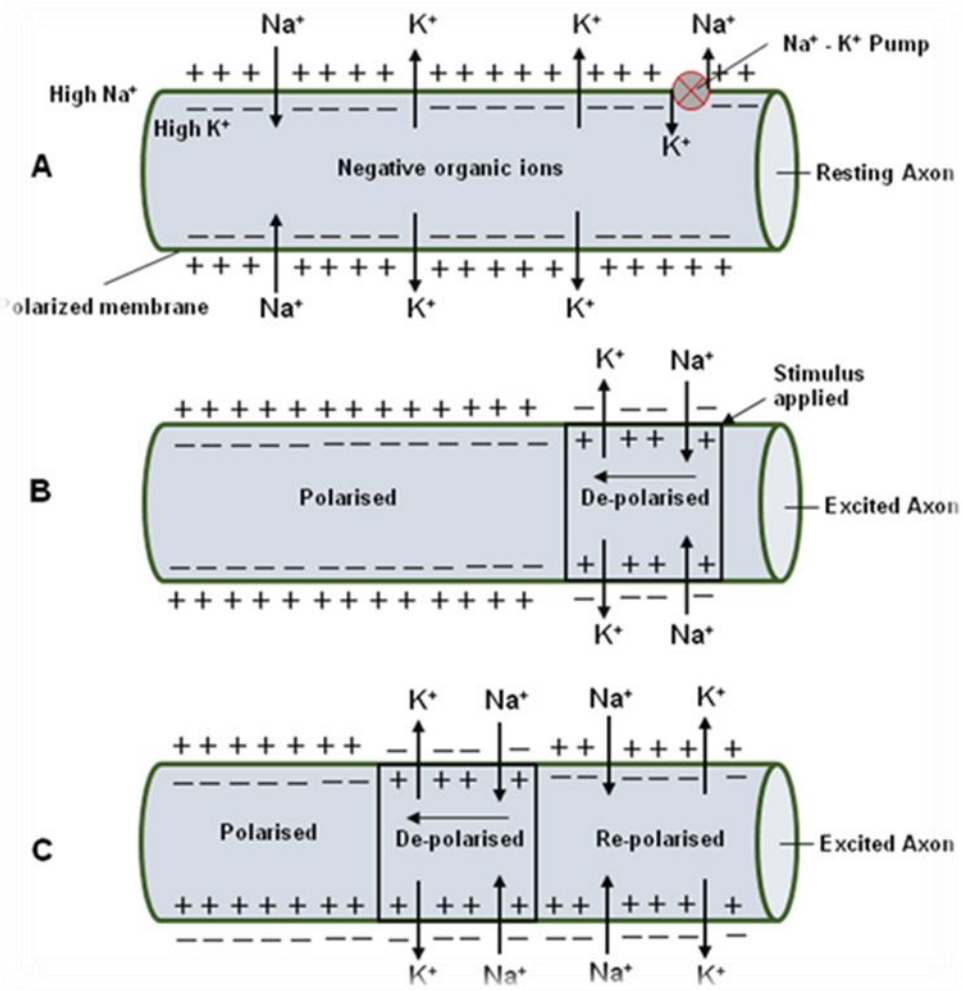


Fig. 15 Nerve impulse transmission along neuron

C. REPOLARIZATION

When the concentration of Na+ ion inside axoplasm increases, the permeability to Na+ decreases and the sodium channel starts to close. The Na-K pump activates, so that Na+ are pumped out and K+ inside until the original resting potential is restored. The process is known as **repolarization** and it starts from the same point from where depolarization starts (Fig. 15 c). The entire process of polarization, depolarization and repolarization occur within fraction of seconds. Now, again the neuron is ready for another impulse. In this way the signal gets transported.

7.3 CENTRAL AND PERIPHERAL NERVOUS SYSTEM

The nervous system has three main functions: sensory input, integration of data and motor output. Sensory input is when the body gathers information

NOTES

or data, by way of neurons, glia and synapses. The nervous system is composed of excitable nerve cells (neurons) and synapses that form between the neurons and connect them to centers throughout the body or to other neurons. These neurons operate on excitation or inhibition, and although nerve cells can vary in size and location, their communication with one another determines their function. These nerves conduct impulses from sensory receptors to the brain and spinal cord. The data is then processed by way of integration of data, which occurs only in the brain. After the brain has processed the information, impulses are then conducted from the brain and spinal cord to muscles and glands, which is called motor output.

The nervous system is comprised of two major parts, or subdivisions, the **central nervous system (CNS)** and **the peripheral nervous system (PNS).** The CNS includes the brain and spinal cord. The brain is the body's "control center." The CNS has various centers located within it that carry out the sensory, motor and integration of data. These centers can be subdivided to Lower Centers (including the spinal cord and brain stem) and Higher centers communicating with the brain via effectors.

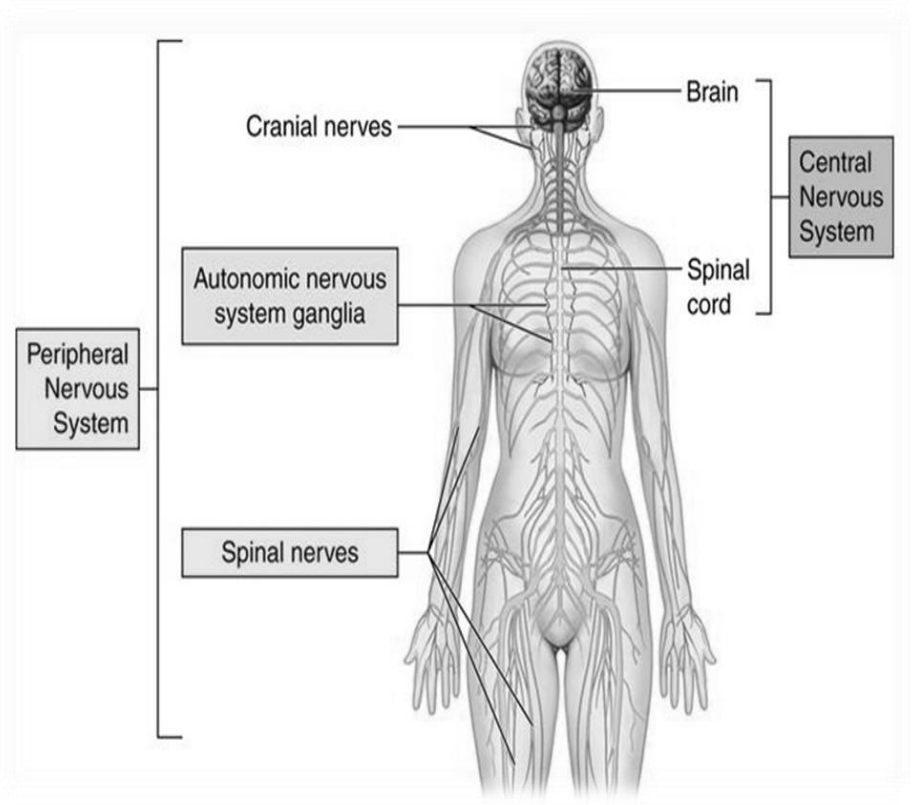


Fig. 16. Central and peripheral nervous system

The PNS is a vast network of spinal and cranial nerves that are linked to the brain and the spinal cord. It contains sensory receptors which help in processing changes in the internal and external environment. This information is sent to the CNS via afferent sensory nerves. The PNS is then subdivided into the **autonomic nervous system** and the **somatic nervous system**.

The autonomic has involuntary control of internal organs, blood vessels, smooth and cardiac muscles. he autonomic motor division is divided into two complementary subsystems: the **sympathetic system**, which works to shift the body into more prepared states; and the **parasympathetic system**, which facilitates more relaxed states. The constant shifting of control between these two occurs in response to demands such as the fight or flight response.

The somatic has voluntary control of skin, bones, joints, and skeletal muscle. The two systems function together, by way of nerves from the PNS entering and becoming part of the CNS, and vice versa.

7.4 SYNAPSE AND ITS TRANSMISSION

The nerve cells communicate to one another through **synapse.** At the synapse, the firing of an action potential in one neuron—the **presynaptic**, or sending, neuron—causes the transmission of a signal to another neuron—the **postsynaptic**, or receiving, neuron—making the postsynaptic neuron either more or less likely to fire its own action potential.

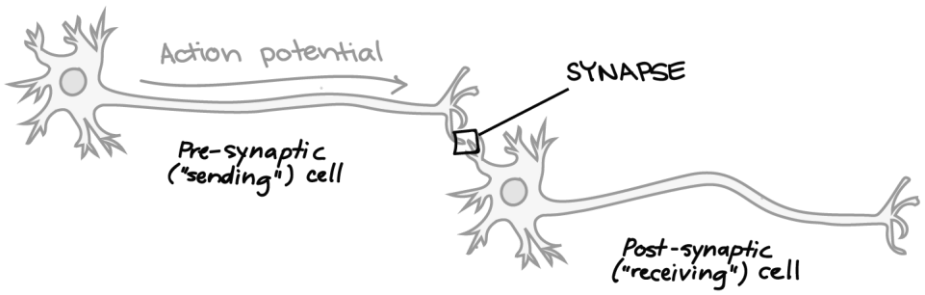


Fig. 17. Nerve signal transmission through synapse

Synapses are junctional complexes between presynaptic membranes (synaptic knobs) and postsynaptic membranes (receptor surfaces of recipient neurons or effectors). The prefixes "pre-" and "post-" reflect the direction of synaptic transmission: presynaptic is the transmitting side (synaptic knob) and postsynaptic is the receiving side (dendrite, soma, or effector). Synaptic knobs contain many membrane-bounded synaptic **vesicles** , 40 to 100 **nanometers** in diameter. Synaptic vesicles contain the neurotransmitter. Synaptic knobs also contain **mitochondria** , microtubules, and other **organelles** .

Synapses are named according to their location on the postsynaptic neuron: Axospinous synapses are synapses on dendritic spines (tiny projections on the dendrites), axodendritic synapses are on shafts of dendrites, axosomatic synapses are on the soma of neurons, and axoaxonal synapses are synapses on other synaptic knobs. Synapses on skeletal muscle cells are neuromuscular junctions.

Action potentials arriving at synaptic knobs trigger the release of neurotransmitter into the synaptic cleft. The molecular mechanism is not completely understood. A "synaptic delay" of one to two milliseconds occurs between the arrival of the action potential and the neurotransmitter release. Action potentials open calcium channels in the membrane of the

NOTES

synaptic knob, which causes an inward movement of calcium **ions**. Calcium ions trigger the release of neurotransmitter from synaptic vesicles into the synaptic cleft. The synaptic vesicles fuse with the presynaptic membrane during this process of exocytosis. The membranes of old vesicles become part of the presynaptic membrane and new vesicles pinch off from an adjacent area of membrane. These new vesicles are subsequently refilled with newly synthesized **neurotransmitters**.

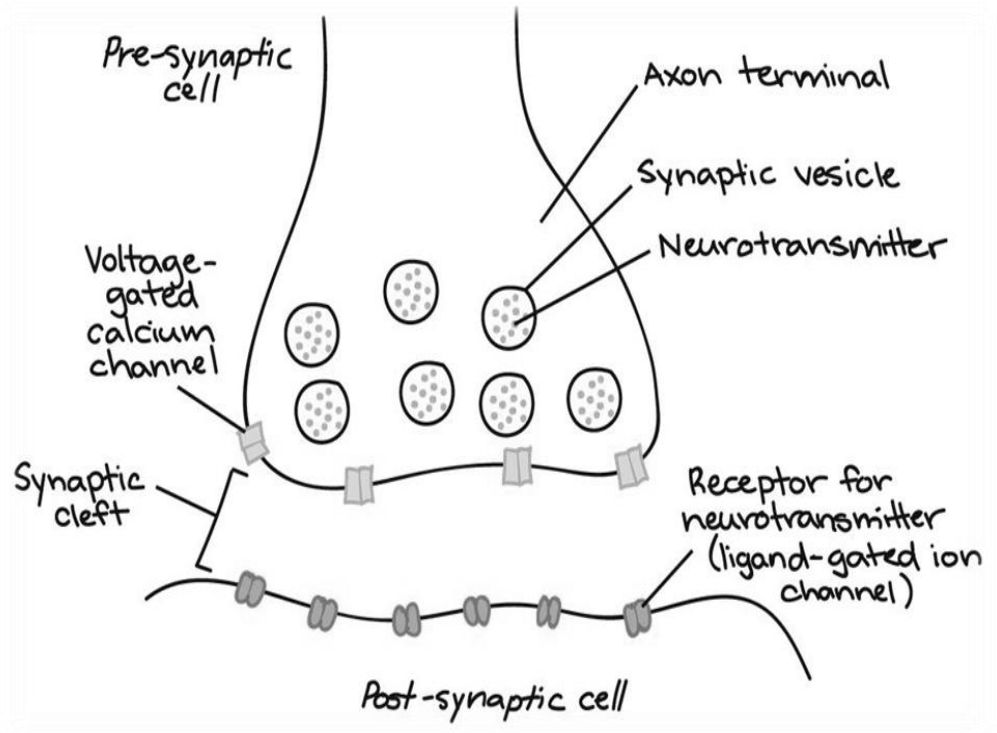


Fig. 18. Structure of synapse

The molecules of neurotransmitter diffuse across the synaptic cleft and bind to receptor proteins on the postsynaptic cell. Activation of postsynaptic receptors leads to the opening or closing of ion channels in the cell membrane. This may be **depolarizing**—make the inside of the cell more positive—or **hyperpolarizing**—make the inside of the cell more negative—depending on the ions involved.

7.5 NEUROMUSCULAR JUNCTION (NMJ)

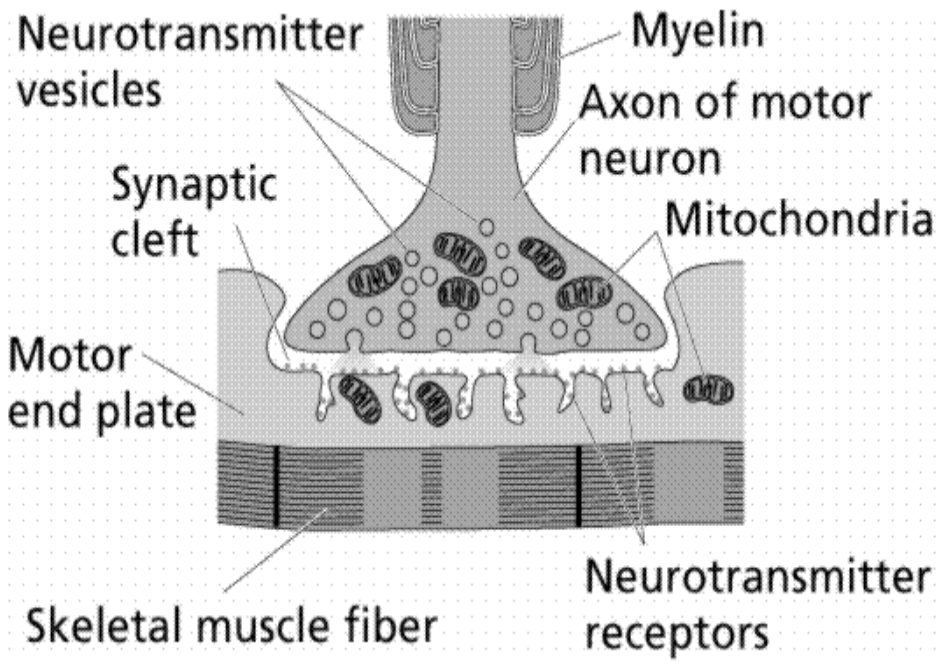


Fig. 19. Neuromuscular junction (NMJ)

The neuromuscular junction (NMJ) is a type of synapse formed between motoneurons and skeletal muscle fibers (Fig. 19). Large and easily accessed experimentally, this peripheral synapse has contributed greatly to the understanding of the general principles of synaptogenesis and to the development of potential therapeutic strategies for muscular disorders. The NMJ uses different neurotransmitters in different species; for example, acetylcholine (ACh) in vertebrates and glutamate in *Drosophila*, both of which are excitatory and cause muscle contraction. In *Caenorhabditis elegans*, there are two types of NMJs: at excitatory NMJs, ACh causes muscle contraction, whereas inhibitory NMJs release γ-aminobutyric acid (GABA) to cause muscle relaxation. Motor nerve terminals differentiate to form presynaptic active zones, where synaptic vesicles dock and release neurotransmitters and activate the muscle.

7.6 LET US SUM UP

The nervous system helps the communication and response reactions of different parts of the body. The nervous system in higher animals are made of central nervous system (CNS) consisting of brain and spinal cord and peripheral nervous system consisting of 12 pairs of cranial nerves and 31 pairs of spinal nerves arising from spinal cord. The neuron is a unit of nervous system. It consist of central body (Soma), dendrites and axon. The neuron is classified as unipolar, bipolar and multipolar based on different types of cell processes. The signal conduction in nerves happen through mechanical, chemical or chemical changes occurs in neuron. The neurotransmitters help the passage of signal from one nerve to other nerves. The neuromuscular junction helps the message pass from nerve to

muscle. In which during excitatory neuromuscular junction (NMJ) acetylcholine secreted. During inhibitory neuromuscular junction GABA secreted.

7.7. UNIT END EXERCISES

NOTES

1. The electric charge of neuron during resting potential is

   a. 70V, b. 3V c. 6V, d.-70mV

2. During depolarization of the nerve ----------

   a. Na+ move inside b. Na+ do not change c. Cl- move inside d. None of the above

3. The nerve cells communicate one another through

   a. axon b. Myalin c. dendrite d. Synapse

4. The nervous system which control the voluntary action of muscles is called --- nervous system

   a. autonomic b. somatic c. neurotransmitter d. none of the above

5. Acetylcholine is a

   a. neurohormone b.lipid c. endocrine hormone d. neurotransmitter

7.8. ANSWER TO CHECK YOUR PROGRESS

1. d, 2. a, 3.d, 4.b, 5.d

7.9. SUGGESTED READINGS

Reznikova, Z. (2007) Animal intelligence: From individual to Cognition, Cambridge university press, Cambridge.

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

Hall, J. E. 2015. Guyton and Hall Text book of Medical Physiology, 13th Edition, Relx India Pvt. Ltd.

BLOCK III

EFFECTORS AND RECEPTORES

UNIT VIII MUSCLES

Structure

8.1 INTRODUCTION

The muscular system, in vertebrates, is controlled through the nervous system, although some muscles, like cardiac muscle, can be completely autonomous. Muscle is contractile tissue and is derived from the mesodermal layer of embryonic germ cells. Its function is to produce force and cause motion, either locomotion or movement within internal organs. Much of muscle contraction occurs without conscious thought and is necessary for survival, like the contraction of the heart or peristalsis, which pushes food through the digestive system. Voluntary muscle contraction is used to move the body and can be finely controlled, such as movements of the finger or gross movements that of the biceps and triceps.

In organisms the body activities are either directly or indirectly under the control of the nervous system. Direct control is exercised by supplying nerves to the various organs and tissues, while indirect control is exercised through the endocrine glands and circulatory system. The nervous system receives a variety of stimuli from the various parts of the body; depending on the nature of the stimuli it sends out appropriate signals to concerned organs. The stimuli which nervous system receives are of two kinds: stimuli (sensations) like pressure, pain, heat etc., which are caused due to external conditions, are called exteroceptive sensations. The vision by the eye and sound reception by ear are most important exteroceptive sensations. Sensations which convey the physical state of the body are called proprioceptive sensations. These include information regarding the functioning of internal organs.

Both extero- and proprioceptive sensations are brought to the brain and spinal cord through sensory nerves. Orders which are carried out in response to these sensations are conveyed to the appropriate organs through motor nerves. In this unit first we see the muscle and muscular

NOTES

contraction. Then we look at nerve cells and nerve conduction. Finally we will see about the different types of sensory receptors which are helpful for the survival of the organisms.

The main framework of the body (skeleton) is covered by muscles, whose function is to permit movement and maintain posture. Sensory receptors in the muscles monitor the tension and length of the muscles and provide the nervous system with crucial information about the position of the body parts, thereby enabling posture to be maintained. Muscle tissue has four main properties: Excitability (ability to respond to stimuli), Contractibility (is ability to contract), Extensibility (the ability of a muscle to be stretched without tearing) and Elasticity (the ability to return to its normal shape).

The muscles are doing both voluntary actions like movement, stretching and other activities which are under the control of the animals, on the other hand the muscles are doing involuntary actions like heart beat, respiration, excretion etc. without the action of these muscles the organism will eventually die. So the muscles are essential for the sustenance of life of the animals.

8.2 GENERAL STRUCTURE AND TYPES OF MUSCLES

Muscle is made up of **sarcomere**. Sarcomere is the basic unit of a myofibril. The sarcomere consist of two kinds of longitudinal filaments namely, **thick filaments** and **thin filaments**. Thick filament is composed of a bundle of protein molecules called **myosin**. Each myosin molecule consists of a head, a neck and a tail. The head is also called cross bridge as it attaches with **actin** during muscle contraction. The head is modified myosin called meromyosin. The head projects out of the thick filament.

A thin filament consists of three proteins, namely **actin, tropomyosin** and **troponin.** Actin molecules are globular and are arranged in the form of a double helix. Tropomyosin molecules are filamentous and lie in the grooves of twisted actin strands. Troponin molecule is nearly oval in shape and is associated with the end of each tropomyosin molecule that lies towards the centre of sarcomere.

i, Actin

Actin is a roughly globular protein with a molecular weight of approximately 46,000 called G actin. In the presence of ATP, G actin causes hydrolysis of the ATP and aggregates into a double helical structure called F-actin having a molecular weight of approximately 14,000,000. F actin can interact with troponin and tropomyosin (see figure 20). The bound ADP can interact with the head units of myosin. The interaction of actin with myosin can lead to motion in muscle.

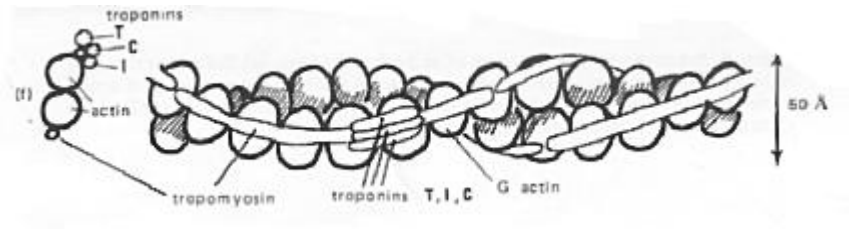


Fig. 20. Structure of muscle fiber

ii, **Tropomyosin and troponin**

Two other proteins associate with actin to from the thin filaments. Tropomyosin is compose of two polypeptides (a- and b-tropomyosin). Together they make up from 5 to 8% of the myofibrillar protein. These polypeptides aggregate to form long filaments that fit within the grove formed by the two chains of actin. Each molecule spans seven actin molecules and controls the reactivity of these actin molecules. Troponin is made up of three subunits. Troponin C contains a calcium binding domain, troponin, T interacts with tropomyosin and troponin I can block the actin binding site for myosin. One set of three troponin subunits is associated with each molecule of tropomyosin and is involved with the activity of seven actin molecules.

iii, **Myosin**

In the muscle, thick filaments are made of Myosin. They are actin binding contractile molecules. The myosin molecule has a molecular weight of 480,000 daltons and is made up of six polypeptide chains, two heavy chains and four light chains. The two heavy chains wrap around each other to form double helix, which form the tail and body of the myosin molecules. The light chains combine with the terminal part of the heavy chains to form a globular head of myosin molecule. The myosin molecule present in the skeletal muscle has two heads and is called Myosin II. Each myosin has two attachment sites, one site for actin and another for ATP. The head is also called cross bridge as it attaches with the actin during muscle contraction. A thick filament consists of a bundle of myosin tails with the head projecting outwards. During muscle contraction, the myosin combines with actin to form acto-myosin and the actin filaments slide on the myosin filaments. The actin filaments are actually pulled by the heads of myosin.

TYPES OF MUSCLE

There are three types of muscles smooth muscles, cardiac muscles and skeletal muscles.

8.2.1. SMOOTH MUSCLE

Smooth muscle or "involuntary muscle" consists of spindle shaped muscle cells found within the walls of organs and structures such as the esophagus, stomach, intestines, bronchi, uterus, ureters, bladder, and blood vessels. Smooth muscle cells contain only one nucleus and no striations. Smooth muscle primarily supports visceral functions, rather than locomotion and other behaviour.

Like striated muscle, smooth muscle contracts when actin and myosin filaments slide past each other, pulled by myosin cross-bridges. As in cardiac muscle, each fiber is an individual cell containing a single nucleus. Unlike either class of striated muscle fibers, many smooth muscle fibers have little or no sarcoplasmic reticulum, and they lack T tubules. Instead of being organized into sarcomeres, the myofilaments of smooth muscle are gathered into bundles of thick and thin filaments that are anchored in structures called dense bodies. Most smooth muscle cells contract and

NOTES

relax more slowly than striated muscle fibers and are capable of more sustained contraction.

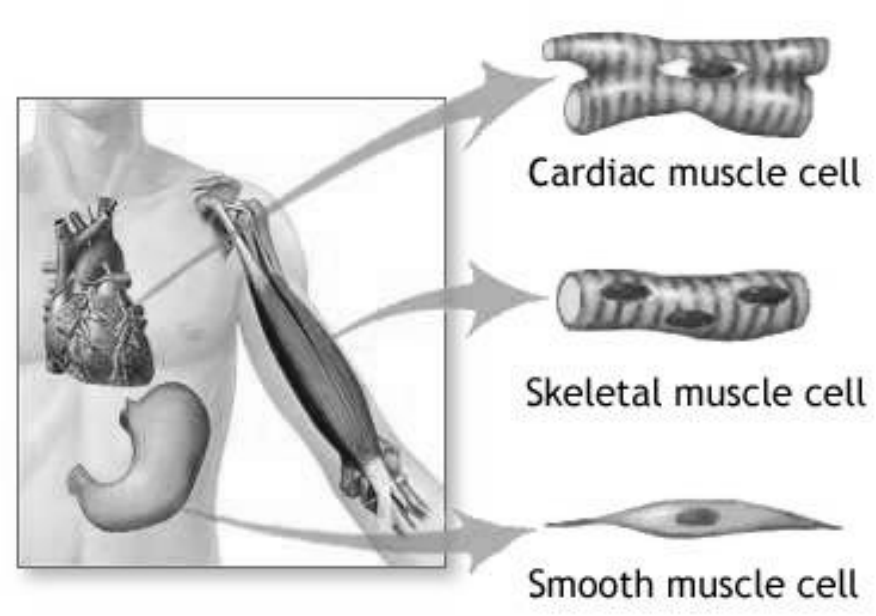


Figure 21. Showing different types of muscles present in human body

8.2.2. CARDIAC MUSCLE

Cardiac muscle is also an "involuntary muscle" but it is striated in structure and appearance. Like smooth muscle, cardiac muscle cells contain only one nucleus. Cardiac muscle is found only within the heart. Cardiac and skeletal muscles are "striated" in that they contain sarcomeres and are packed into highly regular arrangements of bundles; smooth muscle has neither (Fig. 21). While skeletal muscles are arranged in regular, parallel bundles, cardiac muscle connects at branching, irregular angles (called intercalated discs). Striated muscle contracts and relaxes in short, intense bursts, whereas smooth muscle sustains longer or even near-permanent contractions.

Cardiac muscle is adapted to be highly resistant to Fatigue: it has a large number of mitochondria, enabling continuous aerobic respiration via oxidative phosphorylation, numerous myoglobins (oxygen-storing pigment) and a good blood supply, which provides nutrients and oxygen. The heart is so tuned to aerobic metabolism that it is unable to pump sufficiently in ischaemic conditions. At basal metabolic rates, about 1% of energy is derived from anaerobic metabolism. This can increase to 10% under moderately hypoxic conditions, but, under more severe hypoxic conditions, not enough energy can be liberated by lactate production to sustain ventricular contractions.

Under basal aerobic conditions, 60% of energy comes from fat (free fatty acids and triglycerides), 35% from carbohydrates, and 5% from amino acids and ketone bodies. However, these proportions vary widely according to nutritional state. For example, during starvation, lactate can be recycled by the heart. This is very energy efficient, because one NAD^+ is reduced to NADH and H^+ (equal to 2.5 or 3 ATP) when lactate is

oxidized to pyruvate, which can then be burned aerobically in the TCA cycle, liberating much more energy (ca 14 ATP per cycle).

8.2.3. SKELETAL MUSCLE

Skeletal muscle or "voluntary muscle" is anchored by tendons to the bone and is used to effect skeletal movement such as locomotion. Skeletal muscle cells are multinucleated with the nuclei peripherally located. Skeletal muscle is called 'striated' because of the longitudinally striped appearance under light microscopy (Fig. 22). Functions of the skeletal muscle include:

- Support of the body
- Aids in bone movement
- Helps maintain a constant temperature throughout the body
- Assists with the movement of cardiovascular and lymphatic vessels through contractions
- Protection of internal organs and contributing to joint stability

Skeletal muscle are striated in that they contain sarcomere and are packed into highly-regular arrangements of bundles; smooth muscle has neither. Striated muscle is often used in short, intense bursts, whereas smooth muscle sustains longer or even near-permanent contractions.

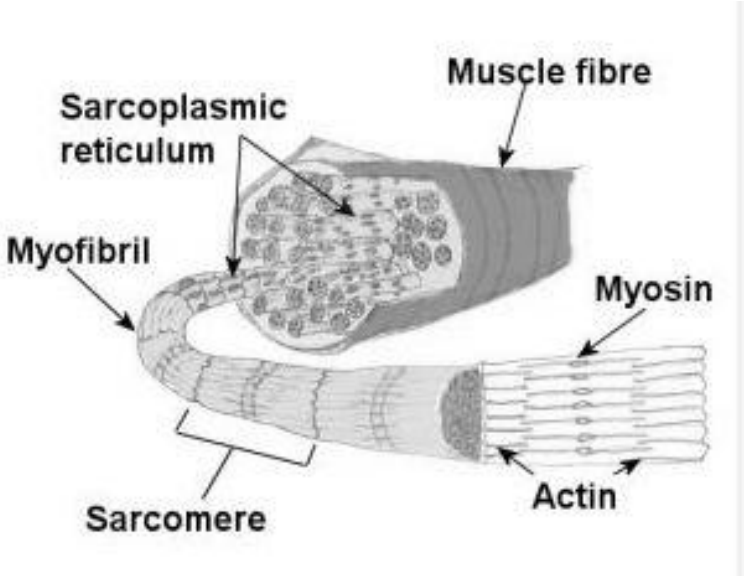


Fig. 22. Ultra structure of skeletal muscle

The skeletal muscles are attached to the skeletal system and are involved in the voluntary movement of the body. There are about 400 skeletal muscles present in the human body. Each skeletal muscles are attached to the bones with a connective tissue called tendons. Each muscle is made up of large number of muscle cells called muscle fibers which are covered by a thin connective tissue called endomyceum. Groups of muscle fibers form bundles called fascicule. Each faciculus is covered by a connective tissue layer called perimysium. Several fasciculi unite to form a large muscle called triceps or biceps. Each muscle is formed of several muscle cells called muscle fibers. The plasma membrane of the muscle fiber is called

NOTES

sarcolemma and the cytoplasm is called sarcoplasm. The sarcoplam contains numerous longitudinal protein filaments called myofibrils.

The skeletal muscles are excitable to adequate stimulai. The stimulus may be mechanical, chemical or electrical. Due to stimuli the skeletal muscle contracts and then attain the normal position through relaxation. This contraction and relaxation of muscle fibers due to stimulus is called muscle twitch. This muscle twitch is studied by the instrument called kymograph. The muscle twitch consist of three phases called latent period, period of contraction and period of relaxation. The latent period is the interval between the application of stimulus and the beginning of contraction and it last for 0.01 second. This is the time taken for the nerve stimuli to the sarcolemma to initiate contraction. Then the contraction period last for about 0.04 seconds. Then the muscle start to relax and it lasts for 0.05 seconds.

The process by which the muscles are shortening is termed muscle contraction. This may be isometric or isotonic. In the isometric contraction the contracting muscle retains its original length. The tension may form in the muscle but it does not do any mechanical work. For example when we press our hand on the wall muscle tension is developed but no mechanical work is performed. On the other hand, in the isotonic contraction the muscle shortens during contraction , walking, and the lifting of weight are the examples of isotonic contraction.

8.3. MECHANISM OF MUSCLE CONTRACTION

There are two important theories regarding muscle contraction. They are as follows

1. ELECTROKINEMATIC THEORY

This theory explains that the myosin filaments carry a series of negative charges. The actin filaments are neutral since they carry equal number of positive and negative charges. In the resting condition, there is no electrostatic attraction between the two types of filaments.

During activation, Ca^{++} ions are released from the cytoplasm from the sarcoplasmic reticulum. The released Ca^{++} ions make the actin filaments positive. Now because of charge variations, the positively charged actin filament and the negatively charged myosin filament attract one another. Hence the actin filaments slide towards the myosin filaments.

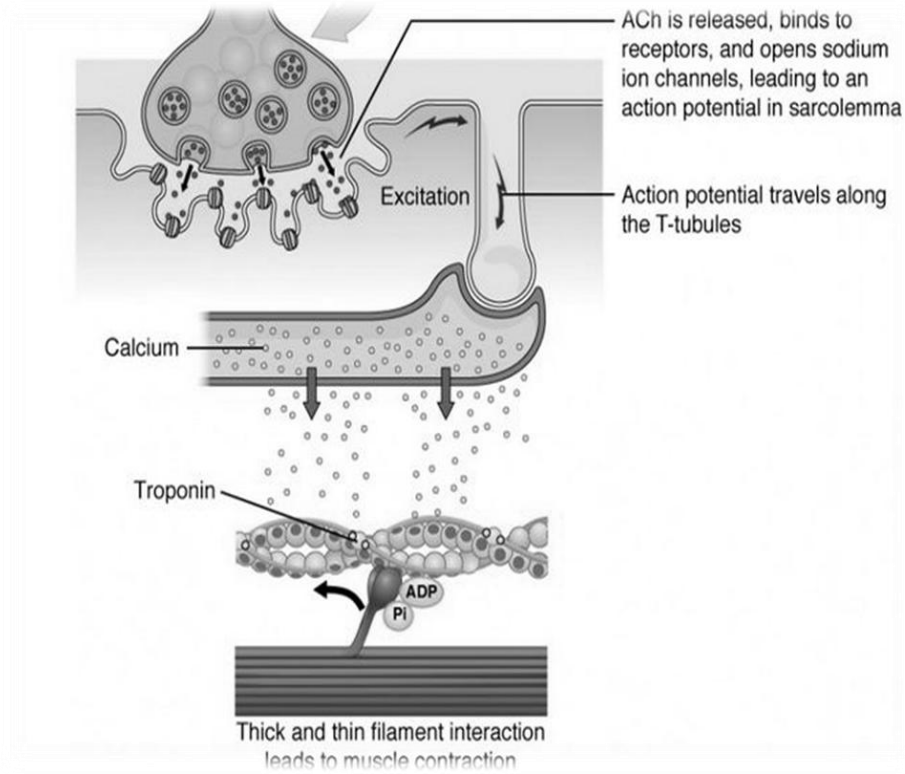


Fig. 23. Electrokinematic theory of muscle contraction

2. SLIDING FILAMENT THEORY

This theory was proposed by Huxly and Hanson (1957). It is based on the structural changes occurring in the muscle fibers during contraction. According to Sliding filament theory, the following events occur during muscle contraction (Fig. 24).

1. The length of the thin actin filaments and thick myofilaments do not change during contraction.
2. Thin actin filaments slide inward toward the H-zone of the dark band.
3. As a result the sarcomere becomes shortened.
4. The head of thick myofilaments become connected with the active sites of thin actin filaments.
5. The thin and thick, actin and myosin filaments slide past each other.
6. As the thick myofilaments move past the thin filaments, the width of the H-zone between the ends of the thin actin filaments meet at the centre of the sarcomere.
7. In fact, the head of thick myofilaments pull the thin actin filaments of each sarcomere far inward that their ends overlap.
8. As the thin actin filaments slide inward, the Z-lines are drawn towards the dark band and the sarcomere is shortened.

9. The sliding of myofilaments and shortening of sarcomere cause the shortening of the muscle fibers.
10. The myosin heads play an important role in muscle contraction. They serve as the cross bridges connecting the actin and myosin filaments in the muscle. During muscle contraction, the cross bridges do not remain attached to the same point on the actin filament throughout this process. It has been reported that during the sliding process, the cross bridges are attached to one site on the actin filaments, then detach and reattach themselves at a new site further along. At each site where cross bridge and actin filament interact, one molecule of ATP splits to generate a sliding force.

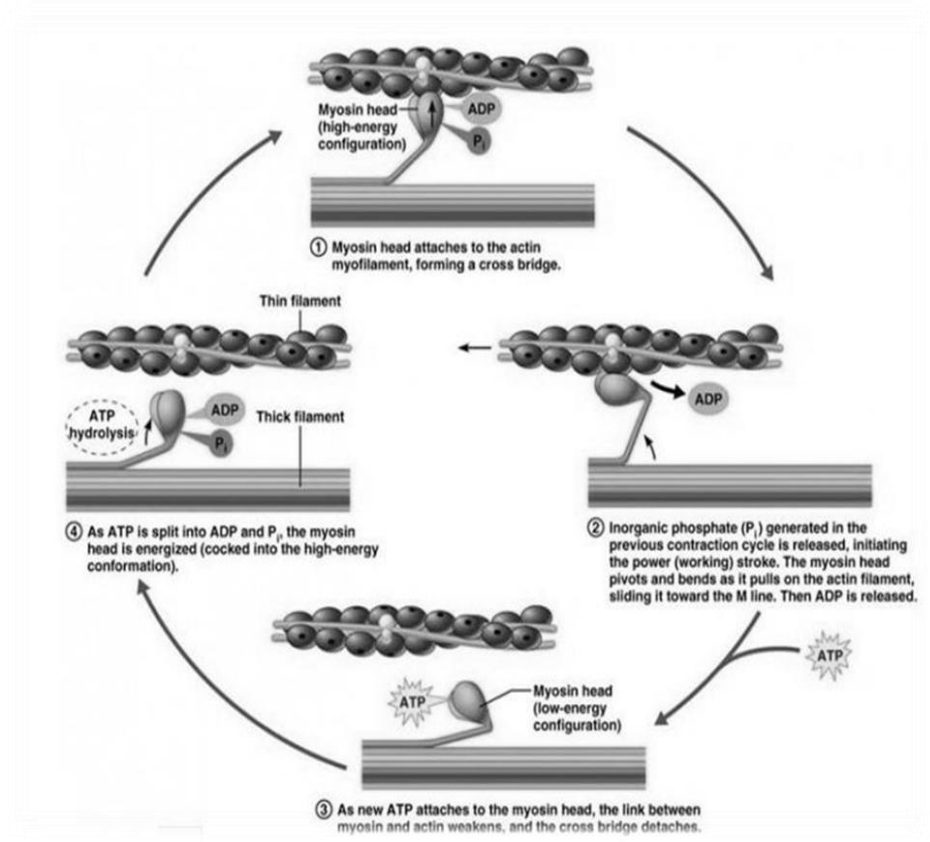


Fig. 24. Sliding filament theory of muscle contraction

8.4 CHEMICAL CHANGES DURING MUSCLE CONTRACTION

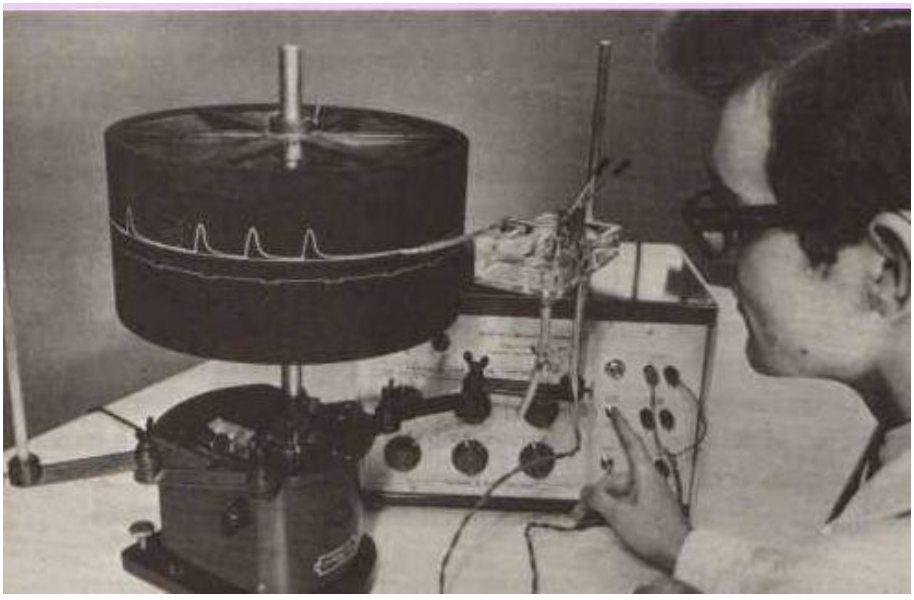
The three types of muscle (skeletal, cardiac and smooth) have significant differences. However, all three use the movement of actin against myosin to create contraction. In skeletal muscle, contraction is stimulated by electrical impulses transmitted by the nerves, the motor nerves and motoneurons in particular. Cardiac and smooth muscle contractions are stimulated by internal pacemaker cells which regularly contract, and propagate contractions to other muscle cells they are in contact with. All

skeletal muscle and many smooth muscle contractions are facilitated by the neurotransmitter acetylcholine.

Muscular activity accounts for much of the body's energy consumption. All muscle cells produce adenosine triphosphate (ATP) molecules which are used to power the movement of the myosin heads. Muscles conserve energy in the form of creatine phosphate which is generated from ATP and can regenerate ATP when needed with creatine kinase. Muscles also keep a storage form of glucose in the form of glycogen. Glycogen can be rapidly converted to glucose when energy is required for sustained, powerful contractions. Within the voluntary skeletal muscles, the glucose molecule can be metabolized anaerobically in a process called glycolysis which produces two ATP and two lactic acid molecules in the process (note that in aerobic conditions, lactate is not formed; instead pyruvate is formed and transmitted through the citric acid cycle). Muscle cells also contain globules of fat, which are used for energy during aerobic exercise. The aerobic energy systems take longer to produce the ATP and reach peak efficiency, and requires many more biochemical steps, but produces significantly more ATP than anaerobic glycolysis. Cardiac muscle on the other hand, can readily consume any of the three macronutrients (protein, glucose and fat) aerobically without a 'warm up' period and always extracts the maximum ATP yield from any molecule involved. The heart, liver and red blood cells will also consume lactic acid produced and excreted by skeletal muscles during exercise.

8.5. KYMOGRAPH

Kymograph is an instrument which is commonly used in physiology lab. It helps to record the muscle or tissue movements, muscle twitch and heart beat of the animals. This is a simple instrument consisting of revolving drum, which bears the kymogram paper on which the needle moves up and down displaying the effect of drugs on contractile tissues. This instrument is commonly used in electrophysiology and pharmacology laboratories in teaching institutions. Muscle or tissue movements are recorded on paper fixed on the moving drum using recording device (Fig. 25).



NOTES

Fig. 25. Electrophysiological reading taken by scientist using kymograph

8.6. LET US SUM UP

The muscular system is mesodermal in origin. Muscle cells are called myofibrils. They are made up of sarcomeres. Sarcomeres are composed of actin and myosin. In general muscle filaments are segregated as thick filaments and thin filaments. Thick filaments consist of myosin. Thin filaments consist of actin, trophomosin and troponin. Based on their function, they are divided as voluntary muscles and involuntary muscles. The voluntary muscles can be controlled according to our will, for example the skeletal muscles. The involuntary muscles such as cardiac muscles and smooth muscles are involved in the vital functions of the body. There are two important theories about muscle contraction and both are generally accepted. According to electrokinematic theory, the release of Ca++ions makes the muscle to contract and the absorption leads to relaxation. According to sliding filament theory the thick myosin head sliding along the thin filament during muscle contraction. During these process the energy is obtained from ATP. The muscle activity can be studied through the instrument called Kymograph.

8.7 UNIT END EXERCISES

1. The structural and functional unit of muscle is called

   a. Actin, b. Myosin c. Sarcomere d. None of these

2. The smooth muscles are

   a. Voluntary b. Skeletal muscles c. Cardiac muscles d. involuntary

3. Thick filaments are made of

   a. Actin b. Myosin c. Troponin d. Tropomyosin

4. The muscle twitch is studied through

   a. ECG b. EEG c. Kymograph d. None of these

5. The contracting muscle retains its original length is called as

   a. Isometric b. Isotonic c. Mesotonic d. Mesometric

8.8 ANSWERS TO CHECK YOUR PROGRESS

1. c, 2. D, 3. B, 4. c, 5. A

8.9.SUGGESTED READINGS

Hall, J. E. 2015. Guyton and Hall Text book of Medical Physiology, 13th Edition, Relx India Pvt. Ltd.

Verma, P.S., B.S. Tyagi, V. K. Agarwal, 2000. Animal Physiology, S. Chand & Co. India.

Rastogi, S. L. 1997. Essential of Animal Physiology, New Age International Publishers, India

UNIT IX - PHYSIOLOGY OF VISION, HEARING AND TACTILE RESPONSE

Structure

9.1 INTRODUCTION

An organism receives all the information about the outside world, as well as changes within the body through sensations, and this information is necessary for the normal functioning of the body. Vision is by far the most used of the five senses and is one of the primary means that we use to gather information from our surroundings. More than 75% of the information we receive about the world around us consists of visual information. Among the sensory organs vision and hearing are more important than the other senses. A photoreceptor, or photoreceptor cell, is a specialized type of neuron (nerve cell) found in the eye's retina that is capable of phototransduction. The great biological importance of photoreceptors is that as cells they convert light (electromagnetic radiation) into the beginning of a chain of biological processes. More specifically, the photoreceptor absorbs photons from the field of view, and through a specific and complex biochemical pathway, signals this information through a change in its membrane potential. The impairment of the vision causes the organism to live in the dark world. So the loss of vision cause the organism greatly disadvantage in the day lit world, however the organism that resides in the permanent dark caves losses its eye sight. But the tactile sense is much developed in these animals. Similarly hearing is very much helpful for the animals for communication as well as for foraging. The normal hearing range of the humans is between 20 to 20,000 hertz. The hearing range below the hearing range is called infrasonic sounds which are used by elephants for communication. Similarly the frequency above 20,000 hertz is called ultrasonic sounds which are used by bats for communication. The external ear is the window for receiving sound for the vertebrates. The ear is not only the organ of hearing but it also contains receptors for equilibrium in the vestibular apparatus located in the inner ear.

9.2 PHYSIOLOGY OF VISION

In the terrestrial vertebrate eye, the incident light is focused in two stages. In the initial stage, incident light rays are bent or refracted, as they pass through the clear outer surface of the eye the cornea. The light rays further refracted as they pass through the second structure the lens, and finally form an inverted image on the rear internal surface of the eye, the retina.

LAYERS OF EYE

The human eye is wrapped in three layers of tissue:

1. THE SCLEROTIC COAT

This tough layer creates the "white" of the eye except in the front where it forms the transparent **cornea**. The cornea admits light to the interior of the eye and bends the light rays to that they can be brought to a focus (Fig 25).

The surface of the cornea is kept moist and dust-free by secretions from the tear glands.

2. C**HOROID COAT**

This middle layer is deeply pigmented with **melanin**. It reduces reflection of stray light within the eye. The choroid coat forms the **iris** in the front of the eye. This, too, is pigmented and is responsible for eye "color". The size of its opening, the **pupil**, is variable and under the control of the autonomic nervous system. In dim light (or when danger threatens), the pupil opens wider letting more light into the eye. In bright light the pupil closes down. This not only reduces the amount of light entering the eye but also improves its image-forming ability (as does "stopping down" the iris diaphragm of a camera).

3. RETINA

The retina is the inner layer of the eye. It contains the light receptors, the **rods** and **cones** (and thus serves as the "film" of the eye). The retina also has many interneurons that process the signals arising in the rods and cones before passing them back to the brain. Retina contains special photosensitive cells called rods and cones. The rods are cylindrical in shape and cones are pyramidal in shape. Each eye contains about 100 million rods and 7 million cones. The rods contain a pigment called rhodopsin and cones contain another pigment called iodopsin. The cones are responsible for bright light vision or colour vision and acuity of vision; the rods are responsible for dim light vision.

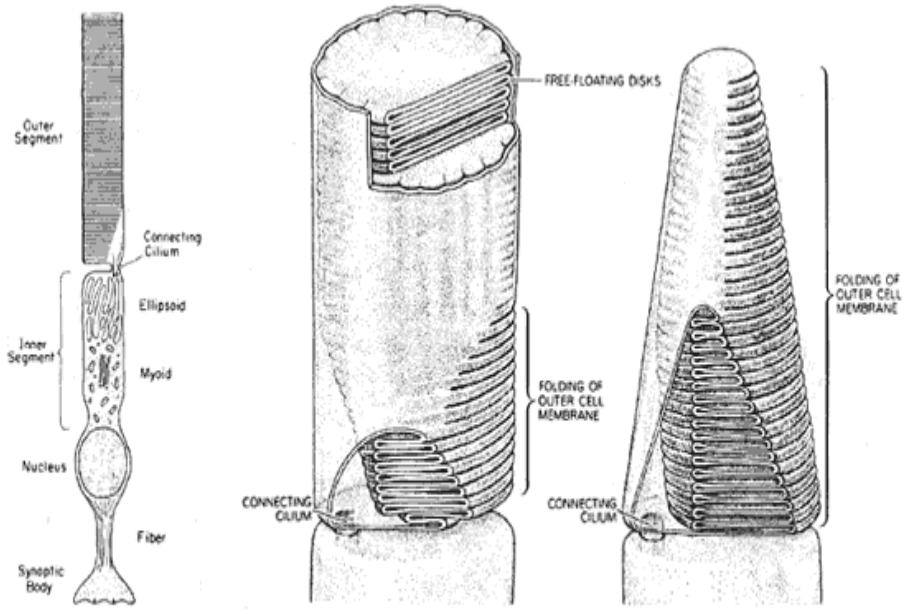
9.2.1 PHOTO RECEPTORS AND RETINAL PIGMENTS

There are two types of photo receptors in the retina of the eye, they are rods and cones. These photoreceptor cells convert light into atomic motion and then into a nerve impulse. These cells are arranged vertically and parallel in a palisade fashion. The rods outnumber the cones in human retina.

A. ROD CELLS

Rods are the retinal elements responsible for vision in the dim light; the cones are involved in vision in bright light and the perception of colour. Rods are slender, elongated structures, typically 1mm in diameter and 40 mm in length (Fig. 26). The outer segment of a rod is specialized for photoreception. It contains a stack of about 1,000 discs, which are closed, flattened sacs about $160A^0$ thick. These membranous structures are densely packed with photoreceptor molecules. The photosensitive molecule in rods is visual purple or rhodopsin, which consists of opsin, a protein and 11-cis-retinal, a prosthetic group. Opsin does not absorb visible light. The colour of rhodopsin and its responsiveness to light depend on the presence of 11-cis-retinal, which is a very effective chromophore. Rhodopsin is synthesised by ribosomes that are attached to the endoplasmic reticulum. The inner segment of the rod cell, has a large number of mitochondria which are known as the ellipsoid. The inner segment generates ATP at a very rapid rate and is highly active in synthesizing proteins. It is contiguous with the nucleus, which is next to the synaptic body.

The discs in the outer segment have a life of only ten days and are continually renewed. The visual pigment rhodopsin present in this segment absorbs the light energy and initiates the visual stimulus from the rod cell. These cells are used for peripheral vision and for vision at low levels of light intensity (twilight or **scotopic vision**), for example, the dim light in the interior of a darkened room.



At the left is a generalized conception of the important structural features of a vertebrate photoreceptor cell. At the right are shown the differences between the structure of rod (left) and cone (right) outer segments. These diagrams are from Young (1970) and Young (1971).

Fig. 26. Structural features of rod and cone cells

B. CONE CELLS

The lamellate plates present in the outer segment of a cone cell do not contain rhodopsin but another visual pigment often called visual violet or **iodopsin**. The cones are thinnest in the fovea where the visual activity is greatest. The cones are sensitive to bright light and colour (**photopic vision**) (Fig. 27). Spectrophotometric studies have revealed that there are in fact three types of cone cells: blue, green, and red-absorbing. The effect of different wavelengths of light on the cones results in the perception of different colours.

For the sensory cells of the retina to be stimulated by light and respond, a sufficient number of light quanta must be absorbed. This is achieved with the aid of a light absorbing pigment. The best known such pigment is rhodopsin, which is found in the rods of the vertebrate eye. Rhodopsin can be isolated from retinas of animals whose eyes are fully dark adapted. It is light sensitive, and when exposed to light breaks down to retinene, a molecule closely related to Vitamin A, and a protein called opsin.

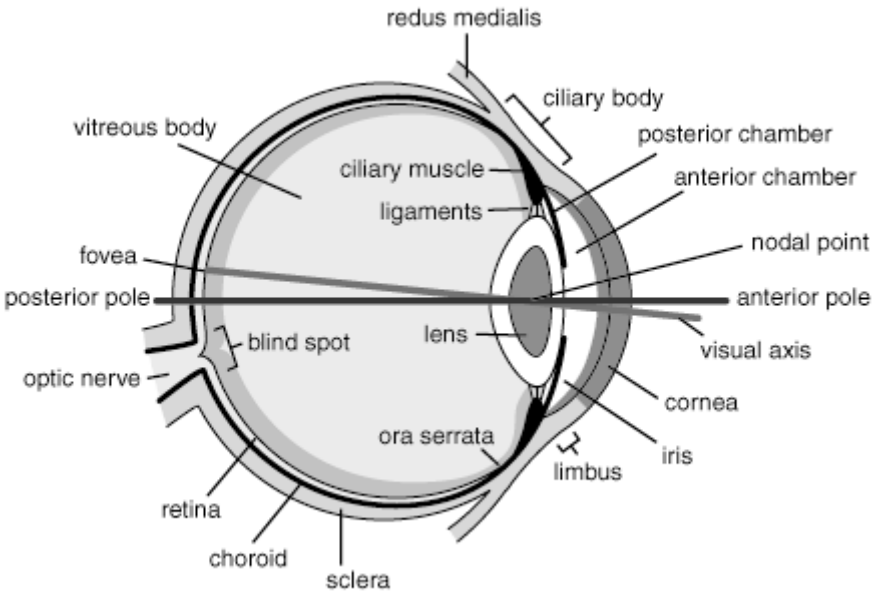
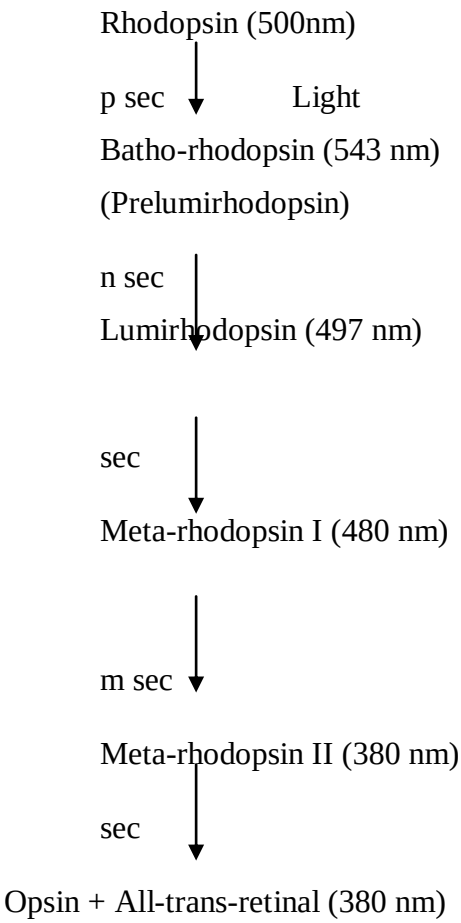


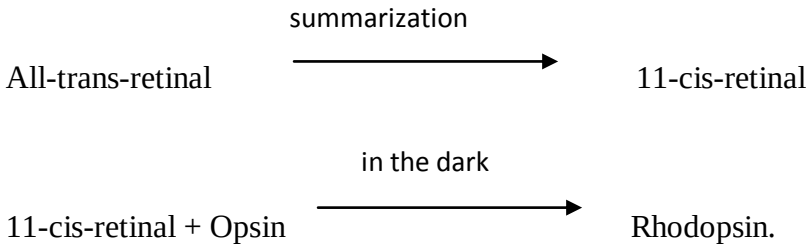
Fig.27. Structure of human eye

9.2.2 PHOTOCHEMISTRY OF VISION

When light falls on the retina, 1-cis-retinal group of rhodopsin is isomerised to all-trans-retinal through several stages. With in a fee picoseconds of the absorption of a photon, rhodopsin is first converted into a photolytic intermediate, called **batho-rhodopsin** or **prelumirhodopsin.** In a nanosecond, batho-rhodopsin is converted into **lumirhodopsin** and then to **meta-rhodopsin I** in a microsecond. The transition from meta-rhodopsin I to **meta-rhodopsin II** takes about a millisecond. Meta-rhodopsin II is hydrolysed in about a minute to yield **opsin** and **all-trans-retinal,** which diffuses away from the protein.



All-trans-retinal is isomerised in the dark to 11-cis-retinal, which associates with **opsin** to regenerater **rhodopsin:**



Finally, the ultimate precursors of 11-cis-retinal are the carotenes, which have a very broad biological distribution.

The rhodopsin must be resynthesised immediately for the next response. The synthesis of rhodopsin can take place either from retinene or from Vitamin A. The retinene is in the from of all trans-retinene. It is isomerised in the dark by the retinene isomerase into II-cis- retinal. The II-cis-retinal combines with opsin spontaneously to form rhodopsin. In the light II-cis-retinal of rhodopsin is converted into the all trans-retinal that is present in the luminorhodopsin. It is converted into all trans Vitamin A by alcohol dehydrogenase in the presence of NAD. The all trans Vitamin A is isomerised by isomerase into cis-Vitamin A1 which is then oxidized to cis-retinal.

9.3 PHYSIOLOGY OF HEARING

Hearing is the process by which the ear transforms sound vibrations in the external environment into nerve impulses that are conveyed to the brain, where they are interpreted as sounds. Sounds are produced when vibrating objects, such as the plucked string of a guitar, produce pressure pulses of vibrating air molecules, better known as sound waves. The ear can distinguish different subjective aspects of a sound, such as its loudness and pitch, by detecting and analyzing different physical characteristics of the waves. Pitch is the perception of the frequency of sound waves—i.e., the number of wavelengths that pass a fixed point in a unit of time. Frequency is usually measured in cycles per second, or hertz. The human ear is most sensitive to and most easily detects frequencies of 1,000 to 4,000 hertz, but at least for normal young ears the entire audible range of sounds extends from about 20 to 20,000 hertz. Sound waves of still higher frequency are referred to as ultrasonic, although they can be heard by other mammals. Loudness is the perception of the intensity of sound—i.e., the pressure exerted by sound waves on the tympanic membrane. The greater their amplitude or strength, the greater the pressure or intensity, and consequently the loudness, of the sound. The intensity of sound is measured and reported in decibels (dB), a unit that expresses the relative magnitude of a sound on a logarithmic scale. Stated in another way, the decibel is a unit for comparing the intensity of any given sound with a standard sound that is just perceptible to the normal human ear at a frequency in the range to which the ear is most sensitive. On the decibel scale, the range of human hearing extends from 0 dB, which represents a level that is all but inaudible, to about 130 dB, the level at which sound becomes painful.

In order for a sound to be transmitted to the central nervous system, the energy of the sound undergoes three transformations. First, the air vibrations are converted to vibrations of the tympanic membrane and ossicles of the middle ear. These in turn become vibrations in the fluid within the cochlea. Finally, the fluid vibrations set up traveling waves along the basilar membrane that stimulate the hair cells of the organ of Corti. These cells convert the sound vibrations to nerve impulses in the fibres of the cochlear nerve, which transmits them to the brainstem, from which they are relayed, after extensive processing, to the primary auditory area of the cerebral cortex, the ultimate centre of the brain for hearing. Only when the nerve impulses reach this area does the listener become aware of the sound.

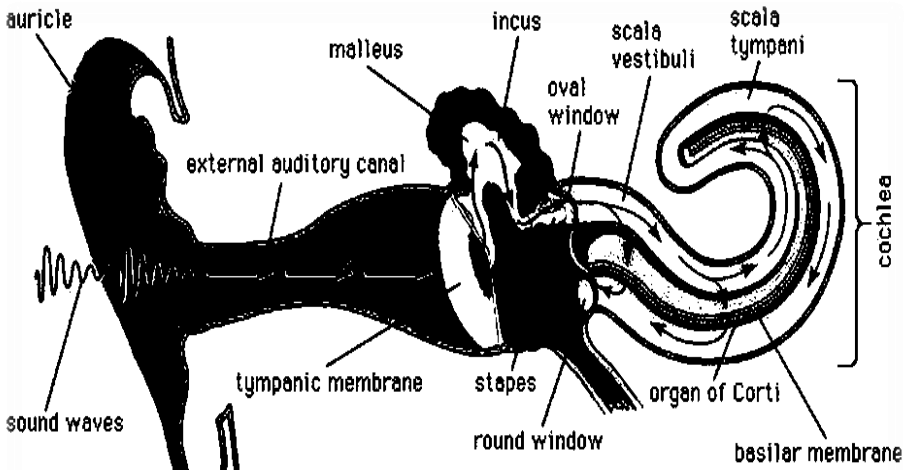


Fig. 28. Structure of human ear

9. 3. 1. THE MECHANISM OF HEARING

Sound waves enter the outer ear and travel through the external auditory canal until they reach the tympanic membrane, causing the membrane and the attached chain of auditory ossicles to vibrate. The motion of the stapes against the oval window sets up waves in the fluids of the cochlea, causing the basilar membrane to vibrate. This stimulates the sensory cells of the organ of Corti, atop the basilar membrane, to send nerve impulses to the brain.

The outer ear directs sound waves from the external environment to the tympanic membrane. The auricle, the visible portion of the outer ear, collects sound waves and, with the concha, the cavity at the entrance to the external auditory canal, helps to funnel sound into the canal. Because of its small size and virtual immobility, the auricle in humans is less useful in sound gathering and direction finding than it is in many animals. The canal helps to enhance the amount of sound that reaches the tympanic membrane. This resonance enhancement works only for sounds of relatively short wavelength—those in the frequency range between 2,000 and 7,000 hertz—which helps to determine the frequencies to which the ear is most sensitive, those important for distinguishing the sounds of consonants. Sounds reaching the tympanic membrane are in part reflected and in part absorbed. Only absorbed sound sets the membrane in motion. The tendency of the ear to oppose the passage of sound is called acoustic impedance. The magnitude of the impedance depends on the mass and stiffness of the membrane and the ossicular chain and on the frictional resistance they offer (Fig. 28).

When the tympanic membrane absorbs sound waves, its central portion, the umbo, vibrates as a stiff cone, bending inward and outward. The greater the force of the sound waves, the greater the deflection of the membrane and the louder the sound. The higher the frequency of a sound, the faster the membrane vibrates and the higher the pitch of the sound is. The motion of the membrane is transferred to the handle of the malleus, the tip of which is attached at the umbo. At higher frequencies the motion of

the membrane is no longer simple, and transmission to the malleus may be somewhat less effective.

The malleus and incus are suspended by small elastic ligaments and are finely balanced, with their masses evenly distributed above and below their common axis of rotation. The head of the malleus and the body of the incus are tightly bound together, with the result that they move as a unit in unison with the tympanic membrane. At moderate sound pressures, the vibrations are passed on to the stapes, and the whole ossicular chain moves as a single mass. However, there may be considerable freedom of motion and some loss of energy at the joint between the incus and the stapes because of their relatively loose coupling. The stapes does not move in and out but rocks back and forth about the lower pole of its footplate, which impinges on the membrane covering the oval window in the bony plate of the inner ear. The action of the stapes transmits the sound waves to the perilymph of the vestibule and the scala vestibuli.

In order for sound to be transmitted to the inner ear, the vibrations in the air must be changed to vibrations in the cochlear fluids. There is a challenge involved in this task that has to do with difference in impedance—the resistance to the passage of sound—between air and fluid. This difference, or mismatch, of impedances reduces the transmission of sound. The tympanic membrane and the ossicles function to overcome the mismatch of impedances between air and the cochlear fluids, and thus the middle ear serves as a transformer, or impedance matching device.

The ossicular chain not only concentrates sound in a small area but also applies sound preferentially to one window of the cochlea, the oval window. If the oval and round windows were exposed equally to airborne sound crossing the middle ear, the vibrations in the perilymph of the scala vestibuli would be opposed by those in the perilymph of the scala tympani, and little effective movement of the basilar membrane would result. As it is, sound is delivered selectively to the oval window, and the round window moves in reciprocal fashion, bulging outward in response to an inward movement of the stapes footplate and inward when the stapes moves away from the oval window. The passage of vibrations through the air across the middle ear from the tympanic membrane to the round window is of negligible importance.

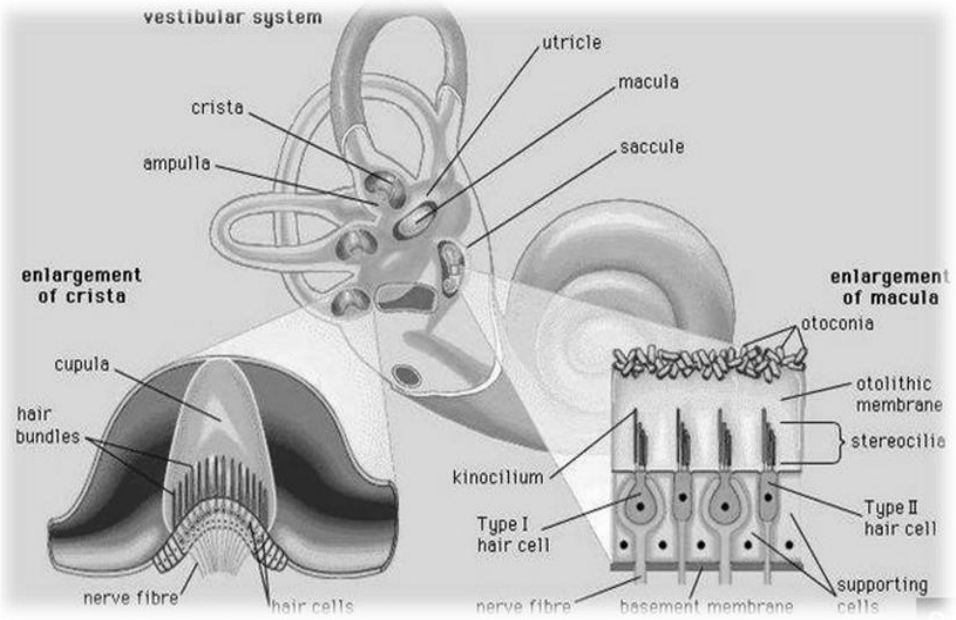


Figure: 29. Inner ear showing cochlea and hair cells

The inner ear consists of the cochlea and several non-auditory structures (Fig. 29). The cochlea has three fluid-filled sections, and supports a fluid wave driven by pressure across the basilar membrane separating two of the sections. Strikingly, one section, called the cochlear duct or scala media, contains an extracellular fluid similar in composition to endolymph, which is usually found inside of cells. The organ of Corti is located at this duct, and transforms mechanical waves to electric signals in neurons. The other two sections are known as the scala tympani and the scala vestibuli; these are located within the bony labyrinth which is filled with fluid called perilymph. The chemical difference between the two fluids (endolymph & perilymph) is important for the function of the inner ear.

9.4 TACTILE RESPONSE

In humans the tactile response is perceived by tactile or mechano receptors. Mechanoreceptors in the skin are described as encapsulated or unencapsulated. A free nerve ending is an unencapsulated dendrite of a sensory neuron; they are the most common nerve endings in skin. Free nerve endings are sensitive to painful stimuli, to hot and cold, and to light touch. They are slow to adjust to a stimulus and so are less sensitive to abrupt changes in stimulation.

Mechanoreceptors sense stimuli due to physical deformation of their plasma membranes. They contain mechanically-gated ion channels whose gates open or close in response to pressure, touch, stretching, and sound. There are four primary tactile mechanoreceptors in human skin: Merkel's disks, Meissner's corpuscles, Ruffini endings, and Pacinian corpuscle; two are located toward the surface of the skin and two are located deeper.

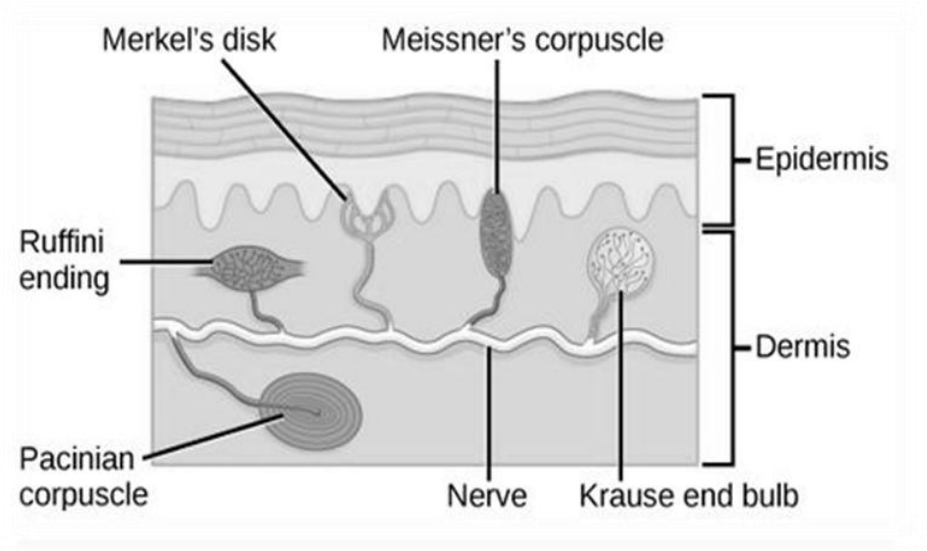


Fig. 30. Mechano or tactile receptors in the skin

Merkel's disks are found in the upper layers of skin near the base of the epidermis, both in skin that has hair and on glabrous skin; that is, the hairless skin found on the palms and fingers, the soles of the feet, and the lips of humans and other primates (Fig. 30). Merkel's disks are densely distributed in the fingertips and lips. They are slow-adapting, unencapsulated nerve endings, which respond to light touch. Light touch, also known as discriminative touch, is a light pressure that allows the location of a stimulus to be pinpointed. The receptive fields of Merkel's disks are small, with well-defined borders. That makes them very sensitive to edges; they come into use in tasks such as typing on a keyboard.

Meissner's corpuscles, also known as tactile corpuscles, are found in the upper dermis, but they project into the epidermis. They are found primarily in the glabrous skin on the fingertips and eyelids. They respond to fine touch and pressure, but they also respond to low-frequency vibration or flutter. They are rapidly- adapting, fluid-filled, encapsulated neurons with small, well-defined borders which are responsive to fine details. Merkel's disks and Meissner's corpuscles are not as plentiful in the palms as they are in the fingertips (Fig. 30).

Deeper in the dermis, near the base, are Ruffini endings, which are also known as bulbous corpuscles. They are found in both glabrous and hairy skin. These are slow-adapting, encapsulated mechanoreceptors that detect skin stretch and deformations within joints; they provide valuable feedback for gripping objects and controlling finger position and movement. Thus, they also contribute to proprioception and kinesthesia. Ruffini endings also detect warmth. Note that these warmth detectors are situated deeper in the skin than are the cold detectors. It is not surprising, then, that humans detect cold stimuli before they detect warm stimuli.

Pacinian corpuscles, located deep in the dermis of both glabrous and hairy skin, are structurally similar to Meissner's corpuscles. They are found in the bone periosteum, joint capsules, pancreas and other viscera, breast, and genitals. They are rapidly-adapting mechanoreceptors that sense deep, transient (not prolonged) pressure, and high-frequency vibration. Pacinian

receptors detect pressure and vibration by being compressed which stimulates their internal dendrites. There are fewer Pacinian corpuscles and Ruffini endings in skin than there are Merkel's disks and Meissner's corpuscles.

9.5. LET US SUM UP

The information from outside world is received by the organism through vision, hearing and tactile sense. The vision is perceived through eye. The human eye is wrapped in three layers of tissue. They are scleroid, choroid and retina. The retina contains two types of cells, the cone cells which is responsible for the light and colour vision; the rod cells, which are responsible for dim light vision. Similarly hearing is done by the ears and it is divided into external ear, middle ear and the inner ear. The sound wave is transformed into electrical signal and the message is carried to the brain for encoding the information. When the sound enter into the ear, the three ear ossicles malius, incus and stapis in the middle ear strike on the bony plate of the inner ear, where the sound impulse is transformed into electric signal by the vibration of the coclea. Likewise, the mechano receptors perceive the tactile response, there are four primary mechano receptors in the skin. They are Meissner's corpuscles, Ruffini endings, Pacinian corpuscles and Merkel's disks.

9.6 UNIT END EXERCISES

1. A receptor which responds to mechanical stimulus is called

    a. Photo receptor b. Phono receptor c. Mechano receptor d. none of these

2. The cone cells in retina is responsible for ---

    a. Colour vision b. Dark vision c. Insensitive to light d. none of these

3. In the blind spot of the eye

    a. Cones are absent b. Rods are absent c. Both present d. Both absent

4. Night blindness happens due to the deficiency of –

    a. Vitamin D b. Vitamin B c. Vitamin C d. Vitamin A

5. The human ear is the

    a. Photo receptor b. Chemo receptor c. Phono receptor d. None of these

9.7. ANSWER TO CHECK YOUR PROGRESS

1. c, 2. a, 3. d, 4. d, 5. c

9.8 SUGGESTED READINGS

Verma, P.S., B.S. Tyagi, V. K. Agarwal, 2000. Animal Physiology, S. Chand & Co. India.

Rastogi, S. L. 1997. Essential of Animal Physiology, New Age International Publishers, Indi

NOTES

UNIT X - THERMOREGULATION

Structure

10.1 INTRODUCTION

Homeostasis is a property of a system either open or closed that regulates its internal environment and tends to maintain a stable constant condition. With regards to any given life system parameter, an organism may be a *conformer* or a *regulator*. On one hand, regulators try to maintain the parameter at a constant level over possibly wide ambient environmental variations. On the other hand, conformers allow the environment to determine the parameter. For instance, endothermic animals maintain a constant body temperature, while exothermic (both ectotherm and poikilotherm) animals exhibit wide body temperature variation. We will study in detail about the different types of mechanisms involved in the maintenance of homeotic condition in animals.

Not only has the regulation of temperature animals also needed to maintain their body fluids. The maintenance of optimal concentration of water and salts in the tissues and body fluids of animals is called osmoregulation. For example in fresh water animals the internal fluid concentration is higher than that of the external medium and they need to prevent the salt and mineral lost, whereas, in marine animals the external environment is hyper osmotic, so they need to prevent water loss from body. So both the animals adapted according to their surrounding environment. Likewise the land animals like birds and mammal adapted differently for the conservation of water. We will see the maintenance of homeotic mechanisms in detail in this unit.

People have been fascinated by the behaviour of animal for a long time. But the scientific study of behaviour is a recent phenomenon and it received its most important boost from the writings of Charles Darwin. Darwin included a chapter in *The Origin of species* on ‘instinct’ a term used in his time to refer to the natural behaviour of animals. In this unit we will study about endogenous rhythms of animals and the physiological basis of learning and memory in detail.

NOTES

10.2.THERMOREGULATION

Thermoregulation is the ability of an organism to keep its body temperature within certain boundaries, even when the surrounding temperature is very different. This process is one aspect of homeostasis. If the body is unable to maintain a normal temperature and it increases significantly above normal, a condition known as hyperthermia occurs. The opposite condition, when body temperature decreases below normal levels, is known as hypothermia.

10.2.1. POIKILOTHERMS

A **poikilotherm** is an animal whose internal temperature varies along with that of the ambient environmental temperature. It is also called thermoconformer. When an organism that *thermoregulates* is one that keeps its core body temperature within certain limits, a **thermoconformer** is subject to changes in body temperature according to changes in the temperature outside of its body. They are also called as cold blooded animals e.g., Frogs, Lizards, etc.

Poikilotherms often have more complex metabolisms than homeotherms. For an important chemical reaction, poikilotherms may have four to ten enzyme systems that operate at different temperatures. As a result, poikilotherms often have larger, more complex genomes than homeotherms in the same ecological niche. Frogs are a notable example of this effect. Because their metabolism is so variable, poikilothermic animals do not easily support complex, high-energy organ systems such as brains or wings. Some of the most complex adaptations known involve poikilotherms with such organ systems.

One example is the swimming muscles of Tuna, which are warmed by a heat exchanger.

In general, poikilothermic animals do not use their metabolisms to heat or cool themselves. For the same body weight poikilotherms need 1/3 to 1/10 of the energy of homeotherms. They therefore eat only 1/3 to 1/10 of the food needed by homeothermic animals. It is comparatively easy for a poikilotherm to accumulate enough energy to reproduce. Poikilotherms in the same ecological niche often have much shorter generations than homeotherms: weeks rather than years.

This energy difference also means that a given niche of a given ecology can support three to ten times the number of poikilothermic animals as homeothermic animals. However, in a given niche, homeotherms often drive poikilothermic competitors to extinction because homeotherms can gather food at for a greater fraction of each day.

Poikilotherms succeed in some niches, such as islands, or distinct bioregions (such as the small bioregions of the Amazon basin). These often do not have enough food to support a viable breeding population of homeothermic animals. In these niches, poikilotherms such as large lizards, crabs and frogs supplant homeotherms such as birds and mammals.

10.2.2. HOMEOTHERMS

Warm-blooded (or **homeothermic**) animal species is one whose members maintain thermal homeostasis; that is, they keep their body temperature at

NOTES

a roughly constant level, regardless of the ambient temperature. This involves the ability to cool down or produce more body heat. Warm-blooded animals mainly control their body temperature by regulating their metabolic rates (e.g. increasing their metabolic rate as the surrounding temperature begins to decrease).

In humans and other mammals, temperature regulation represents the balance between heat production from metabolic sources and heat loss from evaporation (perspiration) and the processes of radiation, convection, and conduction. In a cold environment, body heat is conserved first by constriction of blood vessels near the body surface and later by waves of muscle contractions, or shivering, which serve to increase metabolism. Shivering can result in a maximum fivefold increase in metabolism. Below about 40°F (4°C) a naked person cannot sufficiently increase the metabolic rate to replace heat lost to the environment. Another heat-conserving mechanism, goose bumps, or piloerection, raises the body hairs; although not especially effective in humans, in animals it increases the thickness of the insulating fur or feather layer.

In a warm environment, heat must be dissipated to maintain body temperature. In humans, increased surface blood flow, especially to the limbs, acts to dissipate heat at the surface. At environmental temperatures above 93°F (34°C), or at lower temperatures when metabolism has been increased by work, heat must be lost through the evaporation of the water in sweat. People in active work may lose as much as 4 quarts per hour for short periods. However, when the temperature and humidity are both high, evaporation is slowed, and sweating is not effective. Most mammals do not have sweat glands but keep cool by panting (evaporation through the respiratory tract) and by increased salivation and skin and fur licking.

Temperature regulatory mechanisms act through the autonomic nervous system and are largely controlled by the hypothalamus of the brain, which responds to stimuli from nerve receptors in the skin. Continued exposure to heat or cold results in some slow acclimatization, e.g. more active sweating in response to continued heat and an increase in subcutaneous fat deposits in response to continued cold.

Environmental extremes may result in failure to maintain normal body temperature. In both increased body temperature, or hyperthermia, and decreased body temperature, or hypothermia, death may result. Controlled hypothermia is used in some types of surgery to temporarily decrease the metabolic rate. Fever, caused by a resetting of the temperature regulatory mechanism, is a response to fever-causing, or pyrogenic, substances, such as bacterial endotoxins or leucocyte extracts. The upper limit of body temperature compatible with survival is about 107°F (42°C), while the lower limit varies.

10.2.3. MECHANISM TO MAINTAIN HOMEOTHERMY

A, GENERATING AND CONSERVING HEAT

The creatures traditionally regarded as warm-blooded have a larger number of mitochondria per cell, which enables them to generate heat by increasing the rate at which they "burn" fats and sugars. This requires a

much greater quantity of food than is needed by cold-blooded animals in order to replace the fat and sugar reserves.

In many endothermic animals a controlled state of hypothermia called hibernation, or torpor conserves energy by lowering the body temperature. Many birds' and small mammals' body temperature drops during daily inactivity, such as at night for diurnal animals or during the day for nocturnal animals thus reducing the energy cost of maintaining body temperature. Human metabolism also slows down slightly during sleep.

NOTES

Heat loss is a major threat to smaller creatures as they have a larger ratio of surface area to volume. Most small warm-blooded animals have insulation in the form of fur or feathers. Aquatic warm-blooded animals generally have deep layers of fat under the skin for insulation, since fur or feathers would spoil their streamlining. Penguins have both feathers and fat, since their need for streamlining limits the degree of insulation which feathers alone can give them. Birds, especially waders, have blood-vessels in their lower legs which act as heat exchangers - veins are right next to arteries and thus extract heat from the arteries and carry it back into the trunk. Many warm-blooded animals blanch (become paler) in response to cold, which reduces heat loss by reducing the blood flow to the skin.

B, AVOIDING OVER-HEATING

In equatorial climates and during temperate summers over-heating is as great a threat as cold. In hot conditions many warm-blooded animals increase heat loss by panting and or flushing (increasing the blood flow to the skin). Hairless and short-haired mammals also sweat, since the evaporation of sweat consumes a lot of heat. Elephants keep cool by using their huge ears like radiators in automobiles: they flap their ears to increase the airflow over them.

10.2.4. COMPARISON OF HOMEOTHERMY AND POIKILOTHERMY

A, ADVANTAGES OF A FAST METABOLISM

The overall speed of an animal's metabolism increases by a factor of about 2 for every 10 °C rise in temperature (limited by the need to avoid hyperthermia). Warm-bloodedness does not provide greater speed than cold-bloodedness - cold-blooded animals can move as fast as warm-blooded animals of the same size and build when the cold-blooded animal is near or at its optimum temperature. But warm-blooded animals have much greater stamina than cold-blooded creatures of the same size and build, because their faster metabolisms quickly regenerate energy supplies (especially ATP) and break down muscular waste products (especially lactate). This enables warm-blooded predators to run down cold-blooded prey, warm-blooded prey to outrun cold-blooded predators (provided they avoid the initial charge or ambush) and warm-blooded animals to be much more successful foragers. Warm-blooded creatures can be active at more time during the diurnal cycle in places of sharp temperature differences between day and night and during more of the year in places of great seasonal differences of temperature.

NOTES

B, ADVANTAGES OF HOMEOTHERMY

Enzymes have strong temperature preferences and their efficiency is much reduced outside their preferred ranges. A creature with a fairly constant body temperature can therefore specialize in enzymes which are efficient at that particular temperature. Another advantage of a homeothermic animal is its ability to maintain its constant body temperature even in freezing cold weather. A poikilotherm must either operate well below optimum efficiency most of the time, migrate and be inactive sometimes, or expend extra resources producing a wider range of enzymes to cover the wider range of body temperatures.

C, PROTECTION AGAINST FUNGAL INFECTIONS

While hundreds of thousands of species of fungi are known to infect plants, and tens of thousands infect insects, only a few hundreds target mammals, and often only those with a compromised immune system. A recent study suggests that fungi are fundamentally ill-equipped to thrive at mammalian temperatures. Thus warm-bloodedness might have provided an evolutionary advantage.

D. DISADVANTAGES OF WARM-BLOODEDNESS

Because warm-blooded animals use enzymes which are specialized for a narrow range of body temperatures, over-cooling rapidly leads to torpor and then death. Also, the energy required to maintain the homeothermic temperature comes from food - this results in homeothermic animals needing to eat much more food than poikilothermic animals.

Some predators have the capacity to detect warm-blooded prey (typically rodents and small birds) through the heat that the animal generates. Likewise, they are unable to detect cold-blooded prey (such as lizards and frogs)

Shivering and fat-burning to maintain temperature are very energy-intensive, for example,in winter many small birds lose one third of their body weight overnight. In general a warm-blooded animal requires 5 to 10 times as much food as a cold-blooded animal of the same size and build, so cold-blooded animals are better at surviving in barren environments.

10.2.5. TEMPERATURE CONTROL IN HOMEOTHERMS

Homeotherms or endotherms use a wide variety of physiological and behavioural mechanisms to maintain body temperature within a narrow range in both cool and warm environments. The major thermal adaptations of endotherms living in cool or cool environments resolve around producing sufficient body heat and then retaining it.

When the ambient temperature drops below the lower critical temperature, an endothermic animal responds by generating large amount of additional heat from its energy stores, thereby preventing a decrease in its core temperature. There are two primary means of heat production, or thermogenesis, other than locomotor activity; shivering and nonshivering thermogenesis. Both process convert chemical energy into heat by a normal energy converting metabolic mechanism that has been adapted to produce primarily heat.

Shivering is a means of using muscle contraction to produce heat. Shivering thermogenesis is employed by most endothermic vertebrates as well as by some insects. The activation of muscles causes ATP to be hydrolyzed to provide energy for their contraction. Because the muscle contractions are inefficiently timed and mutually opposed, however, they produce no useful physical work, and the chemical energy released during contraction appears as heat.

In non-shivering thermogenesis, enzyme systems for the metabolism of fats are activated throughout the body so that fats are broken down and oxidized to produce heat. Very little energy released is conserved in the form of newly synthesized ATP. A few mammals have evolved an adipose tissue called **brown fat** that is specialized for fat-fueled thermogenesis. Brown fat contains such extensive vascularization and so many mitochondria that it is brown rather than white. Generally found as small deposits in the neck and between the shoulders, brown fat is an adaptation for rapid, massive heat production. In the routine metabolism of ordinary body fat, deposits of fat are first reduced to fatty acids, then exported through the circulation to be taken up by other tissues, where they are oxidized. In brown fat, oxidation takes place within the fat cells themselves, which are richly endowed with fat-metabolizing enzyme systems.

10.2.6. TEMPERATURE CONTROL IN POIKILOTHERMIC ANIMALS

Many cold-blooded animals use behavioral means to adjust their internal temperatures:

- lizards and snakes bask in the sun in the early morning and late evening, and seek shelter around noon.
- many species of bees and moths flap their wings vigorously to raise the temperature of their flight muscles before taking off.
- bees in large hives will cool the hive in hot periods by going to its entrances and using their wings as fans to draw cooling air through the hive. They will warm the hive in cool periods by gathering in the middle and shivering to produce heat.
- termite mounds are usually oriented in a north-south direction so that they absorb as much heat as possible around dawn and dusk and minimize heat absorption around noon.

10.3 TOLERANCE TO HIGH TEMPERATURE

Each animal has its favourite temperature for its survival and reproduction and survival and that temperature is called as the optimum temperature for that animal. If the organism is able to survive at extreme temperature, that animal is called as thermophile. No animal is known to live and carry out its complete life cycle at a temperature over 50^0C . Thermophilic bacteria are more heat tolerant, some live and grow in the hot springs where the temperature is about 92^0 C. Bacteria recovered from deep sea hydrothermal vents in the arctic region have even greater temperature tolerance and many thrive at temperature above 100^0 C.

NOTES

An animal in resting stage may be extremely tolerant to high temperatures. For example, a fly larva (*Polypedilum*) can tolerate dehydration, and in the dehydrated state it can survive a temperature of 102^0 C for one minute and afterward grow and metamorphose successfully. Another example of extreme tolerance is provided by the eggs of fresh-water crustacean (*Triops*); these eggs survive through winter and early summer in dry mud, where they may be exposed to temperatures up to 80^0 C.

The animals exposed to more heat than their heat tolerant level will die. Some factors that have been suggested as contributing to heat death are, 1. Denaturation of proteins, thermal coagulation and the heat shock proteins helps to prevent the denaturation at high temperature, 2. Thermal inactivation of enzymes at rates that exceed rates of formation, since all the enzymes are proteins they will get denatured at high temperature, 3. Inadequate oxygen supply due to high temperature 4. Different temperature effects (Q_{10}) on interdependent metabolic reactions, 5. Temperature effects on membrane structure. These things are the main reasons for the death of animal at higher temperature.

10.4 TOLERANCE TO COLD AND FREEZING

Animals that live in temperate and cold regions are often exposed to long periods of winter temperatures that are far below the freezing point of water. Survival of cold-blooded animals at such subzero temperatures depends on physiological and biochemical characteristics that can be described as cold hardiness. Two general categories for cold hardiness are possible. An animal can be freeze-tolerant, which means that it survives extensive freezing and ice formation in the body. In contrast, an animal can be freeze-intolerant and die if there is any internal ice formation; in cold areas such animals must be able to avoid formation of ice even if exposed to temperatures as low as -40^0C or -50^0 C.

Psychotrops are organisms that thrive in the extreme cold, in contrast to mesotrophs that live at more moderate temperatures. Animal psychotrops, including polar invertebrates and fish, remain active at body temperatures near the point of freezing. Many psychotropic organisms possess cold-adapted proteins that function optimally at very low temperatures. Although these enzymes are more stable in the cold, they are rapidly inactivated at slightly higher temperature.

Ectotherms that live at freezing temperatures use two strategies to survive the cold: freeze-tolerance and freeze avoidance. Freeze-tolerant animals allow their tissues to freeze and even encourage ice to form in the body. Animals that avoid freezing use behavioural and physiological mechanisms to prevent ice crystal formation and growth. When water is below its freezing point, but not yet frozen, it is considered super cooled. Pure water, left undisturbed, can be super cooled to almost -40^0 C before ice forms spontaneously. The trigger for ice formation is a cluster of water molecules that act as a seed for an ice crystal. Alternatively, a macromolecule in solution can act as nucleator, seeding ice crystal formation. Once the ice formation begins, water molecules bind to each face of the growing crystal to create a complex three-dimensional structure.

NOTES

Ice crystals forming within a tissue have two deleterious effects. First, since ice crystals have points and sharp edges, the growing ice crystal can pierce membranes, killing the cell. Second, the ice crystal growth removes surrounding water, causing hyperosmotic stress. If ice forms outside cells, then water is drawn out of drawn out of cells, causing a hypertonic stress that shrinks the cell, perhaps even killing it. Freeze-tolerant animals usually produce ice nucleators to control the location and kinetics of ice crystal growth. Ice is the most damaging when it forms inside cells, so freeze-tolerant animals secrete nucleators out of the cell. This restricts ice formation to the extracellular fluids, such as hemolymph, and allows the intracellular space to remain liquid. Many different types of molecules can act as nucleators in animals: calcium salts, membrane phospholipids, and long chain alcohols. Because ice formation draws water from the cells, freeze-tolerant animals also produce intracellular solutes to counter the movement of water. Large glycogen reserves of the liver are broken down and converted to compatible solutes consisting of organic polyols, such as trehalose and glycerol. First, by increasing the osmotic pressure within the cells, they reduce the movement of water and cell shrinkage. Second, the solutes help stabilize macromolecular structure.

Freeze-avoidance is the second strategy animals use to survive extreme cold. Solutes in general depress the freezing point of a solution, preventing ice formation at subzero temperatures. Some animals possess antifreeze macromolecules- typically anti freeze proteins or glycoproteins- that reduce the freezing point of the body fluids by noncoligiative actions. They disrupt ice crystal formation by binding to the surface of small ice crystals to prevent their growth.

10.5 PHYSIOLOGY OF HIBERNATION AND AESTIVATION

Hibernation is a state of inactivity and metabolic depression in animals during winter. It may last several days or weeks depending on species, ambient temperature, and time of year, and fur on the animal's body. The typical winter season for a hibernator is characterized by periods of hibernation interrupted by sporadic euthermic arousals wherein body temperature is restored to typical levels.

Hibernating ground squirrels may have abdominal temperatures as low as 0 °C, maintaining sub-zero abdominal temperatures for more than three weeks at a time, although the temperatures at the head and neck remain at 0 C or above. Before entering hibernation most species eat a large amount of food and store energy in fat deposits in order to survive the winter. Some species of mammals hibernate while gestating young, which are born shortly after the mother stops hibernating. Hibernating animals get their energy by a process known as gluconeogenesis. Similarly in the cold environment bats also go to hibernation, however the brown fat that is stored in the bats give required energy during the hibernating period.

Estivation or **aestivation** (from Latin *aestas*, summer), also known as "summer sleep", is a state of animal dormancy somewhat similar to hibernation. It takes place during times of heat and dryness, the hot dry season, which is often but not inevitably the summer months. Some air-breathing land snails, including species in the genera *Helix*, *Cernuella*,

NOTES

Helicella and*Otala*, commonly estivate during periods of heat. Some species move into shaded vegetation or rubble. Others climb up tall plants, including bushes and trees, and will also climb man-made structures such as posts, fences, etc., to get away from the intense ground heat.

10.6 LET US SUM UP

Mammals are homeotherms, they maintain their body temperature constant in spite the changes in the surrounding temperature. The body temperature of reptiles and amphibians vary according to the external environment and they are called as ectotherms or poikilotherm or thermoconformers. The temperature regulatory mechanism in mammals act through the autonomic nervous system and controlled by hypothalamous of the brain. In many endothermic animals the controlled state of hypothermia is called hibernation. Similarly to avoid the overheating, the animals go into the summer resting state called aestivation.

10.7 UNIT END EXERCISES

1. The cold blooded animals are also called as

    a. Homeotherms b. Homeostasis c. Poikilotherms d. None of these

2. The endothermic animals are called as

    a. Warm blooded animals b. Cold blooded animals c. Poikilotherms d. None of the above

3. Aestivation helps the animals to escape from

    a. Cold b. Heat c. Salt d. None

4. The fishes escape from freezing from the super cool water by the presence of

    a. Thermolabile substances b. Antifreeze substances c. Glycoprotein d. None

5. The brown fat help the bats during

    a. Hibernation b. Aestivation c. Torpor d. Sleep

10.8. ANSWER TO CHECK YOUR PROGRESS

1. c, 2. a, 3. b, 4. b, 5. a

10.9 SUGGESTED READINGS

Reznikova, Z. (2007) Animal intelligence: From individual to Cognition, Cambridge university press, Cambridge.

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

Hall, J. E. 2015. Guyton and Hall Text book of Medical Physiology, 13th Edition, Relx India Pvt. Ltd.

UNIT XI - OSMO-IONIC REGULATION AND PRESSURE ADAPTAION

Structure

11.1 INTRODUCTION

Each group of animals uses different combinations of tissues to control ion and water balance. For most animals, ion and water balance is regulated by renal tissues (kidney or kidney like tissues) as well as external epithelial tissues, such as gills, skin, and the digestive mucosa. **Osmoregulation** is the active regulation of the osmotic pressure of an organism's fluids to maintain the homeostasis of the organism's water content; that is it keeps the organism's fluids from becoming too diluted or too concentrated.

Animals whose body fluids have the same concentration as that of the surrounding medium are called **isotonic animals**. Such animals never face the problem of osmoregulation. For example, most marine animals have their body fluids isotonic with sea water. Animals which live in a medium of lower salt concentration are called **hypotonic animals**. In these animals, the water continuously enters into their bodies. Examples of such animals are fresh water protozoans and crustaceans that expel their excess water through contractile vacuoles and excretory organs, respectively.

Animals which live in a medium of higher salt concentration, e.g., marine bony fishes, are called **hypertonic animals**. These animals face a danger of dehydration as the water is continually lost from their bodies. As such, they have to drink sea water and to evolve regulatory mechanisms by which excessive loss of water from their body is prevented.

11.2. OSMO-IONIC REGULATION IN FRESHWATER AND MARINE FISHES AND CRUSTACEANS

Two major types of osmoregulation are osmoconformers and osmoregulators. **Osmoconformers** match their body osmolarity to their environment. It can be either active or passive. Most marine invertebrates

NOTES

are osmoconformers, although their ionic composition may be different from that of seawater.

Osmoregulators tightly regulate their body osmolarity, which always stays constant, and are more common in the animal kingdom. Osmoregulators actively control salt concentrations despite the salt concentrations in the environment. An example is freshwater fish. The gills actively uptake salt from the environment by the use of mitochondria-rich cells. Water will diffuse into the fish, so it excretes a very hypotonic (dilute) urine to expel all the excess water. A marine fish has an internal osmotic concentration lower than that of the surrounding seawater, so it tends to lose water and gain salt. It actively excretes salt out from the gills. Most fish are stenohaline, which means they are restricted to either salt or fresh water and cannot survive in water with a different salt concentration than they are adapted to. However, some fish show a tremendous ability to effectively osmoregulate across a broad range of salinities; fish with this ability are known as euryhaline species, e.g. Salmon.

Similarly all animals regulate the ionic profile of intracellular fluids, but animals differ in the nature of the extracellular fluid compartments. An **ionoconformer** exerts little control over the solute profile within its extracellular space. These animals usually live in seawater. Their extracellular fluids resemble seawater in terms of the concentrations of the major anions (Na^{2+}, Ca^{2+}, and Mg^{2+}) and cations (Cl^- and $SO4^{2-}$). Ionoconformers include most simple invertebrates (such as cnidarians), simple dueterostomes (such as ascidians) and the most ancient vertebrates (hagfish).

In contrast to ionoconformers, **ionoregulators** control the ion profiles of the extracellular fluids, employing a combination ion absorption and excretion strategies. Regulating the ionic profile of extracellular fluid compartments eases the burden of ionic regulation placed on individual cells. E.g. Higher vertebrates.

11.2.1 OSMOREGULATION IN FRESH WATER ANIMALS

Osmoregulation in fresh water animals is effected by pumping out of excess water from their bodies. The salt loss through the excretion of water is made good by salt absorbing gills, skin and various parts of the alimentary canal.

A. PROTOZOA

In fresh water protozoans such as Amoeba, Euglena and Paramecium which live in a hypotonic medium, outside water enters into the body and dilutes the body fluid. This excess water enters into the body and dilutes the body fluid. This excess water is eliminated by the rhythmic pulsation of the **contractile vacuole**.

B. CRUSTACEA

The blood of fresh water crustaceans like Palaemon is hypertonic to the surrounding water. The latter, therefore, continuously diffuses into the blood through highly permeable gills. The excess water is excreted in urine by the **antennary or green glands**. Salt loss through urine is made good by the active uptake of chloride, sodium and potassium from the

surrounding medium by chloride cells of gills even if the concentration of salts in the medium is extremely low.

C. FRESHWATER TELEOSTS

These are hyperosmotic to the surrounding medium, i.e., their blood is more concentrated than the external medium. As a result, outside water enters through the thin permeable skin, the smooth surface of the gills and lining of oral and pharyngeal cavities. This water is quickly transported to the well-developed glomerular kidneys which reabsorb desirable solutes and secrete dilute urine. Thus the blood concentration is restored. However, along with the urine, some salts also passes out. The salt loss is made good by **chloride cells** present on the gill epithelium (Fig.31). These cells are capable of absorbing the small quantities of salts present in the fresh water. In this way, kidney of freshwater fishes serves primarily as filter and reabsorber of solutes.

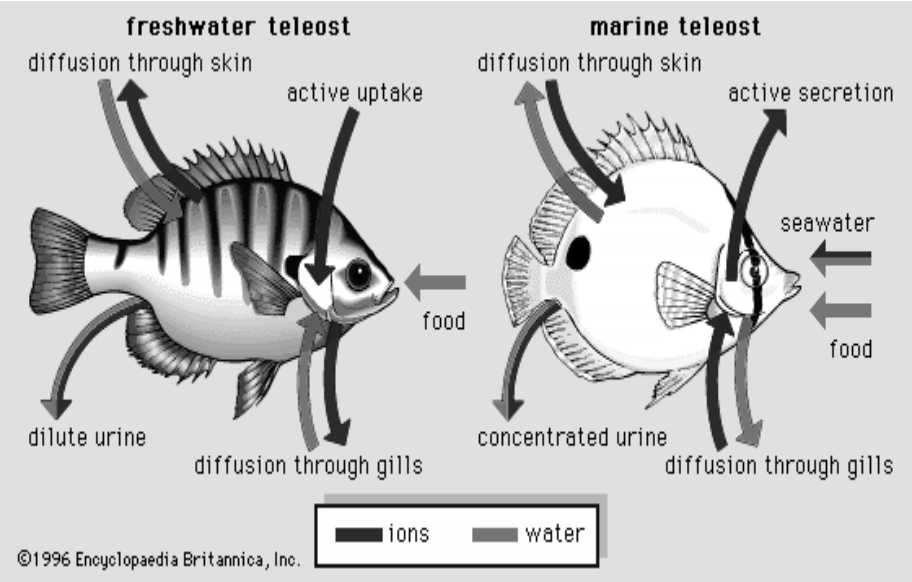


Figure. 31 Illustrates osmotic regulation in freshwater and marine fishes

11.2.2. OSMOREGULATION IN MARINE ANIMALS

A. HAGFISH

A few marine animals such as the hag fish, Myxine, maintain body fluids about as salty as the sea waters of the surrounding ocean (isoosmotic) and so do not tend to lose water by osmosis. However, the glomerular kidney of the hagfish is an ion-regulating structure; it removes Ca^{++}, Mg^{++} and SO_4^- and reabsorbs K^+ and Cl^-.

B. MARINE TELEOSTS

In marine bony fishes the body fluids are hypotonic to the marine environment, having a solute concentration only about 1/3 of sea water. Consequently, they are losing water through the smooth surfaces of the body, like gills and oral epithelia. Thus they are constantly in danger of losing so much water to their environment that the solutes in their body fluids may become extremely concentrated and the fish may die of osmotic

NOTES

desiccation. Therefore, to compensate for their osmotic water loss, they drink sea water. This restores their water content but leads to a new problem- how to eliminate the excess salt ingested. This problem has been solved by the evolution of special "**chloride secreting cells**" in the gills that excrete excess salt. Hence these fishes can take salt water and still remain hypotonic. Water loss through urine is minimized by the development of aglomerular kidneys.

C. MARINE ELASMOBRANCHES

Marine cartilaginous fishes such as Scoliodon and Stegostoma have body fluids isotonic with sea water. They achieve their isotonicity in a different way. Because they have an unusual tolerance for urea, instead of constantly, pumping this waste out, as do all other fish, sharks retain a higher concentration of it in their blood equal to that of sea-water. Though the osmotic removed in this way, the ionic concentration of the body fluids and the surrounding sea-water remains different. The marine elasmobranches achieve their ionic regulations by actively removing the excess salts with the help of a **rectal gland**. They do not have chloride secreting cells in their gills.

D. MARINE REPTILES

Marine reptiles like turtles, sea-snakes and iguana are able to maintain the osmotic and ionic concentration of their body fluids by the same mechanisms as met within marine teleosts. They drink sea-water and consume salty prey. Thus they are able to absorb water but eliminate the salt through special "**salt glands**"

E. MARINE BIRDS

Sea birds eliminate their excess salts, chiefly sodium chloride, in the form of a salty fluid through their nostrils. The salt glands are located in their nasal chambers. In the herring gull, the concentration of sodium chloride thus got rid off is about five times its concentration in the blood.

F. MARINE MAMMALS

Whales, dolphins, porpoises and seals do not drink sea water, hence they depend upon food for their water requirements. These mammals never sweat and in this way avoid loss of water by perspiration from their skin.

11.3 RESONSE TO HYPER AND HYPO-OSMOTIC MEDIA

Animals live in a variety of environments. They live in the terrestrial, fresh water or marine environment and they medium they live may hypo or hyper osmotic and the follow the following mechanism to thrive in the environment.

1. REMOVAL OF EXCESS WATER

The body fluid of the freshwater animals are hyper osmotic compare to the surrounding medium. So the water in the external environment come into the body and the animals need to remove the excess water. For example the unicellular organism Amoeba, removes the excess water in the cell through the contractile vacuole. Similarly the Crustaceans remove the excess water

through green gland and the freshwater fishes remove the excess water through glomerular kidney.

2. COMPENSATION OF SALT LOSS

In the freshwater animals when they expel water from the body, some amount of salt also get lost. This can be compensated through salt absorbing chloride cells present in the gills of crustaceans and fishes.

3. COMPENSATION OF WATER LOSS

The animals which live in the marine environment, the body fluid is hypo osmotic compared to the salt rich hyper osmotic sea water, so the water present in the body is get lost to the surrounding medium. As a result the marine animals get dehydrated and this is compensated by drinking sea water and getting water from the sea food.

The land animals are dehydrated by evaporation and they compensate the water loss by drinking water and getting water from the food and thorugh metabolism.

4. REMOVAL OF EXCESS SALT

The excess salt in the body of the mrine fishes are removed by the chloride secreting cells in the gills. In Marine turtles and bird the excess salt is removed by the salt gland presnt in the head.

11.4. ADAPTATIONS TO PRESSURE IN HIGH ALTITUDE

A. PRESSURE ADAPTATIONS

If shallow-water animals are exposed to high pressures under otherwise normal conditions of temperature and oxygen supply, responses vary greatly from species to species. Many are stimulated to increase oxygen consumption, and often increased activity, by pressures of 50 to 100 atm. High pressures, of a few hundred atmospheres, often are inhibitory and may cause death.

Many of the basic effects of pressure on biological systems can be referred to as the effects of pressure on protein structure and to the effect on the ionization of weak acids. Increases in pressure tend to favor the dissociation of weak acids and bases, and pressure also affects the velocity constants of chemical reactions. The biologically most important effect on proteins is probably on their tertiary structure- the way in which a protein molecule folds upon itself, with weak bonds and other weak interactions providing stabilization. Pressure has a considerable effect on the tertiary structure, which in turn is responsible for many of the biologically important characteristics of protein molecules, enzymes, contractile proteins of muscle, structural proteins in membranes, and so on.

Organisms that live at abyssal depth in the oceans are physiologically adapted to function normally at the high pressures at which they normally live. The functional adaptations of their component

NOTES

proteins, enzymes, and other systems are currently the subject of intensive studies. Experiments on live animals are technically very demanding because organisms from great depth are difficult to collect and must be kept cool and if possible at high pressure throughout the transportation to the surface and during experimentation. It is not easy to carry out experiments inside a closed container that must be able to resist pressures in excess of several hundred atmospheres.

B. HIGH ALTITUDE ADAPTATIONS

High altitude has strong **effects on humans.** The percentage saturation of hemoglobin with oxygen determines the content of oxygen in our blood. After the body reaches around 2,100 m (7,000 feet) above sea level, the saturation of oxyhaemoglobin begins to reduce. However, the human body has both short-term and long-term adaptations to altitude that allow it to partially compensate for the lack of oxygen.

The human body can adapt to high altitude through immediate and long-term acclimatization. At high altitude, in the short-term, the lack of oxygen is sensed by the carotid bodies, which causes an increase in the breathing rate (hyperventilation). However, hyperventilation also causes the adverse effect of respiratory alkalosis, inhibiting the respiratory center from enhancing the respiratory rate as much as would be required. Inability to increase the breathing rate can be caused by inadequate carotid body response or pulmonary or renal disease.

In addition, at high altitude, the heart beats faster; the stroke volume is slightly decreased; and non-essential body functions are suppressed, food digestion efficiency declines (as the body suppresses the digestive system in favor of increasing its cardiopulmonary reserves). But full acclimatization requires days or even weeks. Gradually, the body compensates for the respiratory alkalosis by renal excretion of bicarbonate, allowing adequate respiration to provide oxygen without risking alkalosis. It takes about 4 days at any given altitude and is greatly enhanced by acetazolamide. Eventually, the body has lower lactate production (because reduced glucose breakdown decreases the amount of lactate formed), decreased plasma volume, increased Hematocrit (polycythemia), increased RBC mass, a higher concentration of capillaries in skeletal muscle tissue, increased myoglobin, increased mitochondria, increased aerobic enzyme concentration, increase in 2,3-BPG, hypoxic pulmonary vasoconstriction, and right ventricular hypertrophy.

11. 5. BUOYANCY

Animals are denser than either fresh water or sea water, and therefore tend to sink, unless they have **adaptations** that give **buoyancy**. Larger animals will sink unless they swim or evolve **buoyancy** organs. The best known buoyancy mechanism is the **swim bladder** of the fish. In a marine coastal fish this has a volume of about 5% of the fish's total volume and gives a lift which approximately balances the excess weight in sea water. The great defect of swim bladder is that, since its wall is not rigid, its volume changes greatly with depth. The fish can compensate for changes in depth either by secreting gas into or reabsorbing gas from, the swim bladder but these are usually slow process taking hours or days to reach completion.

Unlike fishes, secondary swimmers (terrestrial animals that returned to an aquatic environment) have no such specific adaptations to the buoyancy problem. They all rely on simple density adaptations to help them. For example, the bones of diving birds are less pneumatic, and their air sacs are reduced (loons, penguins). Mammals that dive deep may hyperventilate before submerging, but they do not fill their lungs. Indeed, they may exhale before diving. Deep-diving whales have relatively small lungs. Sirenians, which may feed while resting on the bottom or standing on their tails, have unusually heavy skeletons; their ribs are swollen and solid. Likewise, the skeleton of the hippopotamus is also unusually heavy. The presence of blubber in marine mammals also contributes to their overall density, and walruses (Odobenidae) have two large air pouches extending from the pharynx, which can be inflated to act like a life preserver to keep the animals' head above water while sleeping.

11. 6 LET US SUM UP

Osmoregulation is the active regulation of osmotic fluid in the body and maintain homeostasis. Based on the ionic concentration of body fluids to that of surrounding medium, animals are classified as isotonic, hypotonic and hypertonic animals. Based on the type of osmo-regulation animals are classified as osmoconformers, in which their osmolarity resemble that of the surrounding medium. The osmoregulators need to maintain their osmolarity. For example, in the fresh water fish, the gills actively uptake salt from the surrounding environment, to compensate salt loss. On the other hand, in marine fish the salt is excreted outside through the cells present in the gills. Similarly the pressure and altitude also influence the physiological mechanism of the animals. Likewise, the buoyancy of the fresh water fishes are facilitated by swim bladder.

11. 7. UNIT END EXERCISES

1. The hypertonic medium contains

    a. Equal amount of salts b. less salt c. More salt d. No salt

2. The chloride cells present in the gills of fresh fishes –

    a. Absorb salt b. Secrete salt c. release waste d. None of the above

3. Organism which tolerate the wide range of salinity is called

    a. Stenohaline b. Euryhaline c. Hypertonic d. Hypotonic

4. The green gland in crustacean removes –

    a. Excess salt b. Excess water c. Absorbs d. None of these

5. Ureotelic animals excrete nitrogenous waste in the form of ---

    a. Ammonia b. Urea c. Uric acid d. None of the above

11. 8. ANSWER TO CHECK YOUR PROGRESS

1. c, 2. a, 3. b, 4. b, 5. B

11. 9. SUGGESTED READINGS

Berry, A.K & K.Berry (2008) A text book of animal physiology, Emkay publications, New Delhi.

Randall, D., Burggren, W. & K. French (2002) Eckert Animal Physiology, W. H. Freeman and Company, New York.

Reznikova, Z. (2007) Animal intelligence: From individual to Cognition, Cambridge university press, Cambridge.

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

Singh, H. (2003) A text book of animal behaviour. Anmol Publications Pvt. Ltd. New Delhi

NOTES

BLOCK IV: ENDOCRINOLOGY AND ANIMAL BEHAVIOUR

NOTES

Structure

12. 1 INTRODUCTION

Endocrine glands in the body secrete hormones. A hormone is a chemical released by a cell in one part of the body that sends out messages that affect cells in other parts of the organism. Only a small amount of hormone is required to alter cell metabolism. It is essentially a chemical messenger that transports a signal from one cell to another. Hormones in animals are often transported in the blood. Cells respond to a hormone when they express a specific receptor for that hormone. The hormone binds to the receptor protein, resulting in the activation of a signal transduction mechanism that ultimately leads to cell type-specific responses. Hormones are secreted by endocrine glands or ductless glands.

Hormones act as body catalyst, resembling enzymes since they are required only in very small amounts and are not used during their catalytic action. However, they differ from enzymes in the following ways:

1. They are produced in an organ other than that in which they ultimately perform their action.
2. They are secreted into the blood in response to body requirements.
3. Structurally, they are not always proteins. They include proteins with molecular weights of 30,000 or less, small polypeptides, single amino acids and steroids.

12.2 ENDOCRINE GLANDS AND THEIR HORMONES

Mammals including humans contain following endocrine glands to maintain homeostasis, they are pituitary gland, thyroid gland, parathyroid gland, adrenal gland, Islets of langerhans, testis, ovary, placenta, thymus and pineal gland.

I. PITUITARY GLAND:

Pituitary gland is often described as the master gland of the endocrine system because it secretes a number of hormones which control and

NOTES

regulate the activity of other endocrine glands. The pituitary gland has dual origin, both components being derived from the ectoderm. They are anterior pituitary or adenohypophysis and posterior pituitary or neurohypophysis. The adenohypophysis arises from the roof of the buccal cavity in the form of an outgrowth called "Rathke's pouch". The neurohypophysis originates from the floor of the diencephalon in the fore brain. Adenohypophysis soon loses its connection with the buccal cavity, whereas neurohypophysis remains attached to the brain by an infundibulum or pituitary stalk.

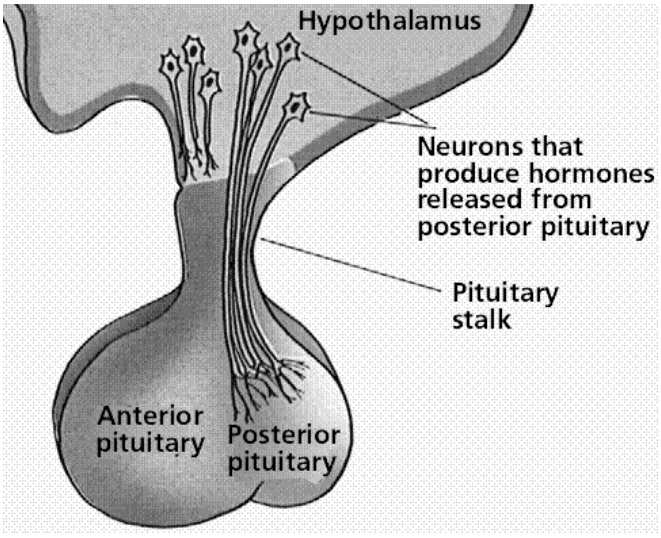


Fig. 32. Structure of pituitary gland

1.Anterior pituitary or Adenohypophysis

This is composed of three parts- the pars intermedia, the pars distalis and the pars tuberalis. The adenohypophysis consists of cells which themselves secrete hormones with the exception of the pars tuberalis which is simply a supporting structure for the gland and its blood vessels.

A. HORMONES OF THE ANTERIOR PITUITARY:

1.Growth hormone (GH) or Somatotrophic hormone (STH)

This hormone stimulates growth of bones, cartilage, muscles, viscera and the body as a whole. The growth hormone promotes protein anabolism, the absorption of calcium from the intestine and conversion of glycogen and glucose. The hypo or reduced secretion of this hormone during childhood resulting stunted growth called **dwarfism.** The increased or hyper secretion of growth hormone during childhood causes **gigantism.** There is excessive skeletal growth before the epiphyses have closed and the individual may become 8 or 9 feet tall. The hyper active gland in the adult life cause **acromeagaly**. There is excessive growth of the bones of the face, especially the frontal bone and the mandible.

NOTES

2.Adrenocorticotropic hormone (ACTH)

This hormone stimulates the cortex of the adrenal gland to produce Glucocorticoids. The production of ACTH is particularly important during emotional and physical stress.

3.Thyroid Stimulating Hormone (TSH) or Thyrotrophic hormone

This hormone controls the growth and activity of the thyroid gland. It influences the uptake of iodine, the synthesis of thyroid hormones (T_3 and T_4) by the thyroid gland and the release of stored hormones into the blood stream.

4.Gonodotropic hormone

These hormones regulate the development and functions of gonads. There are two types one is Follicle Stimulating hormone (FSH) and the other is Luteinizing hormone (LH).

a. **Follicle Stimulating hormone (FSH)**

In females FSH stimulates the development and ripening of the ovarian follicle. During its development the ovarian follicle secrets its own hormone estrogen. In males FSH stimulates the development of seminiferous tubules and spermatogenesis.

b. **Luteinizing hormone (LH)**

In females this hormone promotes the final maturation of the ovarian follicle, ovulation and formation of the corpus luteum which the second ovarian hormone known as progesterone and in males it stimulates the interstitial cells of the testes causing them to release male sex hormones (androgens) into the blood stream. Hence in males, it is also known as Interstitial Cell Stimulating Hormone (ICSH).

5. Lactogenic hormone (Prolactin (PL), Leuteotropic hormone (LH))

The lactogenic hormone has a direct effect upon the breasts or mammary glands immediately after the delivery of a baby and the expulsion of the placenta. In conjunction with other hormones like growth hormones, ACTH and TSH, prolactin stimulates the breasts to secrete milk.

During pregnancy, the ovarian hormones inhibit the secretion of prolactin. Besides, prolactin induces maternalism, strong emotional attachment to the young and drive to bring the offspring to a state of self-sufficiency in males, prolactin promotes protective attitudes towards mates and offspring, intensive food gathering for the family and expressions of paternalism in general.

6.Melanocyte Stimulating Hormone (MSH)

MSH is produced in pars intermedia. Though found in all vertebrate groups, this hormone appears to be functional only in poikilothermic animals. Its secretion causes dramatic darkening of the skin of many fishes, amphibians and reptiles. Although MSH does not seem to play an important role in the normal behavior of human melanocytes, but under

NOTES

certain conditions such as pregnancy, an increase in its secretion does cause some darkening of the skin.

B. HORMONES OF THE POSTERIOR PITUITARY OR NEUROHYPOPHYSIS

Whereas adenohypophysis secretes hormones on its own, neurohypophysis is not secretary in function. It consists of non-myelinated fibers and supporting cells and receives its quota of hormones from neurosecretary cells in the hypothalamus of the brain.

(a) Infundibulum

This part sends a number of release factors or hormones that travel by portal circulation to the anterior pituitary and trigger the secretion of a series of tropic hormones.

These release factors (hormones) may be built up of 3 to 20 amino acid units. For example TRF is a tripeptide, whereas GH-RF is a decapeptide.

The infundibular Process

Extract of the posterior lobe is called pituitrin which contains 2 hormones:

(1) Oxytocin (Birth hormone or milk ejection hormone)

Oxytocin produces contraction of blood muscles to facilitate the ascent of spermatozoa after coitus and for delivery of the foetus. In late pregnancy, the uterus becomes very sensitive to oxytocin. The amount is increased during labour. Facilitates the flow of milk from mammary glands, by contraction of the myoepithelial cells of the lactating breast.

(2) Antidiuretic Hormone (ADH) or Vasopressin

ADH has two important functions:

1. Influence water balance of the animal by reducing its output of urine. It exerts a direct effect upon the facultative reabsorption of water by the kidney tubules.

ADH may be increased by a variety of stimulators of neural activity. Emotional and physical stress, electrical stimulation, acetylcholine, nicotine and morphine increase ADH secretion.

If the antidiuretic hormone is lacking, reabsorption of water is reduced and large amounts of dilute urine is excreted. This ailment is called *diabetes insipidus*. It differs from the more common *diabetes mellitus* in that the urine is free from sugar.

2. Under the influence of ADH, the involuntary smooth muscle of the intestine, gall bladder, urinary bladder and blood vessel contract. Contractions of the muscle layer in the blood walls raise the blood pressure.

II. THYROID GLAND:

It is a bilobed gland situated in the lower part of the neck, ventral to the trachea and immediately behind the larynx. The two lobes of the thyroid are joined together by a narrow bridge of tissue called isthmus which gives the entire gland a more or less H-shaped appearance.

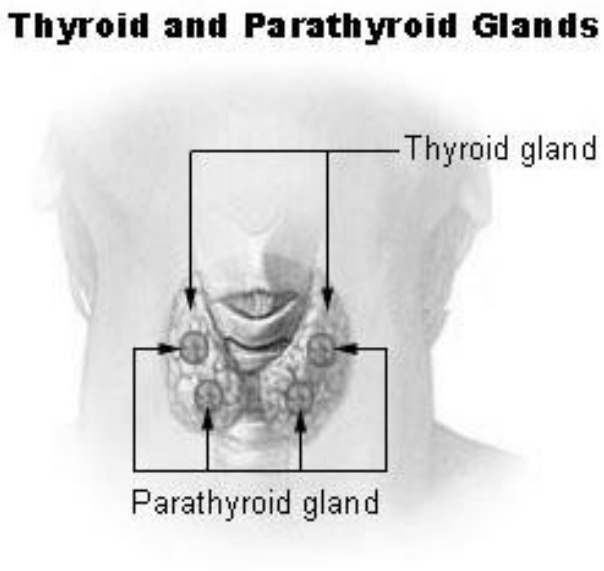


Fig. 33. Thyroid and parathyroid glands.

Histologically, it consists of acini or vesicles lined with cuboidal epithelium. The lumen of these acini is filled with a proteinaceous colloidal secretion, thyroglobulin (an iodized glycoprotein)

About 95 percent of the active thyroid hormone is **thyroxine,** and most of the remaining 5 percent is **triiodothyronine**. Both of these require iodine for their synthesis. Thyroid hormone secretion is regulated by a negative feedback mechanism that involves the amount of circulating hormone, hypothalamus, and adenohypophysis.

If there is an iodine deficiency, the thyroid cannot make sufficient hormone. This stimulates the anterior pituitary to secrete thyroid-stimulating hormone, which causes the thyroid gland to increase in size in a vain attempt to produce more hormones. But it cannot produce more hormones because it does not have the necessary raw material, iodine. This type of thyroid enlargement is called simple goiter or iodine deficiency goiter.

Calcitonin is secreted by the parafollicular cells of the thyroid gland. This hormone opposes the action of the parathyroid glands by reducing the calcium level in the blood. If blood calcium becomes too high, calcitonin is secreted until calcium ion levels decrease to normal.

ABNORMALITIES OF THYROID FUNCTION:

(A) Hyposecretion

A deficiency of thyroid hormones produces a number of clinical disorders depending upon the degree of deficiency and the age at which it occurs. In infants the thyroid hyposecretion causes **cretinism.** It causes lack of skeletal muscle development resulting in deformed bones and stunted body growth. The BMR is lowered accompanied by slow pulse and respiration rate. The sex organs and secondary sexual characters become retarded.

NOTES

In adult the hyposecretion of thyroid causes **myxodema (Gull's disease).** The important symptoms are the reduction of BMR and body temperature and there is undue sensitivity to cold. There is considerable general odema particularly manifested by the puffiness of face and hands due to thickening of the skin by the deposit of an albuminum semifluid material underneath.

(B) **Hypersecretion**

This condition generally occurs in adult life, and is also referred as hyperthyroidism. The hyperthyroidism causes **exopthalmic goiter or Graves' disease.** The general symptoms are the great increase of basal metabolic rate (BMR). There is a raised nervous excitability, restlessness and anxiety, accompanied by fatigue, muscular weakness, tremors and loss of weight. A characteristic protrusion of the eye-balls with a staring look, usually accompanies hyperthyroidism. This protrusion is thought to be due to increased postorbital pressure and possible weakening of the extrinsic muscles of the eye, as a result of excessive TSH.

III. PARATHYROID GLAND:

The parathyroids are four small glands placed on the thyroid, two on each lobe. They secrete a hormone called parathormone or parathyroid hormone (PTH). It is under the feedback control of blood Ca^{++} level.

Functions

1. The primary function of parathormone is to maintain the concentration of ionized calcium (Ca^{++}) in the plasma, with in the narrow range characteristic of this electrolyte, despite wide variations in calcium intake, excretion and deposition in bone

2. Lowers the serum phosphorus by increasing urinary excretion of phosphate but decreases excretion of calcium.

3. Increases the concentration of Ca^{++} in the blood plasma by mobilizing calcium from bones, particularly if the dietary intake of calcium is inadequate.

4. Enhances the rate of absorption of calcium from the intestine.

Hyposecretion

The hyposecretion of the parathyroid causes a disease called **tetany.** It causes muscle twitching leading to muscle spasm of the hand and feet termed carpo-pedal spam and increased neuromuscular irritability and spasm of the eye muscles. Serum level of calcium falls by more than 50% and phosphorus shoots high, resulting in abnormally greater excitation of the nerve fibers and muscles.

Hypersecretion

This is rare and is probably due to tumour of one or more of parathyroid glands. In case of hypersecretion of parathormone osteoclasts become overactive so that there is an excessive destruction of bone (Osteoporesis) and non utilization of calcium. This results in softening of the bones and high blood calcium. Eventually calcium is deposited in the walls of arteries

and lungs. In the areas of destruction in the bones fibrous cysts develop. This condition is called **osteitis fibrosa cystica.** The bones becomes painful and fractures occur frequently.

NOTES

IV. THE ADRENAL OR SUPRARENAL GLANDS

The adrenal glands are situated one on each side of the vertebral column, closely applied to the upper poles of the kidneys. The glands are composed of two distinct parts which differ both anatomically and physiologically. The outer part is known as the cortex and the inner part as medulla (Fig. 1.8).

1. CORTEX:

The cortex region is composed of three layers of cells, they are

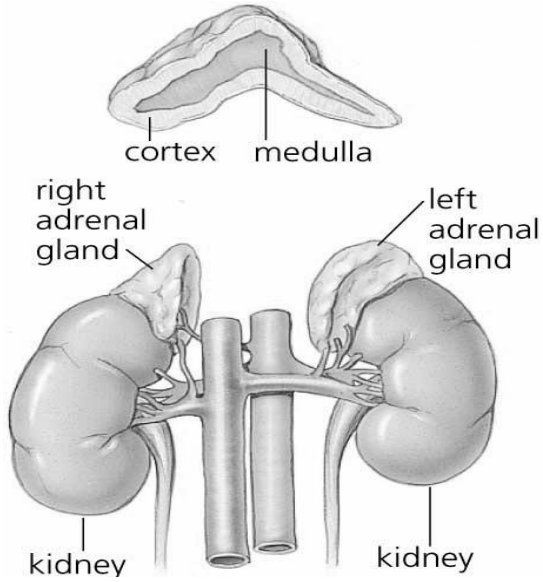
1. The outer layer Zona glomerulosa, made up of comparatively small thickly set ovoid group of cells. These secrete mineralocorticoids which regulate salt and water balance.

2. The middle layer, Zona fasciculata is the widest layer which is made up of polyhedral cells arranged in radiating columns. This layer secretes glucocorticoids affecting carbohydrate metabolism.

3. The inner layer, zona reticularis is made up of an irregular network of rows of cells. These secrete sex hormones.

2. MEDULLA:

The medulla is completely surrounded by the cortex. In man this region is thin, comprising only 5-10 percent of the gland. Medullary cells are essentially neurosecretary cells because they are stimulated by preganglionic sympathetic fibers to produce the hormones *adrenaline* and *noradrenaline*.



NOTES

Fig. 34. The adrenal gland

Functions

I. Cortex

It is called a gland of 4Ss i.e., 1. Salt retaining, 2. Sugar metabolism, 3. Stress management and 4. Sexual function. The adrenal cortex produces a number of potent hormones all of which are steroids derived from cholesterol.

(A) **THE MINERALOCORTICOIDS.** These are associated with the maintenance of electrolyte balance in the body and distribution of water in tissues. Specific examples are *aldosterone* and *deoxycortisterone*. The most potent mineralocorticoid is *aldosterone*. *Deoxycorticosterone* is only 4% as potent as aldosterone.

Functions of Aldosterone

(1) It is a "salt retaining hormone" which promotes the reabsorption of sodium and chloride ions by renal tubules. Retention of these in the blood keeps its osmotic pressure high, as a result of which water is also reabsorbed. This in turn assures normal blood volume and pressure.

(2) Increase excretion of potassium ions. The amount of aldosterone produced is influenced by the sodium level in blood. When the blood sodium level falls, more aldosterone secreted and more sodium reabsorbed.

Hypo and hyper secretion

The **hyposecretion** of aldosterone causes **Addison's disease.** It is characterized by excessive loss of sodium chloride in the urine and elevated levels of potassium in the serum. Hypo secretion causes the lowering of blood pressure, body temperature and BMR. It also causes muscular weakness and hypoglycemia.

Hypersecretion of aldosterone causes Conn's Syndrome characterized by increase in ECF volume and blood volume, hypertension and polyuria.

(B) THE GLUCOCORTICOIDS.

These primarily affect metabolism of carbohydrate, protein and lipids. Specific examples are *corticosterone hydrocortisone* or *cortisol* and *cortisone.* Their secretion is stimulated by ACTH from the anterior lobe of pituitary.

Functions

1. They are metabolically antagonistic to insulin. Under their influence glycogen is changed to glucose in the liver, raising the blood sugar level.

2. During stress, they promote the conversion of fats and proteins to glycogen that is ultimately converted to glucose, hence called anti-stress hormones.

3. They have anti-inflammatory and anti-allergic properties. Cortisol is used in the treatment of rheumatoid arthritis; it is even injected inside the diseased joint.

4. In recent years, this hormone has been utilized to suppress the phenomenon of rejection in transplantation of organs.

5. Together with ACTH, the glucocorticoids serve to counteract the harmful effects of long-lasting stress such as starvation, cold, heat, burns, infections etc; by helping the tissues to develop resistance and adapt them to meet new conditions.

Hypersecretion of cortisol in adults results from one of the two causes

1. Adrenocortical hyperplasia initiated by increased production of ACTH due to hyperactivity o basophile cells in the pituitary gland.

2. The hyper secretion of cortisol causes Cushing's disease

(C) The Androgens and Estrogens

These primarily affect secondary sex characters in their specific target organs. The primary adrenal androgens are Dehydroepindrosterone (DHEA) and Androstenedione. These cause retention of nitrogen (a protein-anabolic effect), phosphorus, potassium, sodium and chloride. If present in excessive amounts, they also lead to masculinisation in the female, called **Androgenital syndrome**.

Adrenal estrogens influence the development and maintenance of the secondary sex characters in females. The primary estrogen is Estradiol, derived from Androstenedione.

II. MEDULLA

The adrenal medulla is a derivative of the sympathetic part of the autonomic nervous system. When stimulated by preganglionic sympathetic nerve fibers, it secretes two hormones *adrenaline* (epinephrine) and *noradrenaline* (norepinephrine). These hormones belong to a class of substance known as **catecholamines** that are derivatives of the amino acid tyrosine.

I, FUNCTIONS OF ADRENALINE

It cause vasodilatation of the arterioles of the skeletal muscles and increase the supply of oxygen and nutritional material for a sustained muscle activity. Dilates trachea and bronchi to permit a greater volume of air to enter the lungs at each inspiration. Increases the rate of heart beat, thus increasing blood pressure. It slows down peristalsis in the digestive tract and limit the flow of saliva. It stimulates the conversion of liver glycogen stored in liver and muscles to glucose that is ready for oxidation. Decreases insulin, thereby preventing the glucose from being taken up by peripheral tissues and preserving it for CNS.

These preparations are valuable for the body in providing a rapid physiologic response to emergencies such as fatigue, shock, fear, excitement and danger.

NOTES

II, FUNCTIONS OF NORADRENALINE

It is a precursor of adrenaline which does not possess a methyl group ($-CH_3$) as is found in the adrenaline. Noradrenaline produces a vasoconstriction of peripheral organs like skin, digestive and reproductive organs. This effect raises blood pressure.

V. PANCREATIC HORMONES

Pancreas is both an exocrine and endocrine gland. The former quality results in the formation of many digestive enzymes and the latter in the regulation of carbohydrate metabolism. The exocrine functions of the pancreas is accomplished by epithelial cells grouped into hollow spheres (acini).

Scattered throughout the pancreas are small islets (groups of specialized cells) which secrete the hormone- insulin and glucagon. The specialized cells are called **islets of Langerhans.** The islets contain at least three distinct cell types: α, β and δ cells. Insulin is secreted by β- cells and glucagon is formed in the α-cells. The δ-cells secrete somatostatin.

Insulin has manifold influences in the body. It acts directly or indirectly to affect many kinds of biochemical processes. An overall effect of the hormone is to facilitate the utilization of glucose at the cellular level. It also prevents excessive breakdown of glycogen stored in the liver and muscles. It has also important regulatory actions on the metabolism of fats and proteins. Insulin favours fat synthesis (lipogenesis) from glycerol acetate units. Insulin also inhibits lipolysis.

Insulin facilitates the movement of amino acids in the cells. Thus it promotes a positive nitrogen balance, and favours the synthesis of protein. At the same time it also acts as an anti-proteolytic agent. This action is similar to the action of GH and testosterone. Three factors regulate the secretion of insulin: (1) hyperglycemia (increased blood sugar levels) induces an increased insulin secretion, (2) carbohydrate-rich food in stomach and duodenum and (3) glucagon. Both epinephrine and nor-epinephrine inhibit the secretion of insulin.

Glucagon is a strait chain polypeptide consisting of 29 amino acids. Its secretion is stimulated by hypoglycemia (decreased blood sugar levels). The actions of glucagon are contrary to that of insulin. Glucagon produces hyperglycemia. Acting in the liver, it stimulates glycogenolysis. The former function is similar to the functions of epinephrine and ACTH. Glucagon also produces lipolysis in the liver and in adipose tissue.

The normal blood glucose of fasting adult persons is 80mg/100ml. Values of blood glucose ranging between 150-200mg/100ml in a fasting individual indicate a disorder of the body known as diabetic state. It is produced by the inhibition of insulin secretion from β-cells of pancreatic islets. Some of the symptoms of the diabetes are: raise in blood sugar and appearance of sugar in urine (glycosuria). The diabetic person passes large amounts of urine (polyuria) and consequently, is thirsty and consumes much fluid. Since tissues cannot utilize glucose normally, even though they need fuel, the diabetic individual is constantly hungry and tends to eat excessively. There is an increase in urinary elimination of nitrogen; the

continuous loss of water from body results in a state of dehydration together with profound disturbances in tissue electrolyte balance. Ketone bodies in blood and urine are at a high level. Wounds are easily infected in the diabetic subjects. The untreated person gradually becomes weaker and loses weight despite a voracious appetite. Diabetic coma ensues, the plasma volume decreases, and kidney fails. This eventually results in the death of the patient.

NOTES

VI. SEX HORMONES:

1. TESTES

In testes the interstitial cells of Leydig are the sources of androgens and secrete testosterone and estrogens. **Testosterone** has a specific function in the maintenance of the testes, reproductive tract and secondary sexual characteristics of male. Testosterone is necessary for spermatogenesis, continued function of the reproductive tract glands, growth of the testis and distribution of body hair and body configuration. Testosterone increases protein synthesis in the body and hence it is an anabolic hormone.

Interstitial cells also secrete estrogens in small quantities. **Estrogen** which is essentially the female hormone has been found in the urine of men and male horses. Estrogen can cause reversal of sex in the male or even complete feminization. Hormones (LH and FSH) from the adenohypophysis control the production and release of testosterone.

2. OVARIES

Ovaries are composed of follicles in various stages of development varying from primary to mature (Graffian) follicles. Distributed among the follicle cells is the interstitial tissue (stroma) of the ovary. In adult mammals the ovary contains degenerating follicles, corpora lutea (formed after ovulation), and corpora albicans (the residue of corpora lutea). The ovaries produce two hormones estrogens and progesterone.

Estrogens are produced during follicular growth by steroid secreting cells among the fibroblasts of theca interna. After the release of the ovum it is also secreted by the remnant of the follicle Corpus luteum. It accounts for the increased uterine growth, and growth of the vagina at puberty. It also stimulates the development of secondary sex organs such as breasts, myometrium, etc. Estrogen also acts in the repair of the endometrium following menstruation. Over-secretion of estrogen causes menstrual cycle irregularities and atrophy or under-development of the breast and the uterus.

Progesterone is secreted by the corpus luteum (a recurring structure associated with menstrual cycle) and by the placenta during pregnancy. Progesterone plays a number of important roles in the reproductive life of mammals. It speeds the movement of the ovum through the fallopian tubes, and prepares the uterine endometrium for implantation. It also inhibits contractility of the uterine myometrium, thus allowing the pregnancy to continue. Under secretion of progesterone causes abortion in pregnant women, and menstrual irregularities in non-pregnant women.

NOTES

VII. ALIMENTARY CANAL

Hormones associated with the digestion of food are called local hormones. They are being produced by a localized area of the gut and acting upon the gut itself or one of its accessory glands.

1. Stomach

Gastric digestion and protein in the stomach stimulates the gastric mucosa to secrete a hormone **gastrin**, which has a strong stimulating effect on the acid-secreting parietal cells of the stomach.

2. Duodenum

The anterior duodenal mucosa secretes the hormone **Secretin,** when acid chime is injected into the duodenum. Secretin stimulates the pancreas to form pancreatic juice and the liver to form bile.

The chime also induces duodenum to release an additional hormone like substance ***Pancreozymin*****.** This hormone stimulates the production of various digestive enzymes from pancreas.

Bile, another digestive substance, is forced into the duodenum by contraction of the muscular layer of the gall bladder. This phenomenon is caused by a hormone- ***Cholecystokinin*****.** It is released by the duodenal mucosa.

3. Small intestine

It secrets two hormones, the enterokinin and enterogastrone. **Enterokinin** hormone stimulates the intestinal mucosa to secrete the intestinal juice.

The presence of fats in the small intestine stimulates the intestinal mucosa to produce another hormone **Enterogastrin.** It eventually stops the secretion of gastric juice in the stomach and calms down peristalsis there.

VIII. RENAL HORMONE

Erythropoietin is formed by kidney that acts on haemopoietic organs for the stimulation of the formation of blood cell, especially in response to anemia. Erythropoietin acts on bone marrow to increase its production of R.B.C's.

IX. THYMUS GLAND

Thymus is partly and endocrine gland and partly a lymphoid structure. Located in the upper part of the thorax, the thymus is quite large in young animal but as the animal grows the gland atrophies.

The thymus normally secretes a polypeptide hormone – **thymosin** or **thymin** which depresses neuromuscular transmission. An excess production of thymin by the abnormal thymus results in a disease **myasthenia gravis** in which the skeletal muscles are weak and there is a derangement of neuromuscular transmission.

The thymus in the infant mammal plays a major role in setting up the lymphocyte-producing machinery of the lymph nodes, thus providing the basis for the development of antibodies.

X. THE PINEAL GLAND

The pineal gland is a small, pea-sized structure lying deep in the groove between the cerebellum and the cerebral hemisphere in rabbit. Histologically, it consists of **Parenchyme cell** and **neuroglia cells.** It secretes a hormone **melatonin**.

In pineal body lies under the corpus callosum between the two cerebral hemispheres of the brain at the tip of the short pineal stalk arising from the roof of the 3rd ventricle of the brain. The pineal body regulates seasonal and circadian rhythm in accordance with day-night cycle, as a "biological clock".

12. 3. MECHANISM OF HORMONE ACTION

A. NONSTEROID HORMONES

Nonsteroid hormones (water soluble) do not enter the cell but bind to plasma membrane receptors, generating a chemical signal (second messenger) inside the target cell. Five different second messenger chemicals, including cyclic AMP have been identified. Second messengers activate other intracellular chemicals to produce the target cell response (Fig. 35).

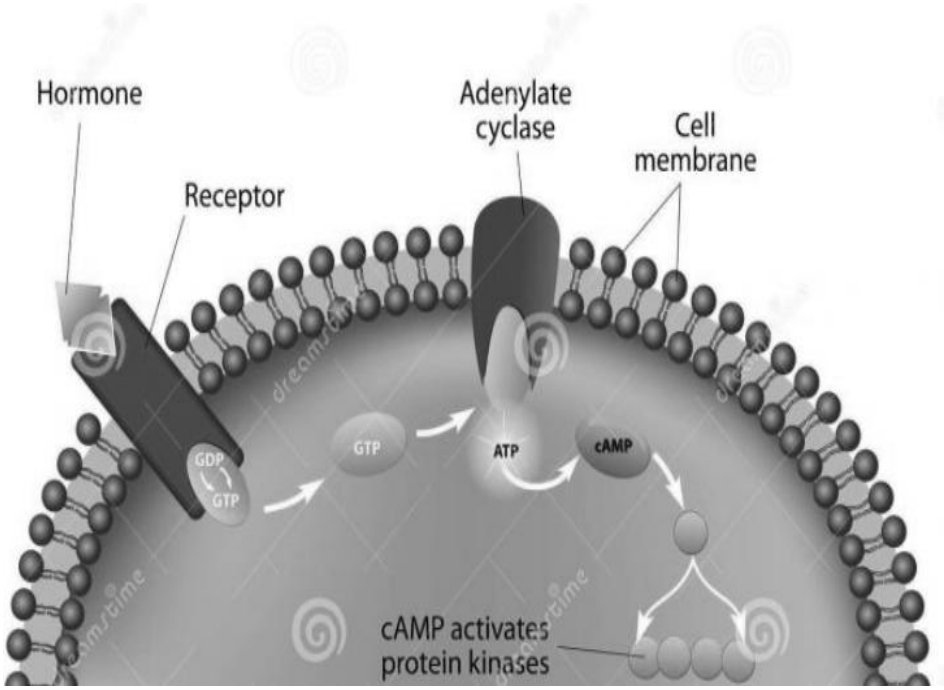


Fig. 35 Mechanism of action of Non steroid hormone

B. STEROID HORMONES

The second mechanism involves steroid hormones, which pass through the plasma membrane and act in a two step process. Steroid hormones bind, once inside the cell, to the nuclear membrane receptors, producing an activated hormone-receptor complex. The activated hormone-receptor complex binds to DNA and activates specific genes, increasing production of proteins (Fig. 36).

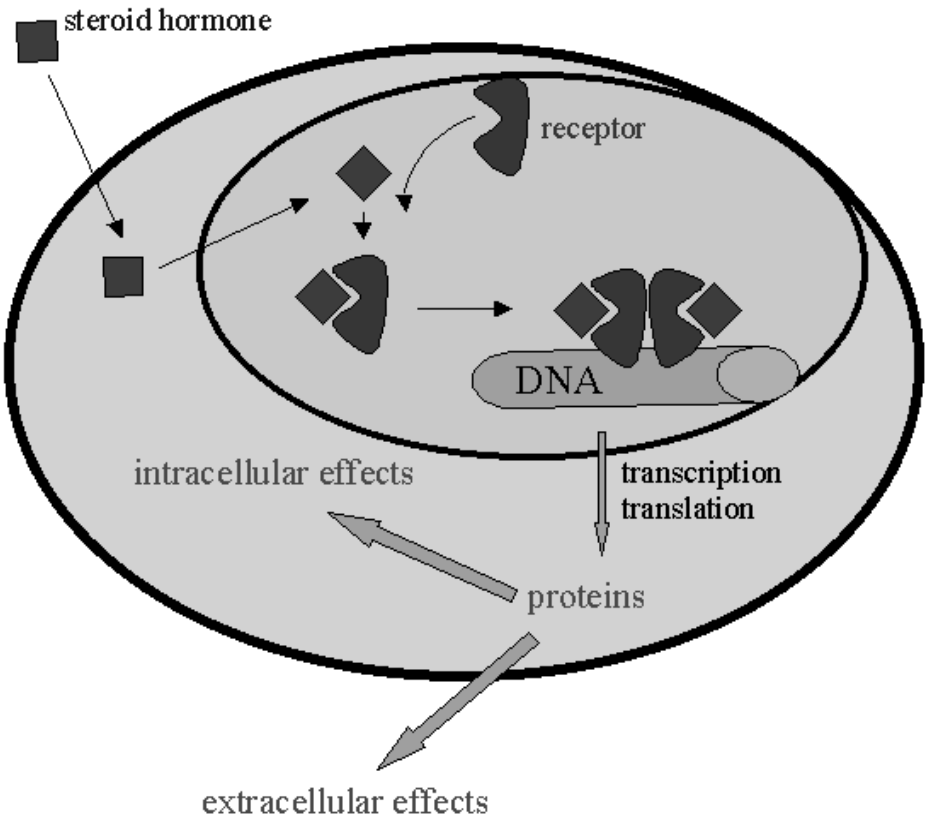


Fig. 36. Mechanism of action for steroid hormone

12.4 LET US SUM UP

Endocrine glands and their secretion are carried by blood. The secretion of the endocrine glands is called as hormones. Among the endocrine gland the pituitary gland secretes many trophic hormones which influence the secretions of other hormones. So the pituitary gland is called as mater gland of the body. Some of the important hormones secreted by Pituitary gland is Growth hormone, Adrenocortico trophic hormone (ACTH), Thyroid stimulatory hormone, Gonadotrophic hormone etc., are secreted at the anterior pituitary and Lactogenic hormone and Antidiuretic hormone (ADH) are secreted at the posterior pituitary gland. Then the Thyroid gland secrete thyroxine and calcitonin. The parathyroid gland secrete parathormone, which maintain concentration of ionized calcium in the plasma. The adrenal gland situated above the kidney secretes a hormone called adrenaline. The adrenal cortex secretes another hormone called aldosterone which maintains the mineral concentration in the body. Similarly islets of Langerhans in pancreas secretes insulin and glucagon, which maintain the glucose concentration in the blood. The action of hormones varied between the steroid and non steroid hormones. The steroid hormones directly enter into the cell and activate it. However, in the case of non steroid hormones, they attach to the surface receptors of the cell and the second messengers like cyclic AMP activates the cells.

12. 5 UNIT END EXERCISES

1. A ductless gland which secretes hormones are called

a. Paracrine b. autocrine c. endocrine d. exocrine

2. The master gland of the body is

a. Pituitary b. Thyroid c. Adrenal d. Pineal

3. The hyper secretion of growth hormone leads to

a. Dwarfism b. Gigantism c. Critinism d. None of these

4. The water concentration in the body is maintained by

a. Insulin b. GH c. TSH d. ADH

5. The serum calcium level is maintained by

a. Parathormone b. Thyroxine c. Insulin d. Glucagon

12. 6 ANSWER TO CHECK YOUR PROGRESS

1. c, 2. a, 3. b, 4. d, 5. a

13.8 SUGGESTED READINGS

Agarwal, R.A., A.K. Srivatstava & K.Kumar (2000) Animal physiology and biochemistry, S. Chand & Company Ltd. New Delhi.

Devlin, T.M. (2005) Text book of Biochemistry with clinical correlations, Willey publishers, USA

Randall, D., Burggren, W. & K. French (2002) Eckert Animal Physiology, W. H. Freeman and Company, New York.

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

NOTES

UNIT - XIII NEUROENDOCRINE GLANDS

Structure

13.1 INTRODUCTION

Neuro-endocrine glands play a prominent role in the life of invertebrates such as the regulation of reproduction and mate attraction, moulting and other activities. These neuroendocrine organs are transformed from nerve ganglia and neurosecretory cells are associated with the neurohaemal organs. These neuroendocrine glands resemble the endocrine glands of the higher animals that secrete hormones. Neuroendocrine control mechanisms are observed in all animals that possess a nervous system. Recent analyses of neuroendocrine functions in invertebrate model systems reveal a great degree of similarity between phyla as far apart as nematodes, arthropods, and chordates. Developmental studies that emphasize the comparison between different animal groups will help to shed light on questions regarding the evolutionary origin and possible homologies between neuroendocrine systems. This review intends to provide a brief overview of invertebrate neuroendocrine systems and to discuss aspects of their development that appear to be conserved between insects and vertebrates.

13.2 NEUROENDOCRINE CONTROL OF HORMONES

In the case of invertebrates certain cells are modified to secrete hormones. These nerve cells are called neurosecretory cells. The secretions of neurosecretory cells are called neurosecretions. The neurosecretions are temporarily stored in special structures called sinus glands in crustaceans and carpus cardiacum in insects. From these neurosecretions are released into the blood when required. The neurotransmitters are different from neurosecretions. The neurotransmitters are secreted at the nerve endings and after their actions they diffuse into the blood. But neurosecretions diffuse into the blood before their action and arte carried to the target cells for bringing their actions.

All the neurosecret\ory cells do not empty their secretion in the blood. Some of them empty into a storage organs. Neurosecretory mechanism is the only system of hormonal control among invertebrates or they have not acquired well developed endocrine glands.

13.3. INVERTEBRATE HORMONES

1. NEUROSECRETION IN COELENTRATA

The nervous system in coelenterates acts as the neuroendocrine system. In jelly fishes, the circum oral ring and its radial nerve fibers contain neurosecretory cells. The secretion released from the cells is essential for ovulation. In hydra, the neurosecretory cells are concentrated at the region of hypostome. They secrete neurosecretory growth hormone. This hormone stimulates cell proliferation and causes interstitial cells to develop into somatic structures such as nematocysts. In the absence of this hormone, growth stops and the interstitial cells form gametes.

NOTES

2. PLATYHELMINTHES

The location of neurosecretoy cells is the cerebral ganglia. Regeneration is controlled by cerebral ganglia in these organisms.

3. ANNELIDS

The neurosecretory cells are present in cerebral ganglion, suboesophageal ganglion, ventral ganglion etc. The neurosecretion serves many functions. They are concern with growth and regeneration, maturation of gonads and sexual development, wound healing etc.

In Nereis, surgical removal of the nerve chain and various ganglia have predictable effect on reproductive process. These facts prove for the existence of more hormones of neural origin. The brain hormone inhibits oocyte development in nereis. The gradual withdrawal of this hormone stimulates vitellogenesis and spermatogenesis. In earthworm, the gonadotropic hormones regulate development of clitellum.

4. ARTHROPODA

Most highly organized neurosecretory system is developed in Arthropoda. In crustaceans, it is highly developed and intimately associated with nervous system. The neurosecretory cells are distributed in the nervous system and ganglia. The important glands in the crustaceans are, the sinus gland situated at the eye stalk which serve as the storage organ for neurosecretion, ganglionic X organs located at different parts of the optic ganglia, act as the neurohaemal organ, the post commissural organ behind the oesophagus serveing storage, act as the release of neurosecretions from the posterior region of the brain, the pericardial organs and gama organ located in the maxillary segments is concern with the moulting. These organs secretes hormones such as retinal pigment hormones, chromatophorotropins, hyperglycaemic hormones, ovary inhibiting hormone, moult inhibiting hormone and heart accelerating hormone.

13.4. HORMONAL CONTROL OF INSECT METAMORPHOSIS

In insects moulting and metamorphosis are controlled by the neuroendocrine glands. The brain contains a group of glandular cells called neurosecretory cells. These cells secrete a hormone called brain hormone. This hormone is transported by the axons of the neurosecretory cells to a pair of lobe like endocrine glands called carpora cardiaca (Fig. 34). The corpora cardiaca releases the brain hormone into the blood. This hormone

NOTES

acts on a highly branched gland present in the prothorax called prothoracic gland. In response to the brain hormone, this gland secretes a hormone called ecdysone. It brings about the ecdysis or moulting of the insect.

There is another pair of lobe like endocrine glands called corpora allata. The Corpora allata secretes juvenile hormone. The juvenile hormone helps to retain the larval characters of the insect. As long as the hormone remains in the larva, the larva does not differentiate into adult. In other words, the withdrawal of juvenile hormone initiates metamorphosis (Fig. 37)

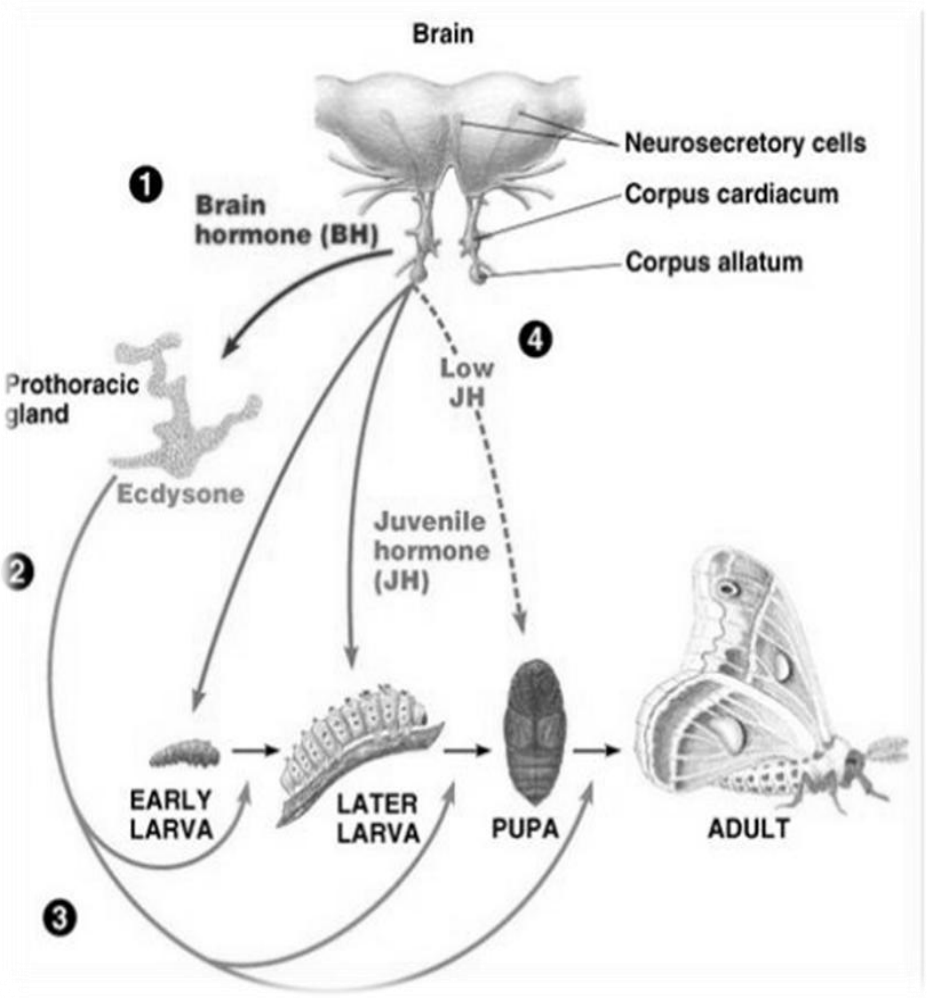


Fig. 37. Role of hormones in insect metamorphosis

13.5 LET US SUM UP

The neuro endocrine glands play a prominent role in the life of invertebrates. The neurosecretions are temporarily stored in special structures called sinus gland in crustaceans and carpus cardiacum in insects. The neuroendocrine secretions are observed from Phylum Coelentrata onwards. In insects the moulting and metamorphosis are controlled by neuroendocrine glands. The brain hormone released by carpora cardiaca acts on thoracic gland to release a neuro hormone called ecdysone, which make the insect to go moulting. Corpora alata secretes a neuro hormone called juvenile hormone. As the insect matures the level of juvenile hormone reduces and the ecdysone increases. In this way the moulting of insects is controlled by neuroendocrine glands.

13.6 UNIT END EXERCISES

1. The prothoracic gland secretes a neuro hormone called

   a. Growth hormone b. Ecdysone c. Carpora cardiaca d. None of these

2. The juvenile hormone is secreted by

   a. Corpora cardiaca b. Corpora alata c. Thoracic gland d .None of these

3. In crustaceans the neurosecretions are stored by

   a. X organ b. Sinus gland c. Pericardial organ d. Gama organ

NOTES

13. 7 . ANSWERS TO CHECK YOUR PROGRESS

1. b, 2. b, 3. b

13. 8. SUGGESTED READINGS

Schmidt-neilson, K (2002) Animal physiology: adaptation and environment, Cambridge University press, Cambridge.

Agarwal, R.A., A.K. Srivatstava & K.Kumar (2000) Animal physiology and biochemistry, S. Chand & Company Ltd. New Delhi.

UNIT - XIV BIOLOGICAL CLOCK

NOTES

Structure

14.1 INTRODUCTION

Chronobiology deals with the adaptations of living organisms to the temporal orders of the environment. These adaptations are expressed in various forms of rhythm. A rhythm has been defined as a sequence of events that repeat themselves through time in the same order and at the same interval. Chronobiology is the important field in the study of the animal behaviour. It deals with the study of the time sense in the animal. Based on the biological rhythm, animals are divided as nocturnal or night active animals, diurnal or day active animals and crepuscular or the animals which are active only at dawn and dusk.

14.2 BIOLOGICAL CLOCK

Biological clock is the endogenous clock present in all the organism that maintain the time sense in animals. Biological rhythm has been defined as a sequence of activities that repeat themselves through time in the same order at same interval. Anumber of biological and behavioural activities in human beings, plants and animals are biological rhythm. These activities are cyclical in nature. The biological rhythms are inherent property of animals and plant and are genetically determined. They are controlled by invisible clock remaining inside the organism called biological clock. Eg. Slepping movement and photosynthesis in plants, sleep wake rhythm in humans, menstrual cycle, heart beat etc.

The biological clock is further divided into circadian rhythm, lunar rhythm and circannual rhythm. Circadian rhythms are daily rhythm, lunar rhythm is a monthly rhythm with a duration of 29 days and circannual rhythm is a yearly rhythm.

14.3 CIRCADIAN RHYTHM

A **circadian rhythm** is a roughly 24-hour cycle in the biochemical, physiological, or behavioural processes of living entities, including plants, animals, fungi and cyanobacteria. The term "circadian" comes from the Latin *circa*, "around", and *diem* or *dies*, "day", meaning literally "approximately one day". Although circadian rhythms are endogenous,

they are adjusted (entrained) to the environment by external cues called zeitgebers, the primary one of which is daylight.

- The rhythm persists in constant conditions (for example, constant dark) with a period of about 24 hours. The rationale for this criterion is to distinguish circadian rhythms from those "apparent" rhythms that are merely responses to external periodic cues. A rhythm cannot be declared to be endogenous unless it has been tested in conditions without external periodic input.
- The rhythm is temperature-compensated, i.e., it maintains the same period over a range of temperatures. The rationale for this criterion is to distinguish circadian rhythms from other biological rhythms arising due to the circular nature of a reaction pathway. At a low enough or high enough temperature, the period of a circular reaction may reach 24 hours, but it will be merely coincidental.
- The rhythm can be reset by exposure to an external stimulus. The rationale for this criterion is to distinguish circadian rhythms from other imaginable endogenous 24-hour rhythms that are immune to resetting by external cues and, hence, do not serve the purpose of estimating the local time. Travel across time zones illustrates the necessity of the ability to adjust the biological clock so that it can reflect the local time and anticipate what will happen next. Until rhythms are reset, a person usually experiences jet lag.

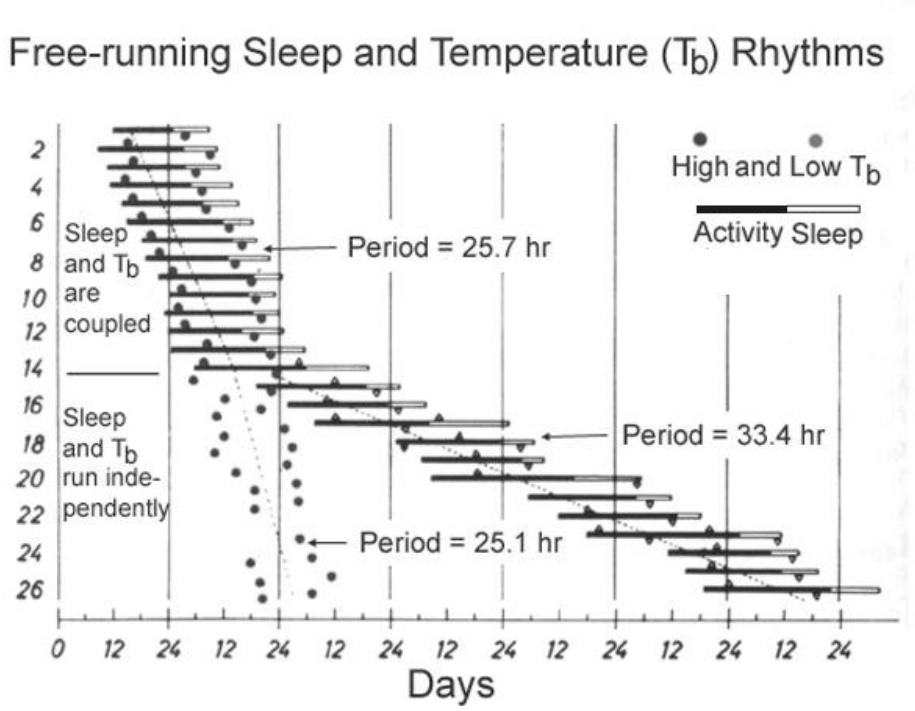


Figure 5.2. Showing free-running sleep and temperature rhythms

NOTES

IMPORTANCE OF CIRCADIAN RHYTHM

Circadian rhythmicity is present in the sleeping and feeding patterns of animals, including human beings. There are also clear patterns of core body temperature, brain wave activity, hormone production, cell regeneration and other biological activities. In addition, photoperiodism, the physiological reaction of organisms to the length of day or night, is vital to both plants and animals, and the circadian system plays a role in the measurement and interpretation of day length.

14.3. 1 IMPACT OF LIGHT–DARK CYCLE

The rhythm is linked to the light–dark cycle. Animals, including humans, kept in total darkness for extended periods eventually function with a free running rhythm. Each "day", their sleep cycle is pushed back or forward, depending on whether their endogenous period is shorter or longer than 24 hours. The environmental cues that each day reset the rhythms are called *zeitgebers* (from the German, *Time Givers*). It is interesting to note that totally-blind subterranean mammals (e.g., blind mole rat *Spalax* sp.) are able to maintain their endogenous clocks in the apparent absence of external stimuli. Although they lack image-forming eyes, their photoreceptors (detect light) are still functional; as well, they do surface periodically.

Free running organisms that normally have one consolidated sleep episode will still have it when in an environment shielded from external cues, but the rhythm is, of course, not entrained to the 24-hour light/dark cycle in nature. The sleep–wake rhythm may, in these circumstances, become out of phase with other circadian or ultradian rhythms such as temperature and digestion. Recent research has influenced the design of spacecraft environments, as systems that mimic the light/dark cycle have been found to be highly beneficial to astronauts.

14. 4 CIRCANUAL AND LUNAR PERIODICITIES

14. 4.1. CIRCANNUAL PERIODICITIES

A **circannual cycle** is a biological process that occurs in living creatures over the period of approximately one year. This cycle was first discovered by Gwinner and Canadian biologist Ted Pengelley. It is classified as an Infradian rhythm, which is biological process with a period longer than that of a circadian rhythm, less than one cycle per 28 hours. These processes continue even in artificial environments in which seasonal cues have been removed by scientists.The term circannual is Latin, circa meaning approximately and annual relating to one year. Chronobiology is the field of biology pertaining to periodic rhythms that occur in living organisms in response to external stimuli such as photoperiod.

Circanual rhythm is the annual rhythm shown by plants and animals. For example certain activities are repeated year by year. Aslgae and laboratory rats show annual variations in enzymatic activities. Seeds show annual variations in capacity to sprout. Newly germinated seedlings exhibit annual variations in their metabolic activities. Some bird show annual

reproductive cycles. The food intake of wood chucks is an annual rhythm. Researchers Ted Pengelley and Ken Fisher studied the circannual clock in the golden-mantled ground squirrel. They exposed the squirrels to twelve hours of light and 12 hours of darkness and at a constant temperature for three years. Despite this constant cycle, they continued to hibernate once a year with each episode preceded by an increase in body weight and food consumption. During the first year, the squirrels began hibernation in late October. They started hibernating in mid August and early April respectively for the following two years, displaying a circannual rhythm with a period of about 10 months.

14.4.2. LUNAR PERIODICITIES

The cyclical activities exhibited by organisms in relation to the 29 day lunar month are called lunar rhythm. The animals that live in the intertidal region are mostly affected by these rhythms. For example during full moon and new moon days the tides in the ocean are greatest and are called spring tide. Spring tides are caused by the cooperative gravitational attractions of the sun and moon. At the moon's quarters, the sun and moon oppose each other resulting in smallest tides called ebb tides. The spring and ebb tides occur at an interval of 14.5 days. Hence this rhythm has 29 days called lunar cycle. Some of the animals which exhibit lunar rhythm are Palolo worms, Grunions, Sea lily, May fly, Menstrual cycle of women etc.

14.5 LET US SUM UP

Chronobiology deals with the sense of time in living organisms during their various biological cycles. Based on the duration of biological rhythm they are classified as circadian rhythm, infradian rhythm and ultradian rhythm. The circadian rhythm deals with the 24 hour cycles such as sleep wake rhythm, temperature cycle etc. The infradian rhythm is more than 24 hour cycle like, annual rhythm, seasonal rhythm, lunar rhythm, menstrual rhythm etc. The ultradian rhythm is below 24 hour cycle such as heart beat, respiration, eye blinking etc. The animals are entrained to the biological clock by the time cues or "Zeitgebers". The clock will free run in the absence of zeitgebers and this may be according to the endogenous clock of the animals. In recent days lot of research in the biological clock is going on in the field of chrono-pharmacology.

14. 6. UNIT END EXERCISES

1. Bats are ---------- animals

    a. Nocturnal, b. Diurnal, c. Crepuscular, d. None of these

2. In the absence of Zeitgebers our endogenous clock will ----

    a. Stops, b. Slow down, c. Free run, d. None of these

3. Menstrual cycle in humans are ----

    a. Infradian, b. Ultradian c. Circadian d. None of these

4. We regularly wake up at morning 6 because our circadian clock is

    a. Free run b. Slow down c. Struck d. Entrained

5. A person travelling foreign countries crossing time zones feels drowsy due to

a. Tiredness b. Thirst c. Hunger d. Jet lag

14. 7. ANSWERS TO CHECK YOUR PROGRESS

1. a, 2. c, 3. a, 4. d, 5. d,

NOTES

14.8 SUGGESTED READIINGS

Shukla, A. N. 2010. Text book of chronobiology, Discovery Publishing Pvt. Ltd., India

Dunlop, J.C., J. J. Loros, P. J. DeCoursey. 2011. Chronobiology, Sinauer Associates Inc., USA

Verma, P.S., B.S. Tyagi. 2000. Animal Physiology, S. Chand, India

Lamoureux, V. S. 2012. Current research in Animal physiology, Apple Academic Press, USA.

Moyes, C. D., P. M. Schulte. 2013. Principles of Animal Physiology, Pearson International Edition. USA.

MODEL QUESTION

DISTANCE EDUCATION- CBCS (2018-19 Academic year onwards)

Question paper pattern (ESE) – Animal Physiology

Zoology

NOTES

Time: 3 Hours Maximum : 75 Marks

Part – A (10 x 2 = 20 Marks)

Answer all Questions

1. Salivary Amylase
2. Neuromuscular junction
3. Bohr's Effect
4. Nephron
5. RBC
6. Heart Beat
7. Sarcomere
8. Aestivation
9. Ecdysone
10. Biological clock

Part- B (5 x 5 = 25 Marks)

Answer all questions choosing either (a) or (b)

11. a. Briefly explain about absorption and assimilation of food.

(or)

b. Write short note on Urine formation and its regulation.

12. a. What are the components of blood plasma?

(or)

b. Explain about the cardiac cycle.

13. a. Write short note on Kymograph.

(or)

b. Draw the structure of human eye.

14. a. Write briefly about the tolerance to high and cold temperature in animals.

(or)

c. Write note on adaptation to high altitude.

15. a. Discuss about the hormones secreted by Pituitary gland.

(or)

b. What is the significance of biological clock?

NOTES

Part- C (3 x 10 = 30 Marks)

(Answer any three out of 5 questions)

16. Discuss in detail about the mechanism of respiration in humans.

17. Explain about the mechanism of signal conduction thorough nerves.

18. Write in detail about the mechanism of muscle contraction.

19. Explain about osmotic and ionic regulation in fresh water and marine fishes.

20. Describe about the mechanism of action of steroid and non steroid hormones.