Uttar Pradesh Rajarshi Tandon
Open University

Bachelor of Science

UGZY-101

Animal Physiology

RIL-152

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Animal Physiology

Block

1

Physiology-I

Course Design Committee

Prof. Ashutosh Gupta **Chairman**
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UPRTOU, Prayagraj.

Prof. Paramhand Pathak **Member**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Prof. Ajay Singh **Member**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Prof. Rajendra Singh **Special Invitees**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Dr. Deepa Chaubey **Member/Secretary**
Academic Consultant, School of
Science UPRTOU, Prayagraj.

Course Preparation Committee

Dr. Deepa Chaubey **Author**
Acadmic Consultant, School of Science
UPRTOU, Prayagraj.

Prof. G.S. Shukla **Editor**
Director, Health Science
UPRTOU, Prayagraj.

Dr. Deepa Chaubey **Coordinator**
Academic Consultant, School of
Science UPRTOU, Prayagraj.

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COURSE INTRODUCTION

- The term physiology originated from a greek word physiologikos meaning discourse of natural knowledge. Physiology deals with the normal functioning of the body. The functional unit of the body is the cell and a group of similar cells constitute a tissue, a group of tissues form a system. Physiology is about the functions of living organisms how they eat, breath, and move about, and what they do just a keep alive.
- In all aspects of physiology, it is important to appreciate the role of mechanisms that control bodily functions. A unique feature of this part is the correlation of function with the structure without the basic knowledge of anatomy; a student can't understand the biological function of the particular organ or system in the body. For example, if a student doesn't have an idea of the brush border, lining of a kidney tubule, he/she can't appreciate the wonderful mechanism of selective reabsorption of useful substances from the nephric filtrate. Similarly he/she will not understand the physiology of muscular contraction properly, is he/she is not quite familiar with the ultrastructure of a skeletal muscle.
- The basic principles and mechanism of physiology of animals form the theme of this course which throws light on the entire syllabus divded into Block I and Block II

Block I- Elementary Physiology I

Block II- Elementary Physiology II

- Block I has 4 units in which you are going to study physiology, digestion, respiration, circulation and excretion.

Block II has 4 units in which you are going to study physiology of osmoregulation, nervous system, muscular system and endocrine system.

- In this course of Animal Physiology you will study about digestion, respiration, circulation, excretion, osmoregulation, nervous, muscular and endocrine system.
- We hope that you find this cause interesting and informative and it inspires you to develop further interest in Animal science

Block I (Physiology I):

- This block is concerned with the physiology of animals. How it necessary in information regarding to animals can eat, breath, eliminate their wastes and maintain an internal steady state. In order to understand the functions of the body, it is convenient to divide them broadly into digestive system, respiratory system, circulatory system, excretory system etc. All of them are interconnected and interdependent. This block begins with a description of how animals obtain their energy Supply that is food.

  - **Unit 1 :-** Physiology of digestion, the first part of nutrition, feeding, digestion. The later part of the unit describes digestion and absorption of food in mammals. The process of digestion is carried on with the help of enzymes present in the oral cavity and gastrointestinal tract. The end products of digestion are mostly absorbed from the small intestine and help in the growth and repair of tissues and in the liberation of heat and energy.

  - **Unit 2 :-** Respiration explains how animals obtain oxygen from their environment; Respiratory system consists of the nasal passage, nasopharynx, larynx, trachea, bronchi, and two lungs on each side. The unit reviews the transport of oxygen and carbon dioxide.

  - **Unit 3 :-** Circulatory system consists of the heat and blood vessels. The heart consists of four chambers two atria and two ventricles. The right atrium receives impure blood through large veins from the upper and lower regions of the body. The pure blood from the lungs is carried through pulmonary veins to the left atrium.

  - **Unit 4 :-** Excretion, deals with the mechanism animals have adopted to eliminate the nitrogen containing end-products of protein catabolism. Structure and functions of the excretory organs of various animals has been discussed in this unit

  - **Objectives :-**

    After studying this block you will be able to:

1. Discuss the various components of nutrition, process of digestion and absorption in mammals.
2. Discuss the mode of respiration and explain the transport of gases.
3. Discuss the general plan of circulatory system.
4. Discuss the mechanism of nitrogen excretion selective reabsorption.

UNIT-1

Physiology of Digestion

Structure

1.1 Introduction

Food is the basic and essential requirement of all living organism. Food not only provides the energy, but it is also necessary for the proper growth and development of the organism.

The food we eat, consists of carbohydrates, Proteins, Lipids, Vitamins and Minerals. The bulk of the food ingested is mostly in a complex macromolecular from, which cannot, as such, be absorbed by the body.

The digestive system includes the digestive tract and its accessory organs. The digestive tract, also called the alimentary canal or gastrointestinal tract, consists of a long continuous tube that extends from mouth to the anus. It includes the mouth, pharynx, oesophagus, stomach, small intestine and large intestine.

The tongue and teeth are accessory structures located in the mouth. The salivary glands, liver, gall bladder and pancreas are major accessory organs that have a role in digestion. These organs secrete fluids into the digestive tract.

Objectives:

After studying this unit you should be able to

- distinguish between macronutrients and micronutrients.
- describe the different types of nutrients.
- describe the process of digestion and digestive enzymes.
- describe the digestion and absorption of carbohydrates, proteins and fats.

1.2 Types of Nutrients

Nutrition : Carbohydrates, lipids, proteins, vitamins and minerals.

Nutrition is nourishment or energy that is obtained from food consumed or the process of consuming the proper amount of nourishment and energy.

The requirement of food by an organism, for its proper growth and development is called nutrition. Nutrition is a dynamic process, in which the food that is consumed is digested, its nutrients are absorbed and finally distributed to all body tissues for proper utilization.

Types of nutrients : Nutrients are organic or inorganic chemicals, present in the food articles. The organic nutrients present in food are carbohydrates, lipids, proteins and vitamins. The inorganic constituents are various minerals and water.

Nutrients identified into two types -

A. Macronutrients.

B. Micronutrients.

A. <u>Macronutrients:-</u>

Carbohydrates, lipids and proteins are macronutrients because these are present in major amount and constitute.

(i) The energy sources for the production of heat and different organic functions.

(ii) Building materials which are responsible for the wear and tear of the body.

B. <u>Micronutrients:-</u>

Vitamins, minerals and water are referred to as micronutrients because they are present in very small amount. These do not provide energy but their presence is essential for normal body functions and growth.

➢ Carbohydrates

Carbohydrates form the main bulk of diet and are the chief source of energy. They are also essential for the oxidation of fats and for the synthesis of certain non-essential amino-acids.

- The simplest sugar are called monosaccharides. These sugars cannot be further degraded to produce more sugars eg. glucose, fructose, galactose.
- The disaccharides eg. sucrose, lactose and maltose.
- Starch is the reserve food materials in plants. It is chief source of energy for the animals.
- Glycogen is the reserve food in animals.
- Digestion of polysaccharide means their conversion into
    - (i) First into oligosaccharides and
    - (ii) Finally into monosaccharide.

Proteins :- Proteins are the main building materials in all organism. These are not very rich in energy contents but these are needed for growth, wear and tear.

These are essential for repair and maintenance of worn out body tissues.

Sources :- Animals sources – milk and milk products egg, meat, fish etc.

Plant sources :- Pulses, cereals, nut, beans, etc.

Chemically proteins are the polymers of amino acids.

- Amino acid in a protein molecule are held together by means of peptide bonds. The leniar arrangement of many amino acids by peptide bonds form a polypeptide chain.
- A peptide chain represents a simple proteins.
- So the digestion of proteins means the hydrolysis of complex proteins by breaking the peptide bond to free the amino acid. Amino acids are further not digested and are absorbed by the intestinal villi.
- Ornithine and citrulline help in the formation of urea in liver.

➢ Fats

Fats are composed of fatty acids. These are energy rich compounds. These are the esters of higher fatty acids (esters are formed by the addition of alcohol with acids).

- Essential for absorption of fat soluble vitamins such as vitamins A, D, E and K.
- It provides support to body internal vital organs such as heart, kidneys, lungs, brain and liver.
- In case of fats the acids are the fatty acids and alcohol is glycerol. So the digestion of fats means bringing the fats in the form of fatty acids and glycerol.

$$\text{Fats} \rightarrow \text{fatty acids} + \text{glycerol}$$

Animal sources :– Ghee, butter, fish, oil, in general, they are poor sources of essential fatty acid but fatty acids are good sources of retinal and cholecalciferol (vitamins A and D respectively).

➢ Vitamins

Vitamins is an organic molecule which are required in small amount, which are essential for the normal growth and development of living organism. That is an essential micronutrient that an organism needs in small quantities for the proper functioning of its metabolism. Vitamins are either water soluble or fat soluble. Most vitamins cannot be synthesized by the body, but are found naturally in foods obtained from pants and animals.

In our body, vitamins usually function as the cofactors of various essential enzymes and therefore regulate the metabolism of the body.

- ### Minerals

Minerals are present in elementary form, these are requires for proper growth and development.

Some minerals are required by the body in large amount are called major minerals ex-calcium, phosphorus, sodium, chlorine, magnesium and sulphur.

Some minerals are required by the body in small amount called minor minerals ex-cobalt, zinc, copper, iodine, fluorine.

Function of minerals

Calcium :- Main constituent of bone and teeth, essential for blood clotting, muscle and nerve function.

Phosphorus is the main component of phospholipids, which form biological membranes.

Many minerals such as copper, iron, zinc, cobalt etc, act as prosthetic group of may enzymes and make them activated.

Calcium required for nerve transmission at synapses.

Sodium and potassium are required for impulse conduction and ionic balance in the body.

1.3 Digestive Tract and Process of Digestion

Gastro-Intestinal Tract (GIT) :-

Gastro intestinal tract (GIT) consists of a hollow muscular tube standing from the oral cavity, where food enters the mouth, continuing through the pharynx, esophagus, stomach and intestine to the rectum and anus. The GIT is an organ system within humans and other animals which takes in food, digests it to extract and absorb energy and nutrients, and expels of the remaining waste as faces (Fig.1.1).

The function of the digestive system in digestion and absorption. Digestion is the breakdown of food into small molecules which are then absorbed into the body. The digestive system is divided into two parts. The digestive tract (alimentary canal) is a continuous tube with two opening the mouth and the anus

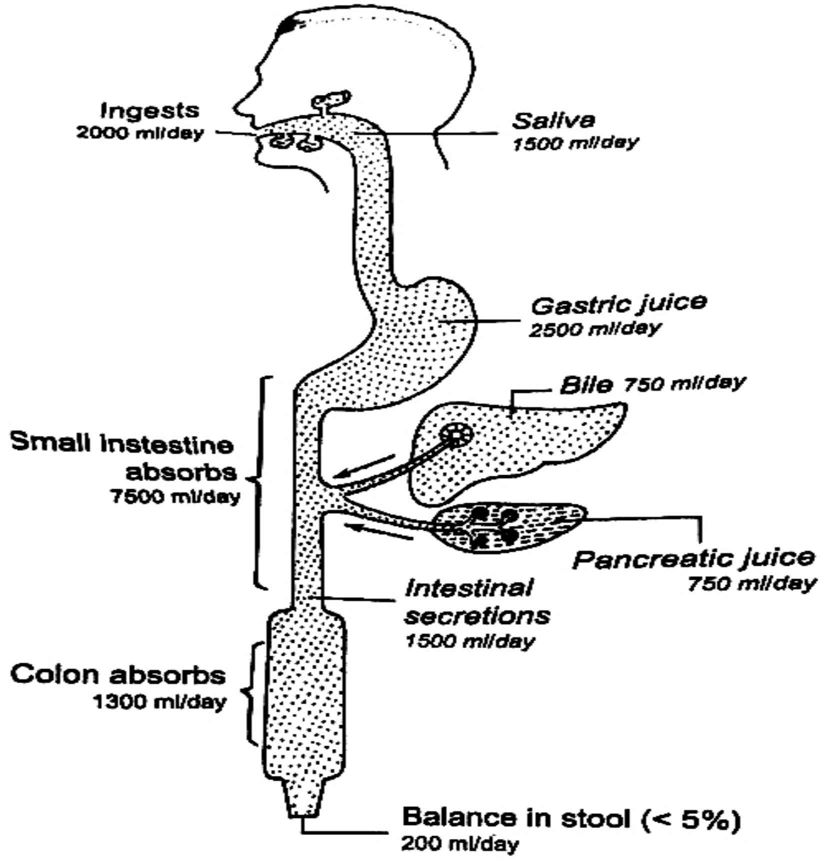


Fig. 1.1 Diagrammatic representation of gastrointestinal tract
Source: http://www.wikipedia.org

Process of digestion :-

Process of digestive ingestion involves-

(i) Placing the food into the mouth.

(ii) Chewing the food into smaller pieces (mastication).

(iii) Moistening the food with salivary secretion

(iv) Swallowing the food (deglutition).

1. Ingestion :-

- Chewing increases the surface area of the food. The mastication is a voluntary process in the man.
- **Swallowing (deglutition) –** The act of taking food. down in the oesophagus, from buccal cavity, through pharynx is called swallowing.
- **Peristalsis –** It is the reflex wave caused by the rhythmic movement of involuntary muscles of the gut wall. It pushes the food in forward direction.

2. <u>Digestion</u> :–

During digestion food is broken down into small particles by grinding action of the GIT and then degraded by digestive enzymes into usable nutrients.

(i) Starches are degraded by 'amylases' into monosaccharides.

(ii) Proteins are degraded by proteases into dipeptides and amino acid.

(iii) Fats are degraded by lipases and esterases into monoglycerides and free fatty acids.

3. <u>Absorption</u> :-

During absorption nutrients, water and electrolyte are transported from the GIT (mainly from the small intestine) to the circulation.

4. <u>Defecation</u> :–

Undigested materials are removed from the body as feces.

1.4 Gastrointestinal Secretion

Process of digestion is accomplished with the help of gastro-intestinal juice. The digestive juice, secreted in the various parts of alimentary tract, are as follows –

- Salivary secretion
- Gastric secretion
- Pancreatic secretion
- Bile secretion

➢ Salivary Secretion

Saliva contains –

(i) Water → up to 99.5% are found.

(ii) Inorganic components – are found 0.2% which includes Na, K, Ca, SO4, PO4 etc.

(iii) Organic matter – organic matter are found upto 0.3%, which include mucin, globulins, albumins, urea, uric acid etc.

(iv) Enzymes – Enzymes like ptyalin or salivary amylase.

➢ Gastric Secretion

The semi-solids food after salivary digestion reaches in the stomach through oesophagus.

Gastric juice secreted by the inner lining of the stomach. It is colourless, highly acidic liquid containing water, some salt, hydrochloric acid and an enzyme called pepsin.

HCI is one of the most important constituent of gastric juice. It is secreted by parietal cells (Fig. 1.2). The acid serves two functions –

(A) It kills any germs which may have entered along with the food.

(B) HCI converts inactive pepsinogen into active enzyme pepsin

Pepsinogen $\xrightarrow{HCI}$ Pepsin

(inactive) (active)

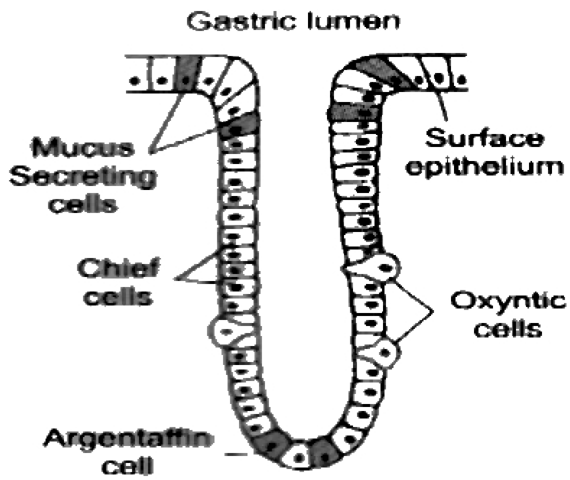


Fig. 1.2 Gastric glands

Source: http://www.wikipedia.org

➢ Pancreatic Secretion

Pancreas is a mixed gland. It has both exocrine activity as well as endocrine activity.

- The exocrine portion secretes pancreatic enzymes, useful in digestion.
- The endocrine portion secretes hormones like insulin, glucagon and somatostanin etc.
- The pancreas is connected to the duodenum through its main duct. This main duct of pancreas is called pancreatic duct (Fig.1.3).
- The exocrine portion of pancreas is about 85%. It consists of many small lobules called acine. The acine synthesis pancreatic juice. The endocrine portion of pancreas is about

15%, it consists of small groups of cells called 'Islets of Langerhans'.

- These islets contain following types of cells –

(i) **Alpha cells** :– These are about 25% of the total cells in an islet. These cells secrete glucagon hormone.

(ii) **Beta cells :–** These cells secrete insulin hormone.

(iii) **Delta cells :–** These cells secrete hormone called somatostanin (growth inhibitory factor)

(iv) **Fcells (PPcells) :-** These cells secrete hormone called pancreatic polypeptide (PP).

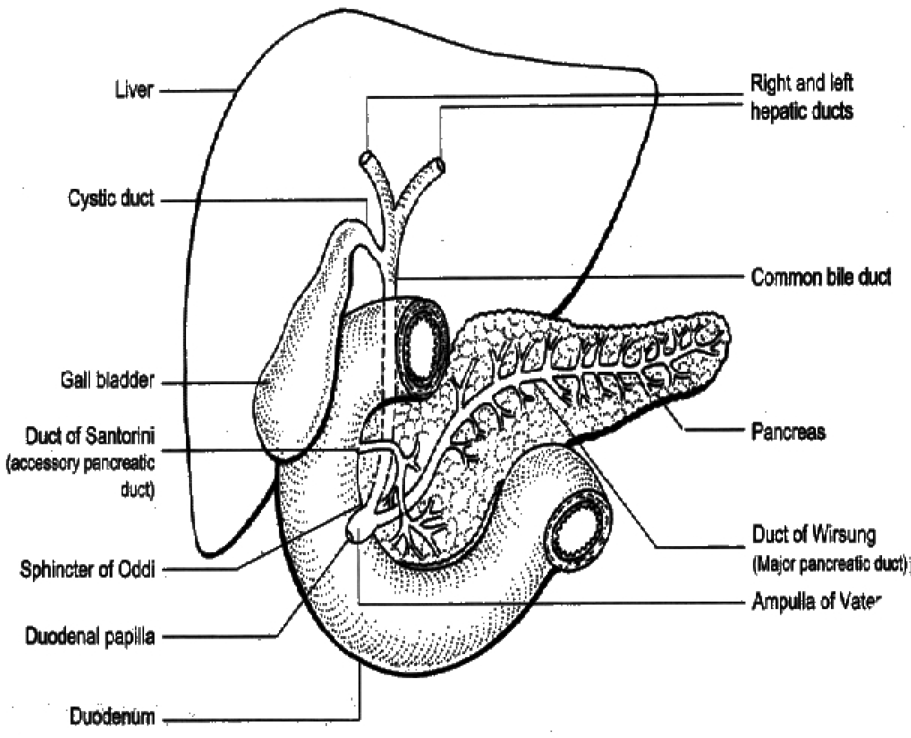


Fig. 1.3 Structure of pancreas

Source: Human Physiology and Biochemistry by Prof. A.K.Jain

➢ Bile Secretion

The secretion of liver is called bile juice. It is greenish yellow, watery liquid which is alkaline in reaction.

- Bile does not contain any digestive enzyme.
- Bile also contains bile pigments – bilirubin and biliverdin.
- These pigments are the waste products of haemoglobin catabolism, (which are formed by the catabolism of haemoglobin).

Function of bile juice :-

Bile salts are necessary for the digestion and absorption of fat because –

- They emulsify fats
- Activate pancreatic lipase.
- Bile salts stimulate the secretion of more bile from the liver.
- Bile salts make the medium alkaline thus help in the functioning of amylases and proteolytic enzymes of pancreas and intestine (which function in alkaline medium only).

1.5 Digestive Enzymes, its regulation and control

The digestive process is not accomplished only by enzymes. Some peptide hormones are also needed during digestive process. These are called gastrointestinal hormones, because these are secreted by gastrointestinal wall. These hormones regulate and control the entire process by regulating secretions of digestive glands.

The three major classes of digestive enzyme are –

(i) **Proteases** – That hydrolyze peptide bonds in proteins.

(ii) **Carbohydrases** – That hydrolyse glycosidic bonds in carbohydrates.

(iii) **Lipases**- That hydrolyse ester bonds in fats.

Gastrointestinal secretion is largely under the control of gastrointestinal hormones secreted by endocrine glands of gastric and intestinal mucosa.

The three main mammalian gastrointestinal hormones are secretin, gastrin and cholecytokinin (CCK). Gastrin is secreted by gastric mucosa (stomach). Cholecystoknini and secretin are secreted by the mucosa of duodenum.

1.6 Digestion of Carbohydrates

The different forms of carbohydrates are as follows-

(i) **Polysaccharides** – Starch, Dextrin, Glycogen and Cellulose

(ii) **Oligosaccharides** – Lactose, Maltose, Sucrose

(iii) **Monosaccharides** – Glucose and Fructose.

- Digestion of carbohydrates begins in the buccal cavity. Saliva contain the starch splitting enzyme ptyalin or salivary amylase, that act on the starch and converts its maltose (disaccharides).

- Now the semidigested carbohydrate food is passed into stomach through pharynx and oesophagus, no digestive enzyme is secreted.
- When the food reached the stomach the pH changes the food becomes acidic, it is now called chyme.
- In the gastric juice does not possess any carbohydrates splitting enzyme, but gastric HCI can carry on some hydrolysis of sucrose.
- The pancreatic juice comes from the pancreas. The pancreatic juice contains two enzymes acting on carbohydrates (Fig.1.4).

  A. Pancreatic amylase – Acting on starch and dextrin.

  B. Maltose – (in traces) acting on maltose.

1. Starch $\xrightarrow[pH\,6.8 to 7.0]{ptyalin}$ disaccharides

2. Starch $\xrightarrow[pH\,8.2 to 8.2]{pancreatic amylase}$ disaccharide

3. Starch, glycogen $\xrightarrow{-1,4 glu\cos idose}$ maltose

4. Maltose $\xrightarrow{Maltase}$ glucose + glucose

5. Sucrose $\xrightarrow{Sucrase}$ glucose + fructose

6. Lactose $\xrightarrow{Lactase}$ glucose + galactose

Now food reaches ileum. In ileum various types of disaccharidases are present, such as sucrose maltase and lactase etc. Thus the digestible carbohydrates are all converted into monosaccharides in which form they are absorbed.

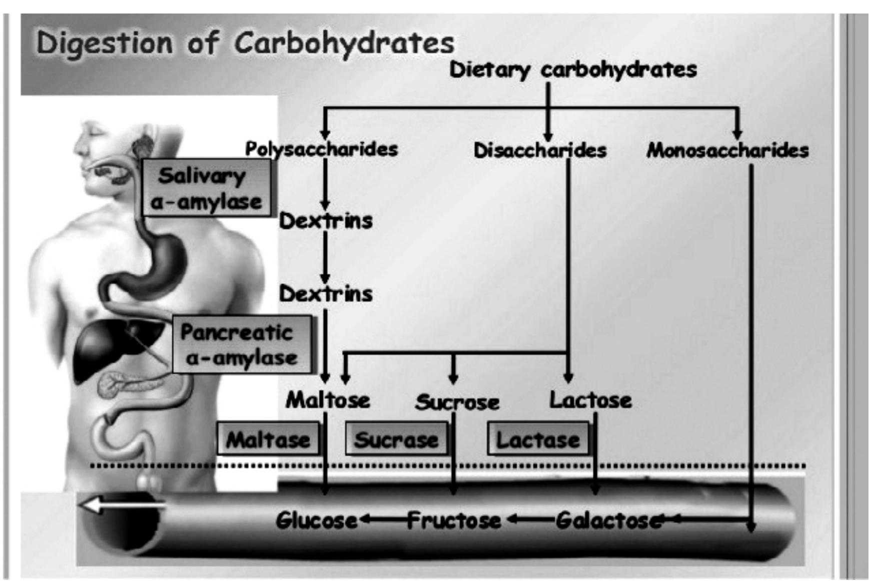


Fig. 1.4 Digestion of carbohydrates
Source: http://www.wikipedia.org

➢ Digestion of proteins

- Digestion of proteins starts in the stomach when food reaches the stomach, it gets mixed with HCl and becomes chyme (acidic).
- The food is passed to duodenum the medium becomes alkaline due to action of bile juice.
- In the gastric juice – pepsin is the proteolytic enzyme of gastric juice. It acts with the help of HCl and converts all digestible proteins up to peptone stage.

Complex proteins $\xrightarrow{\textit{pepsin}}$ Proteases, peptones and large peptides.

<u>Pepsin and its function</u>

- Pepsin is protein in nature.
- It remains as pepsinogen in the peptic cells of stomach, HCl of gastric juice converts it into active pepsin.

Proteins

↓

(pepsin in gastric juice and trypsin in pancreatic juice)

Proteases, peptides

(Proteases in pancreatic juice peptidases in intestinal juice)

↓

Amino acid

Now the food reaches the jejenum and ileum, where many proteolytic enzyme are present. These enzymes finally convert the amino acid (which are end products of protein digestion)

Trypsinogen $\xrightarrow{\textit{enterokinase}}$ Trypsin

Proteins, proteoses, peptone $\xrightarrow{\textit{trypsin}}$ polypeptides, free amino acids

Chymotrypsins are secreted in their inactive forms known as chymotrypsinogens.

The conversion of chymotrypsinogens into active chymotrypsins is made by trypsin (Fig.1.5).

Chymotrypsinogens $\xrightarrow{\textit{trypsin}}$ chymotrypsins

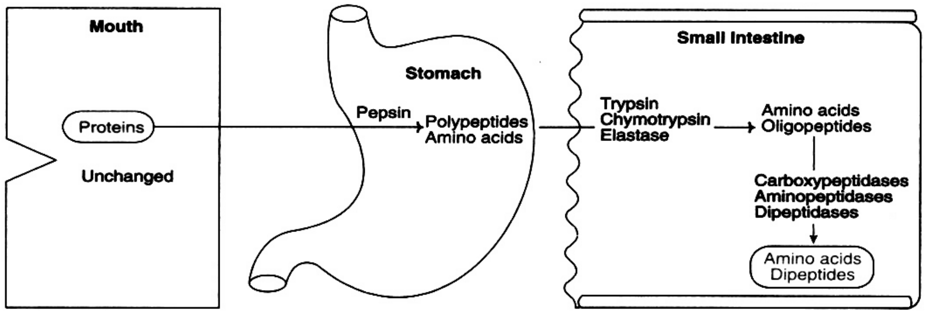


Fig. 1.5 Digestion of proteins

Source: Biochemistry by Dr.U.Satyanarayan

➢ Digestion of Fats

Pancreatic juice also contains a number of lipolytic enzymes such as lipase, phospholipase and cholesterol esterase.

Lipase :-

It is an important enzyme in digestion. Neutral fats are digested into fatty acid and glycerol. Hydrolysis of fats takes place in different stages.

In the first stage there is formation of one molecule of fatty acid and a diglyceride. The diglyceride is broken down into another molecule of fatty acid and a monoglyceride. The monoglyceride is finally hydrolyzed into another molecules of fatty acid and glycerol. So the fat molecule after complete hydrolysis gives rise to 3 molecules of fatty acides and one molecules of glycerol. In human body bile juice is present to dissolve the fats. In duodenum, the bile juice is present (from liver) which emulsify the fats.

Lipase enzymes of pancreas and intestine can act only on emulsified fats. Once the fat is emulsified, the pancreatic lipase and then intestinal lipase play their roles (Fig.1.6).

Pancreatic lipase is the main enzyme for fat digestion. Both enzymes now convert the fat into fatty acids and glycerol. Which are the end products of fat digestion.

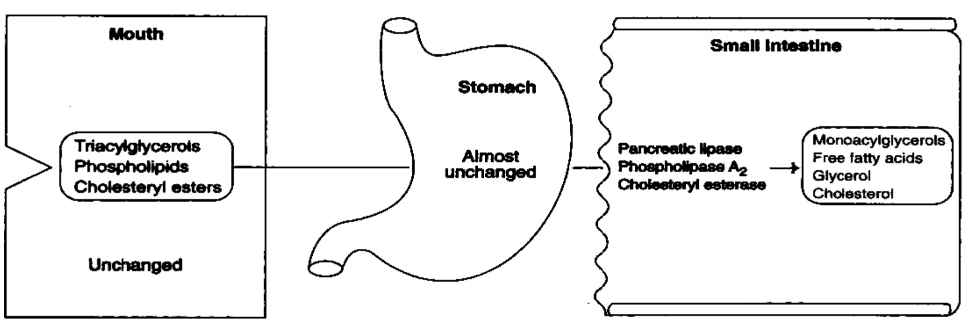


Fig. 1.6 Digestion of fats

Source: Biochemistry by Dr.U.Satyanarayan

1.7 Absorption

Absorption is the process by which the end products of digestion pass through the intestinal epithelium and enter the blood stream.

➢ Absorption of Carbohydrates

Most of the absorption occurs in small intestine, the mucosa of small intestine is provided with numerous finger like projection called villi. Villi and their brush border greatly increase the surface area for absorption of digested food (Fig.1.7).

There are two mechanism of absorption in the intestine (1) Diffusion (2) Active absorption.

- Fructose is transported by simple diffusion in response to a concentration gradient by the absorptive cells of the villi.
- Glucose and galactose are absorbed by active transport.
- This type of absorption (transport) requires metabolic energy.
- These monosaccharides are finally transported to the blood capillaries.

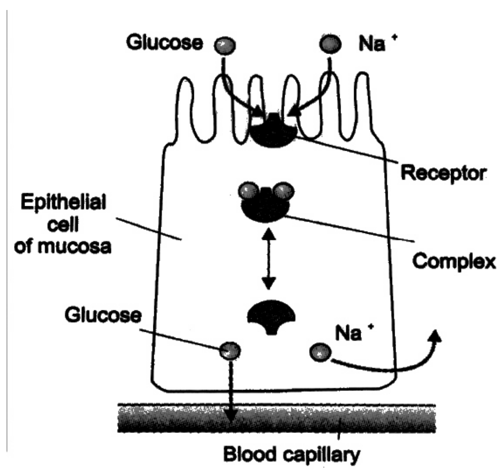


Fig. 1.7 Absorption of glucose

Source: http://www.wikipedia.org

➢ Absorption of Proteins

Most of the proteins are converted to amino acids, a part is left in the form of small polypeptides. Some dipeptides are intracellularly digested, these ester the intestinal cells and a hydrolysed there. The free amino acid are absorbed both by diffusion and active transport. The active transport involves oxidative phosphorylation. The transport of neutral amino acid and sodium go together, but there are separate systems for basic and acidic amino acids.

Amino acids are mainly of two types D types and L type.

- D amino acid are absorbed solely by passive diffusion only. While L – amino acids are actively transported.

- L amino acids are absorbed more rapidly than D isomers

  The absorbed amino acids are also transported to the underlying blood capillaries.

➢ **Absorption of Fats**

Fatty acids are insoluble in water, therefore they cannot reach the blood stream directly. They are first converted into small water soluble droplets called micelles.

1. Lipolytic hypothesis :-

Fatty acids are insoluble in water, therefore they cannot reaches the blood stream directly. Triglycerides (fats) are absorbed mainly in the lymphatics after they have been resynthesised from fatty acid and glycerol in the mucosal epithelial cells (Fig.1.8).

The main process of fat absorption are –

- The short chain and water soluble long chain fatty acids are directly absorbed through the absorptive cells of the intestine into the portal blood system.

- The unbroken fats, long chain fatty acids and glycerides which are in the form of micelles. These micelles can be absorbed into the intestinal cells by diffusion where they are resynthesized into very small fat molecules (droplets) called chylomicrons.

- The chylomicrons are released from the intestinal cells into lymph present in the lymph capillaries known as lacteals.

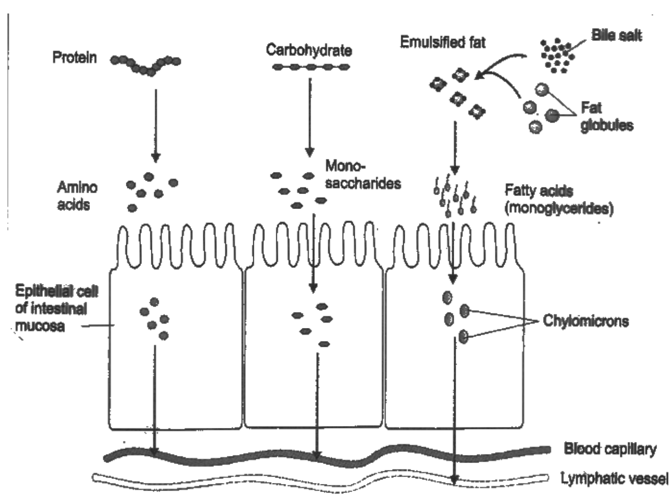


Fig. 1.8 Absorption of different types of digested food particles

Source: http://www.wikipedia.org

- **Absorption of Water**

The absorption of water from the small intestine is associated with the absorption of electrolytes and digested food.

- **Defecation**

The elimination of undigested food material is called egestion (or defection) it is the last step of entire digestive process.

Absorption of Salt :-

Stomach and large intestine absorb a little amount of salt, but small intestine is the main site for salt absorption. The chyme derived from the first food intake requires 36 hours for its solidification to be converted into solid residual matter known as faeces.

1.8 Summary

- Digestion is a process that converts complex foodstuffs into simpler ones which can be readily absorbed by the gastrointestinal tract.
- Digestive tract starts at the mouth and ends at the anus.
- Stomach, duodenum and upper part of small intestine are the major sites of digestion.
- The small intestine is the prime site for the absorption of digested foods.
- Digestion of carbohydrates is initiated in the mouth of salivary amylase and is completed in the small intestine by pancreatic amylase,
- Monosaccharides are the final absorbable products of carbohydrates digestion.
- Protein digestion begins in the stomach by pepsin which is aided by gastric HCI.
- Pancreatic proteases (trypsin, chymotrypin) and intestinal amino peptidases and dipeptidases complete the degradation of proteins to amino acid and same dipeptides.
- Digestion of lipids occurs in the small intestine.
- Emulsification of lipids, brought about by bile salts.

1.9 Terminal Questions

Q. 1: Write an account of the digestion and absorption of lipids.

Answer:..
....
....
....

Q. 2: Describe briefly the digestion of carbohydrates and proteins.

Answer:..
....
....
....

Q. 3: Write briefly on the enzymes of gastrointestinal tract involved in the digestion of food stuffs.

Answer:..
....
....
....

Q. 4: Discuss the role of bile juice in the digestion of food.

Answer:..
....
....
....

Q. 5: Describe briefly the absorption of carbohydrates and proteins.

Answer:..
....
....
....

Q. 6: Discuss the importance of proteins, minerals and vitamins for human beings.

Answer:..
....
....
....

Short notes on the following–

(1) Discuss the functions of saliva

(2) Discuss the hormonal control of digestive secretions.

(3) Role of HCI in protein digestion.

(4) Discuss the term assimilation.

(5) Discuss the emulsification of fats.

Multiple choice questions :-

(1) Bilirubin and biliviridin are found in

(a) Blood (b) Bile

(c) Pancreatic juice (d) Saliva

(2) HCl is secreted by the

(a) Parietal cells (b) Chief cells

(c) Goblet cells (d) Paneth cells

(3) The chief function of bile is

(a) To digest fats by enzymatication.

(b) To regulate process of digestion.

(c) To emulsify fats for digestion.

(d) To eliminate waste products.

(4) Stomach is the site of digestion mainly of

(a) Carbohydrates (b) Proteins

(c) Fats (d) All of these

(5) Digestion of fats, proteins and carbohydrates is completed in

(a) Stomach (b) Small intestine

(b) (c) Large intestine (d) colon

1.10 Answer

1– (b) **2 – (a)**

3– (c) **4– (b)**

5– (b)

UNIT-2

Physiology of Respiration

Structure

2.1 Introduction

All animals depend on oxidation of food materials for their energy requirements. They utilize oxygen and produce carbondioxide during the course of their metabolism. The respiratory system consists of the upper respiratory system consists of the upper **respiratory tract** (nasal passages), the airway conduction system (larynx, trachea, bronchi, bronchioles) and the lower respiratory tract (alveolar ducts and alveoli).

The human respiratory system consists of specialized structures whose function is to take in oxygen from the surrounding environment and expel carbondioxide from the body. The primary organ involved in this process is the lung and each individual contains a right and a left lung. The lungs are found in the thoracic cavity of our body (chest region) air passes into the nose and through the nasal cavity until it gets into the phaynx. From the **pharynx**, it travels into the **larynx**. The opening of the larynx contains a cartilaginous flap called the **epiglottis** from the larynx, the air moves into the trachea (commonly known as the wind pipe) which connects to the **left and right bronchi**. The bronchi in each lung split into tiny airways **called bronchioles**. These bronchioles terminate at balloon like structures called alveoli. Below the lungs is a skeletal muscle called the diaphragm, which is involved in breathing.

Objective :-

After a careful of this unit you will be able to –

- explain the need for respiration.
- describe the structural & functional differences between lungs & trachea.
- explain the process of gas transport between the blood & tissues in mammals.
- discuss the role of haemoglobin in transfer of oxygen & compare it to the transport of carbondioxide in blood.

2.2 Structural organization of lungs & other respiratory organs

2.2.1 Respiratory Passages

The respiratory system consists of the respiratory passage, lungs and associated organs. It consists of air passage, of the nasal canals, pharynx, larynx, trachea, bronchi and bronchioles.

The nasal cavity is the first of the respiratory organs.

Air enters through the nostrils, which opens into internal nares, then open into pharynx.

Three changes thus takes place here -

- The dust particles and bacteria becomes caught up in the nasal mucus and one removed.
- The sense organ of smell being situated inside the nose. The organ of smell helps in selecting the air inspired.

- Thus purified air passes down the nosapharynx, larynx, trachea and enters the lungs and reaches the alveoli;, where gaseous exchange takes place.

2.2.2 Larynx

Situated between the pharynx and the trachea, is a cartilaginous chamber, known as the larynx. It is associated with the production of sound. One of the cartilages of the larynx is called the epiglottis. The trachea is a tubular structure; trachea divides into two bronchi – one for the right lung, the other for the left lung (Fig. 2.1). The trachea is provided with a series of 15-20 C-shaped cartilage rings incomplete dorsally, which prevent the trachea from collapse.

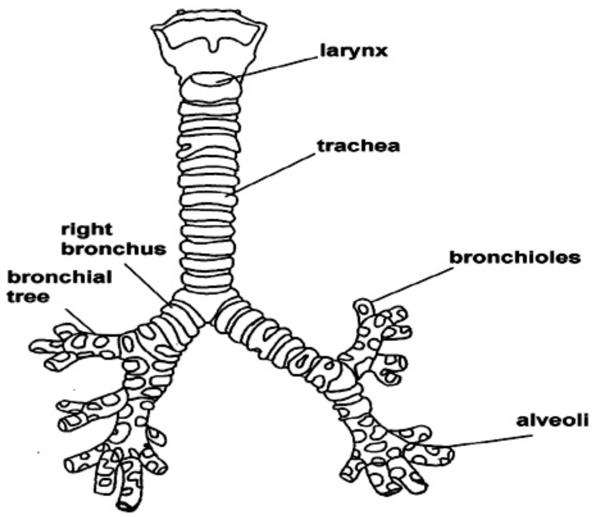


Fig. 2.1 Structure of Trachea

Source: http://www.wikipedia.org

2.2.3 Lungs

The lungs are paired structures, the right lungs are divided into upper, middle and lower lobes by two deep clefts. Whereas the left one is divided into upper and lower lobes by one similar cleft. The bronchioles divide and subdivide and finally end up into blind sacs known as air sacs.

Each air sac looks like a cluster of grapes and consists of several (4-6) microscopic chambers or alveoli. The respiratory tract is lined by ciliated columnar epithelial cells.

The walls of the pulmonary or lung alveoli, on the other hand, one simply composed of a single layer of cuboidal non-ciliated epithelial cells. The alveoli are surrounded by a rich network of capillaries (Fig. 2.2).

These capillaries receive the blood supply from the pulmonary artery which is returned through the pulmonary vein. The exchange of gases between the air and blood takes place in the alveoli. The alveolar wall is permeable only to gases, but not to plasma in the capillaries.

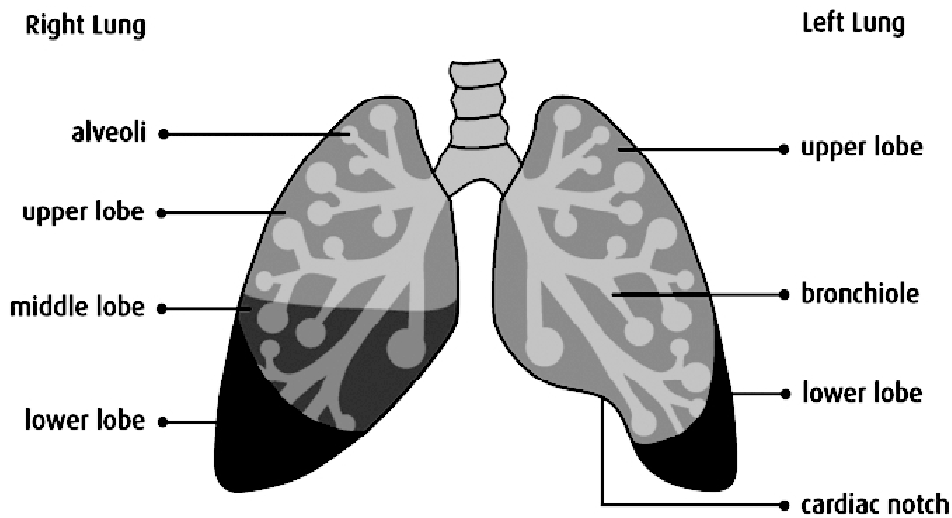


Fig. 2.2 Structure of Lungs

Source: http://www.wikipedia.org

2.2.4 Associated organs

The thorax which contains the lungs is bounded by the rib cage on the lower side of the thorax, however, the lung is bounded by a dome, -shaped sheet of skeletal muscle, the diaphragm within the thorax, the lungs are enclosed in the pleural cavities. The pleural cavity is a membranous double walled structure, the inner wall adjacent to the lungs is known as the visceral pleura, whereas the outer wall is called the parietal pleura. There is a thin layer of serous fluid between the two pleuras.

This prevents friction of the lungs during breathing movements.

2.3 Mechanism of respiration

Respiration includes two processes -

Inspiration and expiration.

Inspiration is the active process, while expiration is passive.

Breathing movements are caused by the alternate expansion and contraction of the chest cavity.

- When the chest expands, its volume increases so that the pressure within the chest cavity falls below the atmospheric pressure.
- Air from outside enters the lung under pressure (inspiration).
- When the chest cavity contracts, its volume is reduced and the air is forced out (expiration).

- The change in volume of the chest cavity is brought about by the alternate contraction and relaxation of the diaphragm and external intercostals muscles present between the ribs.
- Enlargement of chest cavity is attained by the contraction of the dome-shaped diaphragm.
- Respiratory movements are primarily under the control of the autonomic nervous system.

2.4 Function of respiration

Metabolic function :- Oxygen is essential for maintenance of metabolism of tissue. Aerobic process of metabolism, cannot take place in absence of oxygen.

Excretion :-

It excretes volatile substances like ammonia, ketone bodies, essential oils, alcohol, water vapour etc.

Maintenance of acid base balance :-

This is done chiefly by adjusting the amount of CO_2 elimination.

Maintenance of temperature & P^H balance :-

In the expired air, large quantity of heat is lost (the expired air is warmer than inspired air). The respiration plays an important role in the maintenance of pH of blood at normal levels.

Gaseous Exchange :-

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 and internal respiration, gases always tend to diffuse from a high partial pressure to a lower partial pressure.

2.5 Transport of gases in blood

The uptake of O_2 and the release of CO_2 by the blood of the alveolar capillaries can be explained by diffusion, ie. The gases pass from the regions of high pressure to those of low pressure. The pressure of the gas refers to the partial pressure.

The tension of oxygen in the arterial blood is about 100 mm Hg. The oxygen tension in the tissue is less than 40 mm of Hg. Oxygen tension in the arterial blood falls

Dissociation of oxyhaemoglobin in the blood depends upon -

- O_2 tension
- CO_2 tension

- H-ion concentration
- Electrolyte content
- Temperature

CO_2 tension and CO_2 content in the tissues are much higher than that of blood. Due to the difference of pressure CO_2 diffuses from the tissue cells to the blood capillaries CO_2 tension in the blood rises which also favours dissociation of oxyhaemoglobin.

Lung alveolus	100 mm Hg	40 mm Hg
	↓ O2	↓ CO2
Lung capillary	40	46

When the venous blood passes through the pulmonary capillaries into the lungs, it has got the oxygen tension of about 40 mm Hg oxygen tension in the alveoli is about 100 mm of Hg. Hence oxygen diffuses from the alveoli into the venous blood through the pulmonary and capillary endothelium. Oxygen tension rises and more oxyhaemoglobin is formed in the carpuscles.

Simultaneously CO_2 is liberated from the venous blood which also diffuses through the pulmonary and capillary endothelium into the alveoli. CO_2 tension and H-ion concentration in the venous blood fall which favour entry of O_2 in the blood capillaries.

2.5.1 Haemoglobin

Haemoglobin is largely responsible for the transport of O_2 from lungs to tissues.

It is also helps to transport CO_2 from the tissues to the lungs. Haemoglobin is the best known O_2 carrying pigment (Fig 2.3).

Haemoglobin is the red pigment of blood. It is chromoprotein consisting of two parts -

- One part (96%) is a specific simple protein known as globin (histone). Globin is a protein built from 4 polypeptide chain two 'α' and two 'β' chains. Therefore, the normal adult haemoglobin (HbA) is written as HbA (α_2 β_2) of two α chains each contains 141 amino-acids. Each β-chains each contains 146 amino-acids.
- When haemoglobin content of the blood is reduced, the result is anaemia. Haemoglobin is not only a carrier of O_2 and CO_2, but it is also one of the buffering agents in the blood.
- Myoglobin is found in striated muscle of vertebrates and combines with one molecules of oxygen.
- The haemoglobin can occur in two interchangeable forms, one is called T (tense) structure and the other is R (released) structure T structure has relatively low affinity for oxygen and R structure has high affinity for oxygen.

- The uptake of oxygen by one subunit in T structure changes the whole complex to R structure, which then binds to oxygen one hundred times faster than the first haem group.

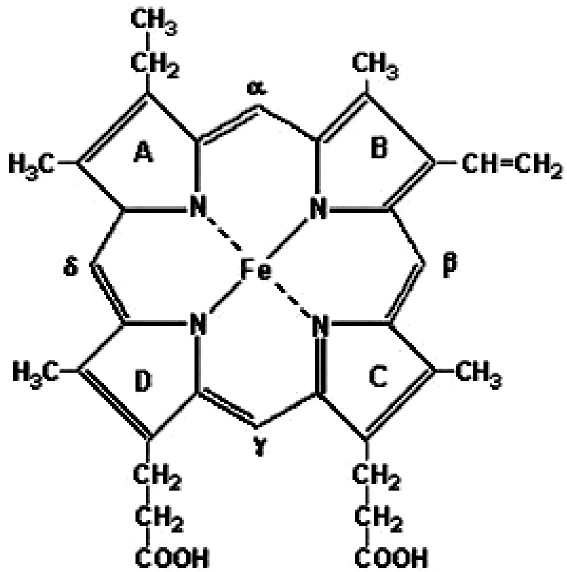


Fig. 2.3 Heme Molecule

Source: http://www.wikipedia.org

<u>Function of Haemoglobin</u> :-

- It is essential for oxygen carriage.
- It plays an important part in CO_2 transport.
- It constitutes one of the important buffers of blood and helps to maintain its acid-base balance.
- Various pigments of bile, stool, urine etc, are formed from it.

<u>Some important definition</u> :-

1. **<u>Oxyhaemoglobin</u> :-** Haemoglobin reacts with oxygen to form oxyhaemoglobin and is represented as HbO_2.
2. **<u>Carbamino-Haemoglobin</u> :-** Carbon dioxide reacts with haemoglobin to form carbamino-haemoglobin.
3. **<u>Reduced (Deoxygenated) Haemoglobin</u> :-** Haemoglobin from which oxygen has been removed is called is called deoxygenated haemoglobin and is represented as Hb.

2.5.2 Oxygen transport in blood

- One molecules of haemoglobin (with four hemes) can bind with four molecules of O_2. This is contrast to myoglobin (with one heme) which can bind with only one molecule of oxygen.

- Myoglobin is monomeric oxygen binding haemoprotein found in heart and skeletal muscle.

2.5.3 Oxygen dissociation curve

- The binding ability of haemoglobin with O_2 at different partial pressures of oxygen (PO_2) can be measured by a graphic representation known as O_2 dissociation Curve (Fig. 2.4).

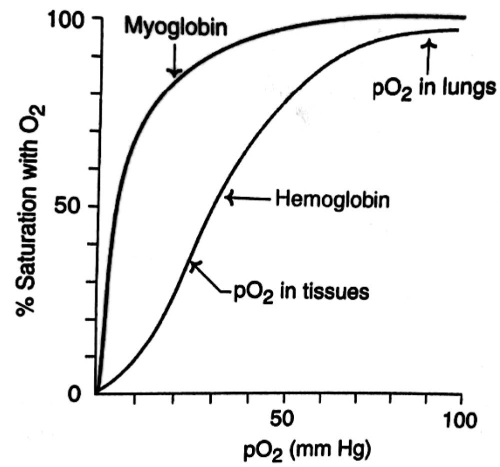


Fig. 2.4 Oxygen dissociation curve of hemoglobin and myoglobin

Source: Biochemistry by Dr. U. Satyanarayana

It is evident from the graph that myoglobin has much higher affinity for O_2 than haemoglobin. Hence O_2 is bound more tightly with myoglobin than with haemoglobin.

- The (O_2) oxygen dissociation curve for haemoglobin is sigmoidal in shape. This indicates that the binding of oxygen to one heme increases the binding of oxygen to other hemes.
- Thus the affinity of Hb for the last O_2 is about 100 times greater than the binding of the First O_2 to Hb. This phenomenon is referred to as cooperative binding of O_2 to Hb or simply heme – heme interaction.
- At high O_2 pressure, the haemoglobin combines with O_2 to form oxyhaemoglobin. Each iron atom can bind one O_2 molecule, and when all sites are occupied, the haemoglobin cannot take on any more, since it is fully saturated.
- At low O_2 pressure, O_2 dissociates from its binding, and the haemoglobin will eventually give up all its O_2.
- The haemoglobin is completely oxygenated (approximately 98% saturation) by an oxygen tension of 100 mm Hg.
- When the oxygen tension falls below 60 mm Hg the oxyhaemoglobin dissociates rapidly. This is indicated by the steeper slope of the curve at low oxygen tensions.

- When the PO_2 is zero, oxyhaemoglobin loses all its oxygen.
- The haemoglobin gets completely oxygenated (98% saturation) in the alveoli of the lungs where the oxygen tension is 100 mm Hg and, later, donates the oxygen to the tissues where the oxygen tension is low and where oxygen is needed most when PCO_2 is gradually increased, the O_2 carrying capacity of blood is also reduced and the O_2 dissociation curve move towards right side. This effect of CO_2 on O_2 carrying capacity of blood is Bohr effects.
- Any increase in protons / or lower PO_2 **shifts the equilibrium to the right** to produce deoxyhaemoglobin as happens in the tissues.
- On the other hand, any increase in PO_2 and / or a decrease in H^+ **shifts the equilibrium** to the left, which occurs in lungs.

Lungs (PO_2 = 100 mm Hg)

$$Hb + O_2 \rightarrow HbO_2 \text{ (Oxyhaemoglobin)}$$

Tissues (PO_2 = 40 mm Hg)

$$HbO_2 \rightarrow Hb + O_2$$

2.5.4 Carbondioxide transport in blood

In aerobic metabolism, for every molecule of O_2 utilized, one molecule of CO_2 is liberated. Haemoglobin actively participates in the transport of CO_2 from the tissues to the lungs.

Haemoglobin also helps in the transport of CO_2 as bicarbonate.

CO_2 transported through the blood in the following ways-

- A small amount (5%) in the form of a simple solution in plasma and forms (H_2CO_3) carbonic acid. $CO_2 + HOH \rightleftharpoons H_2CO_3$
- Increase in its concentration causes the dissociation of H_2CO_3 into H^+ion and a HCO_3^-ion. $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
- A major part (85%) as bicarbonate of sodium and potassium.
- About 10% in combination with haemoglobin in the form of carbaminohaemoglobin (combination of CO_2 with free amino group of Hb)

$$CO_2 + Hb.NH_2 \rightleftharpoons Hb.NH.COOH$$

- When the PCO_2 in the tissues is greater than the PCO_2 in the capillaries carbon dioxide diffuses into capillaries because of concentration gradient.

In physical solution :

A small part of the CO_2 dissolves in the plasma to form carbonic acid

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

- A major part of carbon dioxide from the plasma enters the red blood cells and combines with water. This reaction takes place in the present enzyme carbonic anhydrase which is associated with the haemoglobin in red cells and forms the H_2CO_3, which soon dissociates.

- The carbonic acid dissociates into bicarbonate and hydrogen ions.

$$H_2O + CO_2 \underset{anlydrase}{\overset{Carbonic}{\rightleftharpoons}} H_2\,CO_3\ HCO_3^- + H^+$$

The hydrogen ions thus liberated are taken up by the protein molecules of the blood in exchange for metal ions (K^+ and Na^+)

- Diffusion of CO_2 from respiratory tissues into blood, therefore leads to the formation of bicarbonates of potassium and sodium.

$$KHb + H_2CO_3 \overset{Carbonicanhydrase}{\rightleftharpoons} H.Hb + KHCO_3$$

Carbonic anhydrase also catalyses the splitting of the H_2CO_3 to H_2O and CO_2 in the lungs. This results in a rapid release of CO_2 during expiration.

- When the CO_2 concentration is high, some of the entering the erythrocytes from the tissues reacts with amino group ($-NH_2$) of hemoglobin to form carbaminohaemoglobin.

$$HbNH_2 + CO_2 \underset{LowPCO2}{\overset{HighPCO2}{\rightleftharpoons}} Hb\ NH\ COOH$$

The reaction is very rapid although no enzymes is required. Low CO_2 concentration leads o the dissociation of carbaminohaemoglobin to CO_2 and haemoglobin.

Chloride shift:

The plasma CO_2 diffuses into the RBC along the concentration gradient where it is combines with water to form H_2CO_3.

This reaction is catalyzed by carbonic anhydrase.

In the RBC, H_2CO_3 dissociates to produce H^+ and HCO_3^-

The H^+ions are trapped and buffered by haemoglobin. As the concentration of HCO_3^- increases in the RBC, it diffuses into plasma along with the concentration gradient; the chloride in diffuses into the erythrocytes from the plasma in exchange for Cl^- ions, to maintain electrical neutrality. This phenomenon is known as chloride shift. All the reactions of chloride shift are reversible.

2.5.5 <u>CO_2 dissociation curve:</u>

Curve for oxygenated & deoxygenated blood differ somewhat.

This is because oxyhaemoglobin slightly more acidic then haemoglobin.

Hence, oxygenated blood will bind slightly less CO_2. This phenomenon is closely related to the Bohr Effect, an increased in the CO_2 shift the O_2 dissociation curve to the right, giving more O_2 from the blood to the tissue (Fig. 2.5).

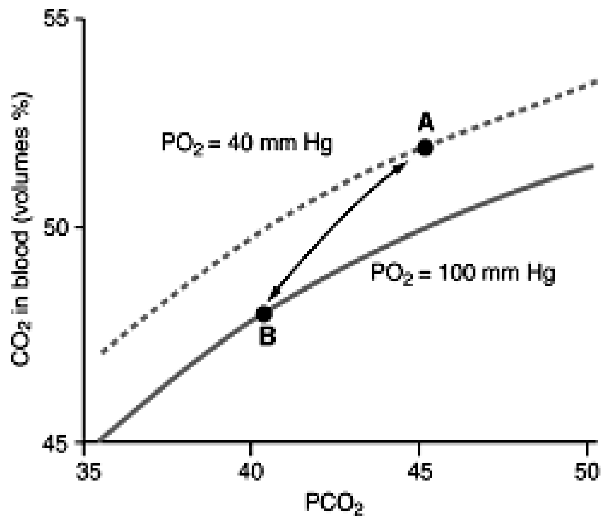


Fig. 2.5 CO_2 dissociation curve

Source: http://www.wikipedia.org

When CO_2 is added to the blood, it pushed the equibrium between oxyhaemoglobin & haemoglobin in the direction of weaker acid (haemoglobin) Bohr Effect (Fig. 2.6).

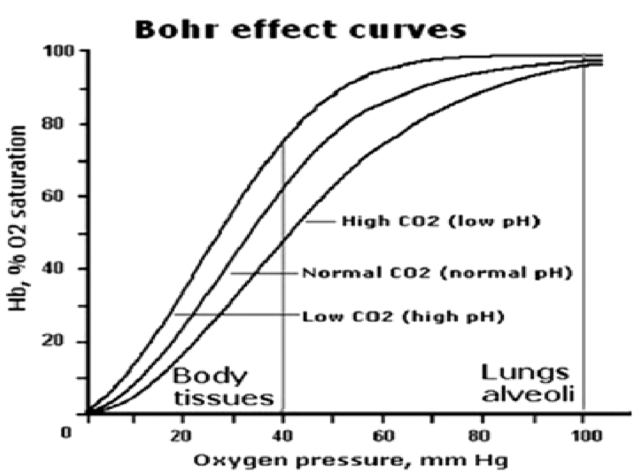


Fig. 2.6 Bohr Effect on oxygen dissociation curve (Effect of pH)

Source: http://www.wikipedia.org

In the body the actual dissociation curve for CO_2 will be the fully drawn line A-V, in which the point A stands for the normal arterial blood and the point V for the mixed venous blood which is never completely deoxygenated and this curve therefore is said to be the functional curve or the physiological dissociation curve.

2.6 Regulation of respiration

The main important factors which are associated with the regulation of respiration-

- Nervous control.
- Chemical control.

2.6.1 Nervous Control

Respiration can be regulated by chemical and neural factors. The process of breathing is essentially involuntary and automatic. However, it is influenced and controlled voluntarily within limits.

Normally inspiration and expiration follow each other and both are basically muscular in action. The contraction and relaxation of the respiratory muscles (diaphragm and several chest muscles) depend on the arrival of nerve impulses originating from the group of neurons collectively forming the respiratory centre located in the medulla oblongata of the brain.

From this centre, nerve impulses pass out in the phernic nerves to the diaphragm & intercostal muscles.

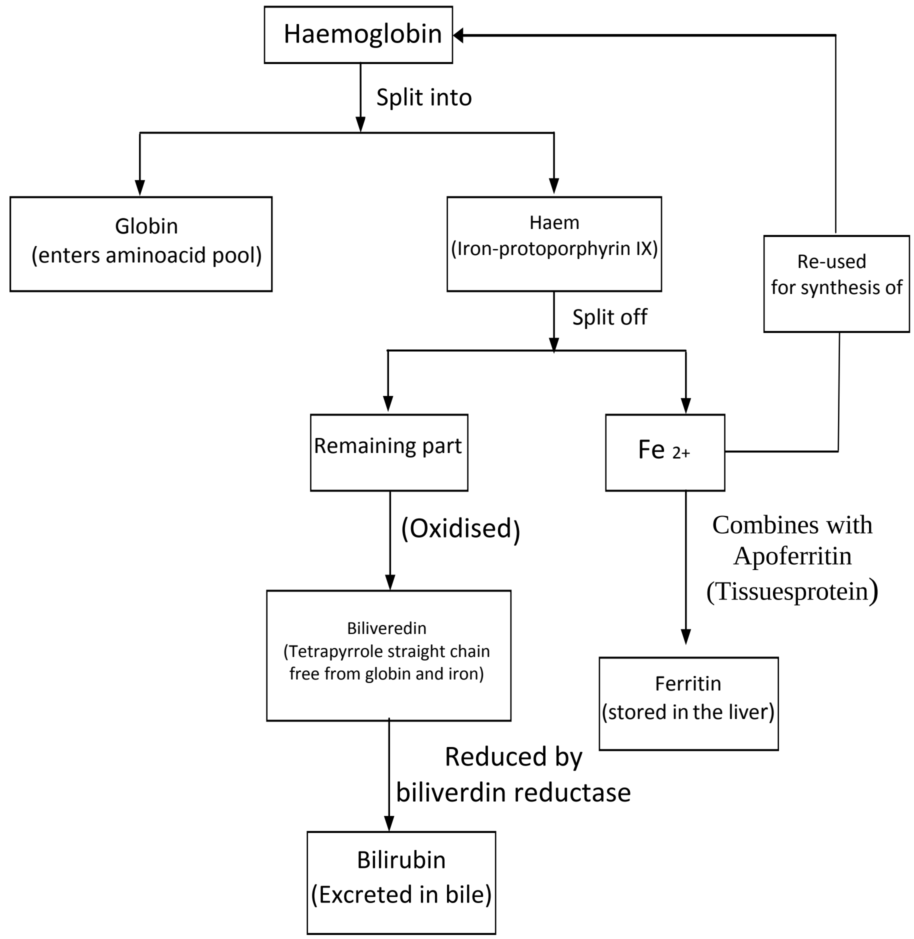
These impulses stimulate the muscles concerned to contract and increase the capacity of the thoracic cavity with the result that inspiration occurs.

2.6.2 Chemical control

The main chemical factors which influence the respiratory centre are the amount of carbondioxide (carbonic acid) and oxygen in solution in the blood. In the carotid body, where the common carotid artery divides, and in the wall of the arch of the aorta there are cells which are sensitive to carbon dioxide excess and oxygen lack.

When these cells are stimulated, impulses pass in branches of the vagus and glossopharyngeal nerves to the respiratory centre in the medulla oblongata.

The accumulation of carbondioxide in solution in the blood is the most important stimulus to respiration. If the amount of carbondioxide rises in the blood, for example during muscular exercise, the respiratory centre is stimulated. It therefore sends out impulses to the respiratory muscles to produce deeper and quicker breathing, so that the carbon dioxide can be given out more rapidly by the lungs. In this way, the respiratory centre controls the rate and depth of breathing.



Fate of haemoglobin in the body

2.7 Summary

- The human respiratory system is a series of organs responsible for taking in oxygen and expelling carbon dioxide. The primary organs of the respiratory system are lungs, which carry out this exchange of gases as we breathe.

  Respiration consists of two phases -

- The first phase consisting of gaseous exchange between the blood and the environment via the lungs, it referred to as external respiration.
- The second phase consisting of oxidative energy yielding reactions of the cells,is called as internal respiration.
- Haemoglobin is responsible for the transport of O_2 from lungs to the tissues.
- Each heme (of Hb) combined with one molecule of O_2 and this is facilitated by cooperative heme-heme interaction.

- Haemoglobin actively participates in the transport of CO_2 from tissues to lungs. Increased partial pressure of CO_2 (PCO_2) accompanied by elevated H^+ decreases the binding of O_2 Hb, a phenomenon known as Bohr effect.
- Gas exchange in lungs takes place in alveoli where partial pressure of oxygen is higher than that in blood hence O_2 diffuses from alveoli to blood.
- In body tissue the partial pressure of O_2 is low hence O_2 diffuses from blood into tissues.
- Respiration is regulated by levels of PCO_2 and by a respiratory centre in the brain which is sensitive to blood PCO_2.
- Respiratory gases are transported mainly by respiratory pigments in blood. The most well-known pigment is haemoglobin which combines with O_2 to form oxyhaemoglobin.
- CO_2 is transported to lungs by formation of carbonic acid in red blood cells.
- This reaction is favoured by high PO_2 in tissues. Carbonic acid ionises into H^+ and HCO_3^-. Hydrogen ion is buffered by haemoglobin but anion balance is maintained by chloride shift.

2.8 Terminal question

Q. 1: Describe the transport of oxygen. Add a note on the oxygen haemoglobin dissociation curve.

Answer:……………………………………………………………………….
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

Q. 2: Describe the transport of carbondioxide. Add a note on the CO_2 dissociation curve.

Answer:……………………………………………………………………….
…………………………………………………………………………………
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Q. 3: Give detailed account of chemical control of respiration.

Answer:……………………………………………………………………….
…………………………………………………………………………………
…………………………………………………………………………………
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Q. 4: Give detailed account of nervous control of respiration.

Answer:……………………………………………………………………….
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

Short answer type question:-

(i) Chloride shift

(ii) Functions of respiration

(iii) Mechanism of respiration

(iv) Bohr effect

Multiple choice questions:-

1. **O_2 dissociation curve is**

   (a) Ball shaped

   (b) S-shaped

   (c) Normal curve type

   (d) Delta shaped

2. **CO_2 enters capillaries by**

   (a) Permeation

   (b) Osmosis

   (c) Diffusion

   (d) Active transport

3. **Hamburger shift is also called**

   (a) Hydrogen shift

   (b) HCO_3 shift

   (c) Chloride shift

   (d) No shift

4. **Gaseous exchange in lungs occurs by**

   (a) Osmosis

   (b) Simple diffusion

   (c) Active transport

   (d) Passive transport

5. Chloride shift is essential for transport of

(a) O_2 and CO_2

(b) N_2

(c) CO_2

(d) O_2

2.9 Answers

1 – (b)

2 – (c)

3 – (c)

4 – (b)

5 – (c)

UNIT-3

Circulatory System

Structure

3.1 Introduction

The circulatory system, also called the cardio-vascular system or the vascular system is an organ system that permits blood to circulate and transport food materials (nutrients such as Amino Acids, glucose and electrolytes), O_2, CO_2, hormones and blood cells to and from the cells in the body.

In other words the primary function of the circulatory system is to provide an adequate supply to all cells of the body of materials needed for their proper function and that carries away the waste products of their metabolism.

The circulatory system is a well organized transport system of the body by which the blood being circulated within a closed system. Under different pressure gradient, created by the pumping mechanism where heart acts as the central pump.

The cardiovascular system includes:–

(i) Heart,

(ii) Arteries,

(iii) Capillaries and

(iv) Veins.

The circulatory system of the blood is seen as having two components –

(a) Systemic circulation: - i.e. greater circulation with high resistance circuit - passing through the tissues.

(b) Pulmonary circulation:- i.e. Lesser circulation with low resistance circuit – passing through the lungs

The two opposite systems again meet in the heart while humans, as well as other vertebrates, have a closed cardiovascular systems (means the blood never leaves the network of Arteries, veins & capillaries), some group of vertebrates have an open cardiovascular system. The lymphatic system, on the other hand, in an open system providing an accessory route for excess interstitial fluid to be returned to the blood.

Objective:

- Describe the composition and functions of body fluids.
- Distinguish between open and closed circulatory systems.
- Discuss the general principles of circulatory system in mammals.
- Describe mammalian heart, cardiac output, regulation of heart beat.
- Discuss the haemostatic mechanisms.

3.2 Compositions of body fluids & blood plasma

3.2.1 Body fluids:-

A significant percentage of human body is water which includes intracellular and extracellular fluids. Water deprivation brings about death earlier than that of food, deprivation. If water is given instead of food, life may continue for several weeks by the loss of most of the body fat and 50% of tissue protein (Fig.3.1).

On average, body water can account of 70% of the total body weight and within which the major cations like sodium, potassium, calcium, hydrogen, magnesium and anions like chloride, bicarbonate and protein of the body are dissolved.

In human being, water is about 65% of the body weight in males and about 10% less in females (reason, woman contains more fat that man).

But the above values vary mostly with the relative degrees of leanness and fatness of the individual. In lean person, the value is higher than that of in obese person.

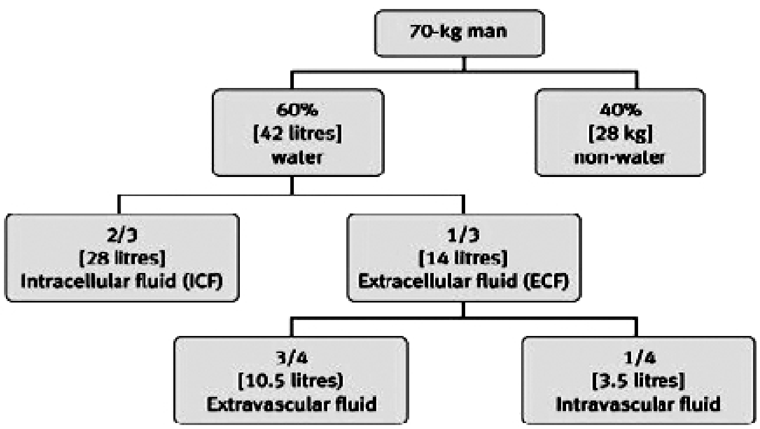

Fig. 3.1 Body Fluids Compartments

Source: http://www.wikipedia.org

Fluid compartments:-

There are two major body fluid compartments,

(a) Extra-cellular compartment – 45%.

(b) Intra-cellular compartment – 55%.

(A) Extra-cellular compartment (45%):-

Extracellular fluids in usually all body fluid outside of cells and consist of plasma, interstitial and transcellular fluid etc.

The extracellular fluid compartment is heterogeneous collections of fluids (i.e. different groups of phase).

The extracellular fluid phase can be divided into following subcompartments:-

(a) Transcellular water – 2.5%

(b) Dense connective tissue and cartilage water – 7.5 %.

(c) Plasma water that is confined within the vascular system – 7.5%.

(d) Interstitial fluid and lymph – 20%.

(e) Inaccessible bone water – 7.5%,

(B) **<u>Intra-cellular fluid compartment:-</u>**

The intracellular fluid is the liquid found inside the cells. This intracellular fluid contains 30-40% of the body weight and holds about 55% of the whole body water.

The intracellular fluid is the sum of the fluid contents of all the cells of the body. It is neither a continuous nor a homogeneous phase.

In a cell, there are many anatomical subdivisions and for this reason. There is a striking difference in water content and ionic composition in between the cytoplasm. Nucleus, mitochondria and microsomes of various cells types (Fig.3.2).

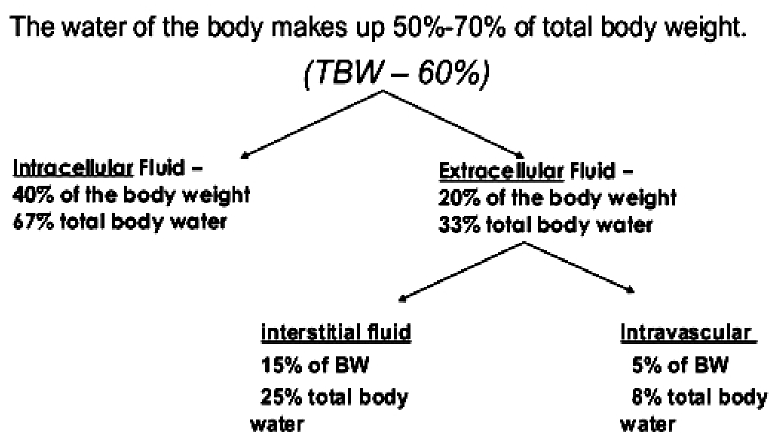

Fig 3.2 Functional components of the body fluid

Source: http://www.wikipedia.org

3.2.2 Blood plasma

Blood is a body fluid (a type of connective tissue) in humans and other animals that delivers necessary substances such as nutrients and O2 to the cells & transports metabolic waste products away from those same cells. In vertebrates, it is composed of blood cells suspended in blood plasma.

Blood plasma is a yellowish liquid component of blood that normally hold blood cells the white blood cells, the red blood cells and the platelets, suspended in the plasma.

Blood plasma is the intravascular fluid part of extracellular fluid (all body fluid outside cells).which makes up about 55% of the body's total blood volume mostly water (about 91-92%) (Fig.3.3).

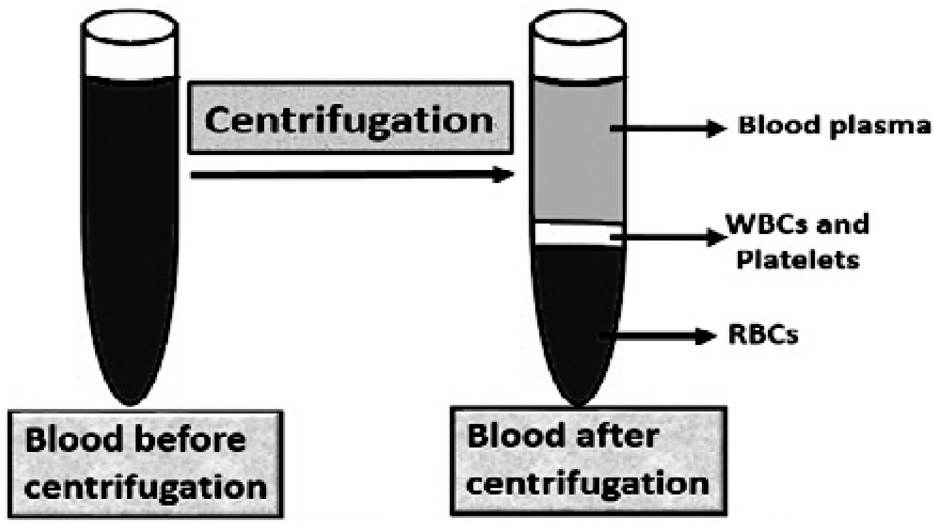

Fig. 3.3 Components of Blood

Source: http://www.wikipedia.org

<u>Composition of blood plasma (Fig3.4):-</u>

(a) Water – 91 – 22 %

(b) Solids – 8 – 9 %

- Proteins – 75% (serum albumin, serum globulin, fibrinogen, prothrombin etc.).
- Inorganic constituents – 0.9 %
- (Sodium, potassium, calcium, magnesium, phosphorus, iron, copper etc.).
- Non-protein nitrogenous substances (NPN), urea, uric acid, Xanthenes, hypoxanthine, creatine, creatinine, ammonia etc.
- Fats natural fat, cholesterol etc.
- Carbohydrate – glucose etc.
- Other substances – internal secretions, antibodies, and various enzymes (amylase, proteases, lipase etc).
- Coloring matter – The yellow colour of plasma in due to small amounts of bilirubin, carotene and xanthophylline.

- Blood plasma has a density of approximately 1025 kgm / m^3 or 1.025 gm / ml.

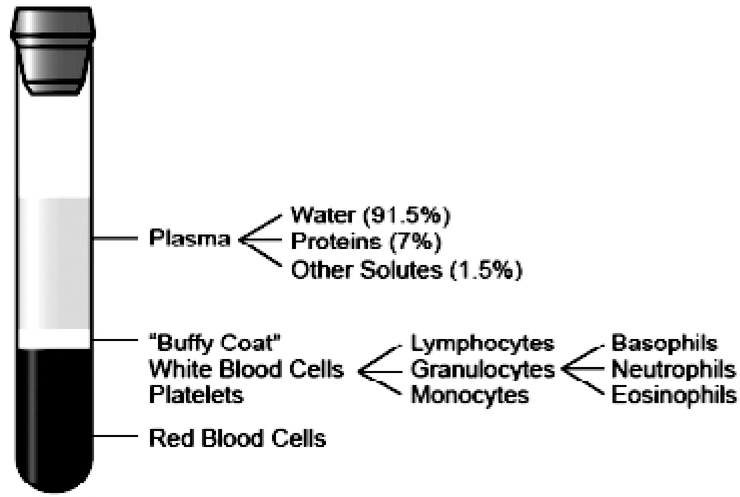

Fig.3.4 <u>Composition of blood plasma</u>

Source: http://www.wikipedia.org

3.3 General plan of circulatory system

There are two types of circulations, that's are -

<u>Open circulation:-</u>

In many invertebrates, however, blood is pumped by the heart into a vessel which opens into the open fluid spaces so that the tissues are bathed by the blood which is known as **haemolymph** in this case. Such a system is known as **open circulatory system.**

<u>Closed circulation:-</u>

Vertebrate blood is carried through a system of clastic tubes the **arteries**, **capillaries** and **veins**. The blood returns to heart without actually leaving this system of tubes. Since blood remains in this closed system it is known as **closed circulation.**

In vertebrates the circulatory system is of **closed type**, consisting of a set of tubes, blood vessels through which blood flow and pump, the heart, which produces thin flow to make available to the tissues its different metabolic needs and on the other hand to carry away from the tissues. The CO_2 and other metabolic waste products for elimination from the body.

In mammals, there are two circuits of blood circulation. **Systemic and pulmonary circulation**. These two systems originate and terminate in the heart, which is divided longitudinally into two functional halves. Blood is pumped via one circuit, the <u>pulmonary circulation</u> from right half of the heart. The blood pumped out via the second circuit, the <u>systemic circulation</u> from the left half the heart passes through all parts of the body (except the lungs) and return back to the right half of the heart.

In both circuits, the blood vessels carrying blood away from the heart are called arteries, and the vessels conveying blood from the lungs and tissues back to the heart are called veins.

3.3.1 <u>Systemic circulation:-</u>

In the systemic circulation the blood carries O_2 (oxygenated blood) from the left ventricle of heart through the arteries to the capillaries in the tissues of the body from the tissue capillaries blood return with CO_2 (Deoxygenated blood) through a system of veins to the right atrium of the heart via inferior and superior vena cava from the lower and upper portion of the body respectively (Fig.3.5).

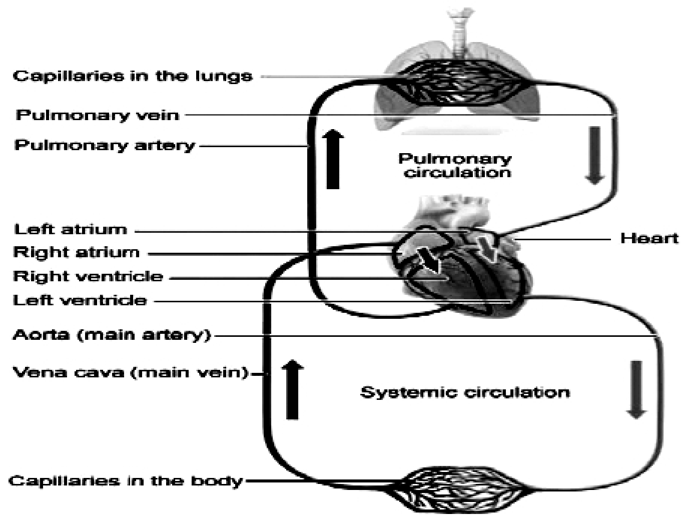

Fig.3.5 Pulmonary and Systemic Circulation

Source: http://www.wikipedia.org

3.3.2 Pulmonary circulation

In the pulmonary circulation, the blood carries Deoxygenated blood (blood with CO_2) away from right half of the heart (right ventricle) to the lung through the pulmonary arteries, within the lung the arteries divide successively into arterioles & capillaries which unite to form small venules. Then pulmonary veins & returns to the left atrium and ventricle of the heart with oxygenated blood (blood with O_2) (Fig3.5).

3.4 Structure of the heart

The heart is roughly "Heart-shaped" structure and rests obliquely in the Thoracic cavity. There are three surfaces of the heart:-

- The anterior surface of the heart faces the sternum.
- The posterior surface the base of the cone faces the vertebral column, and

- The inferior or diaphragmatic surface rests on the diaphragm.

The heart muscle is asymmetrical due to the distance blood must travel in the pulmonary and systemic circuits. Since the right side of the heart sends blood to the pulmonary circuit, it is smaller than the left side which must sent blood out to the whole body in the systemic circulation (Fig3.6).

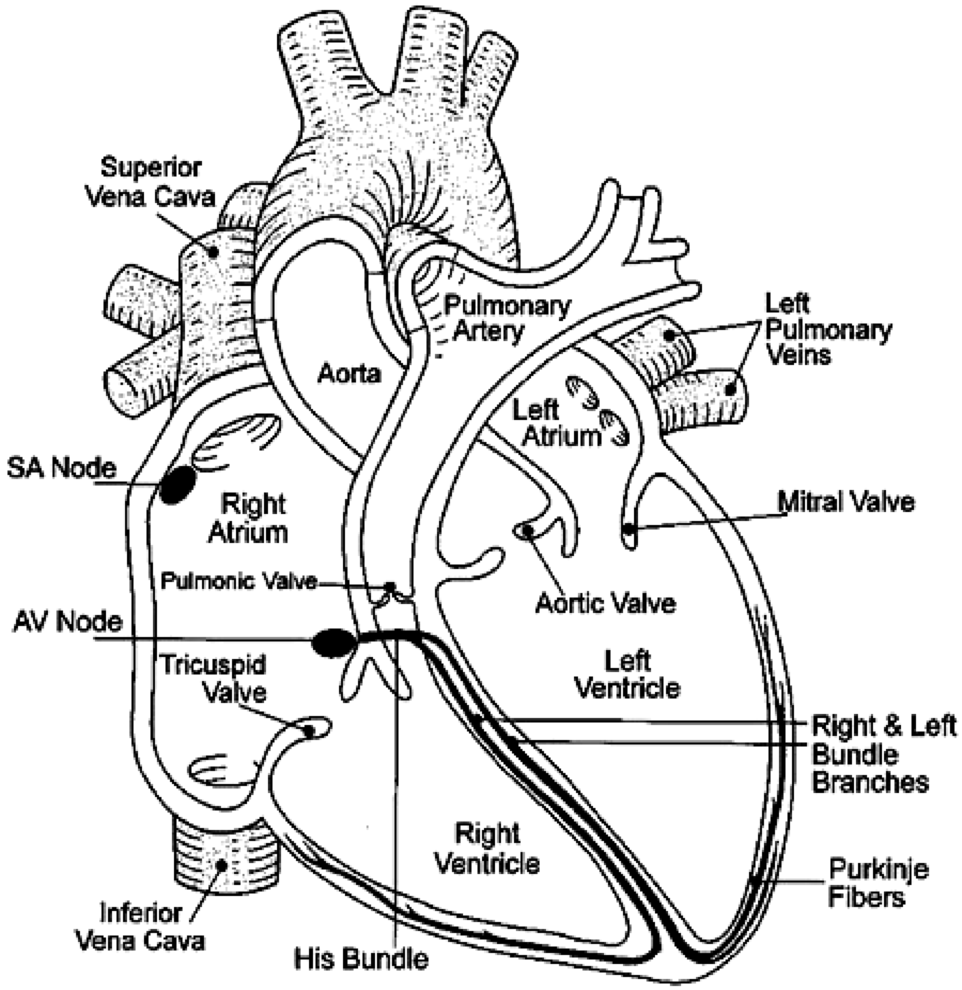

Fig. 3.6 Structure of Heart

Source: http://www.wikipedia.org

The wall of the heart consists of the three layers-

- The inner wall of the heart has a lining called the “Endocardium”. Is thin membrane lined with flattened endothelium, which thicker in the atria than in the ventricle.
- The middle layer “Myocardium” consists of the heart muscle cells and form the bulk of the heart wall, called cardiac muscle, its consist of peculiar striated muscle fibers with myofibrils running longitudinally as in skeletal muscles. The myocardium is thin in

the auricles but very thick in the ventricles, more so in the left ventricle.

- The outer layer of the heart muscles is called "Visceral Pericardium or Epicardium" in a serous membrane covered on its free surface with a layer of mesothelial cells which secrete a serous fluid into the space between the visceral and parietal pericardium.

The parietal pericardium also called only pericardium which the second membranous layered structure that surround and protects the heart. The serous fluid in the visceral & parietal pericardial space allow smooth movement when the heart beats.

The heart is divided into four chambers, two atria and two ventricles. There is one atrium and one ventricle, on each side right & left; which are separated by septum, the intertribal septum is thinner than the interventricular septum.

There are four valves in the heart chamber on left side.

(a) The two <u>atrioventricular (AV)</u> valves the <u>mitral valve (Bicuspid valve)</u> with two flaps or valves and the right side <u>Tricuspid valve</u> with three flaps or valves which are between the upper chambers (Atria) and the lower chambers (ventricles).

(b) The two semiluner (SL) valves the aortic valve and the pulmonary valve, which are in the arteries leaving the heart.

Fine tendinous cards – The "<u>chrodae tundnae"</u> are attached to the ventricular surface of the valves. On the other hand the chrodae tendnae are attached to cone-shaped projections of the ventricular wall known as the papillary muscles.

During atrial systole, blood flows from the atria to the ventricles when the ventricles contract the valves close & the chrodae Tendinae support the valves preventing reflux of blood into the Atria.

- The heart has its own blood vessels that supply the heart muscle with blood. I.e. the coronary arteries branch from the Aorta and surround the outer surface of the heart like a crown. They diverge into capillaries where the heart muscle is supplied with O_2 before converging again into the coronary veins to take deoxygenated blood back to the right atrium.

- The atria are the chambers that receive blood and the ventricles are the chambers that pump blood.

<u>The right atrium</u> <u>r</u>eceived deoxygenated blood from –

(i) **<u>Superior vena cava –</u>** which drain blood from the jugular vein that come from the brain & from the arms.

(ii) **<u>Inferior vena cava-</u>** which drains blood from the lower organs and the legs as well as.

(iii) **<u>Coronary sinus (vein)-</u>** which drain deoxygenated blood from the heart itself.

- From the right atrium deoxygenated blood passes to right ventricle through atrio-ventricular (Tricuspid valve). After it is filled the right ventricle pumps the blood to pulmonary arteries by passing the semilunar valve (or pulmonary valve) to the lungs for re-oxygenation. The valves open in only one direction & prevent the Backflow of blood.

- The left Atrium receives the oxygenated blood from the lungs via the pulmonary veins. This O2 rich blood passes to left ventricle through left Atrio-ventricular valve

(Mitral or bicuspid valve) from where the O2 rich blood is pumped out through Aorta (the major Artery of the body) passes through left semilunar (Arotic) valve & taking oxygenated blood to organs & muscle of the body (systemic circulation).

This pattern of pumping is referred to as double circulation & is found in all mammals.

<u>Blood vessel</u>

The blood vessels are the components of the Circulatory System that transports blood throughout the body. These vessels transport blood cells, nutrients, and oxygen to the tissues of the body. They also take waste and carbon dioxide away from the tissues. Blood vessels are needed to sustain life, because all of the body's tissues rely on their functionality.

There are five types of blood vessels: the arteries, which carry the blood away from the heart; the arterioles; the capillaries, where the exchange of water and chemicals between the blood and the tissues occurs; the venules; and the veins, which carry blood from the capillaries back towards the heart.

The inner surface of every blood vessel is lined by a thin layer of cells known as the endothelium. The endothelium is separated from the tough external layers of the vessel by the basal lamina, an extracellular matrix produced by surrounding epithelial cells. The endothelium plays a critical role in controlling the passage of substances, including nutrients and waste products, to and from the blood.

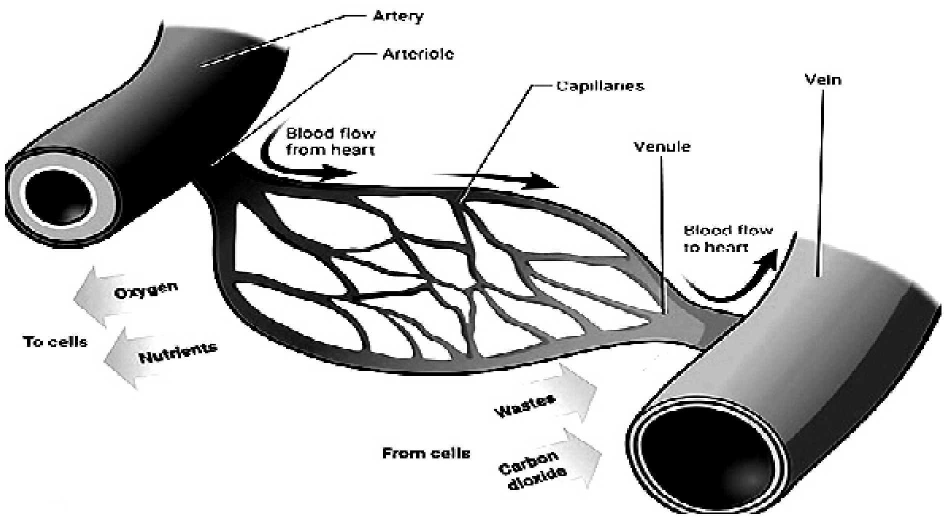

Fig.3.7 Functions of blood vessels

Source: http://www.wikipedia.org

Blood vessels function to transport blood (Fig.3.7). In general, arteries and arterioles transport oxygenated blood from the lungs to the body and its organs, and veins and venules transport deoxygenated blood from the body to the lungs. Blood vessels also circulate blood throughout the circulatory system Oxygen (bound to hemoglobin in red blood cells) is the most critical nutrient carried by the blood. In all arteries apart from the pulmonary artery, hemoglobin is highly saturated (95–100%) with oxygen. In all veins apart from the pulmonary vein, the saturation of hemoglobin is about 75%. (The values are reversed in the pulmonary circulation.) In addition to carrying oxygen, blood also carries hormones, waste products and nutrients for cells of the body.

Lymphatic System:-

The lymphatic system is a network of tissues and organs that help rid the body of toxins, waste and other unwanted materials. The primary function of the lymphatic system is to transport lymph, a fluid containing infection-fighting white blood cells, throughout the body.

The lymphatic system primarily consists of lymphatic vessels, which are similar to the veins and capillaries of the circulatory system. The vessels are connected to lymph nodes, where the lymph is filtered. The tonsils, adenoids, spleen and thymus are all part of the lymphatic system.

There are hundreds of lymph nodes in the human body. They are located deep inside the body, such as around the lungs and heart, or closer to the surface, such as under the arm or groin, according to the American

Cancer Society. The lymph nodes are found from the head to around the knee area.

The major components of the lymphatic system include lymph, lymphatic vessels, and lymphatic organs that contain lymphoid tissues.

- Lymphatic Vessels. Lymphatic vessels are structures that absorb fluid that diffuses from blood vessel capillaries into surrounding tissues. ...
- Lymph Nodes. ...
- Thymus. ...
- Spleen. ...
- Tonsils. ...
- Bone Marrow.

Functions of Lymphatic System:-

The lymphatic system has multiple interrelated functions: It is responsible for the removal of interstitial fluid from tissues. It absorbs and transports fatty acids and fats as chyle from the digestive system. It transports white blood cells to and from the lymph nodes into the bones.

3.5 Cardiac cycle

The cardiac cycle is the performance of the human heart from the ending of one heart beat to the beginning of the next i.e. the changes that occur in the heart during one beat, are repeated in same order in the next beat. This cyclical repetition of the various changes in the heart, from beat to beat, is called cardiac cycle.

Cardiac cycle time:-

This is the time required for one complete cardiac cycle. It is 0.8 sec with the normal heart rate of 75 per minute means 60/75 = 0.8 sec). It means that every event in the cycle will be repeated of the interval of 0.8 sec. It is inversely proportional to the heart rate.

A cardiac cycle consists of :–

(i) Atrial systole or contraction of the Atria – 0.1 sec.

(ii) Ventricular systole or contraction of the ventricles – 0.3 sec.

(iii) Complete cardiac diastole or relaxation of the Atria and ventricles – 0.4 sec (Fig.3.8).

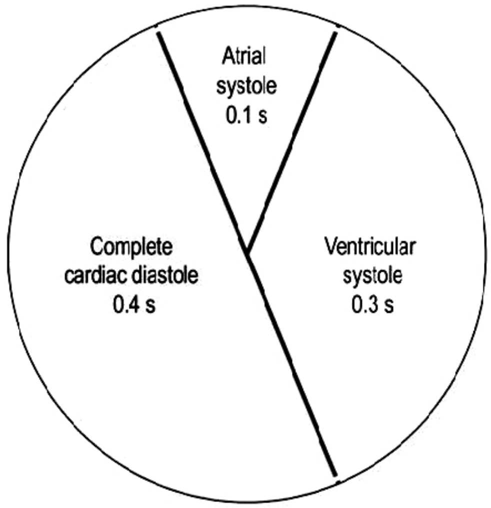

Fig.3.8 Duration of Cardiac Cycle

Source: http://www.wikipedia.org

3.5.1 Atrial systole

Atrial systole initiates the cycle, because the pace maker SA Node is situated in it. The Sino-Atrial (SA) node generates an impulse of contraction which spreads as wave of contraction over the atrial myocardium, pushing the blood through the Atrio-ventricular valve into the ventricles (take time 0.1 sec).

3.5.2 Ventricular Systole

At the end of atrial systole, ventricular systole starts (duration 0.3 sec.). When the wave of contraction reaches the Atrio-ventricular (AV node). It is stimulated to generate another impulse of contraction, which spreads the ventricular muscle via the bundle of His and Purkinje fibres.

This results in a wave of contraction which spreads upwards from the apex of the heart and pushed the blood into systemic Aorta and Pulmonary Arteries.

3.5.3 Complete cardiac diastole:-

After contraction of the ventricle, the heart rest (relaxed) for 0.4 sec. known as complete cardiac diastole.

At the end of diastole, atrial systole repeats & thus the cardiac cycle (0.8 sec) goes on.

Heart Sounds:-

In healthy adults, there are two normal heart sounds, often described as "**a lub and a dub**", that occur in sequence with each heart beat. These are the first heart sound (S1) and second heart sound (S2), produced by the closing of the atrioventricular valves and semilunar valves, respectively. Two other hearts Sounds S3 and S4 are also present in different medical conditions.

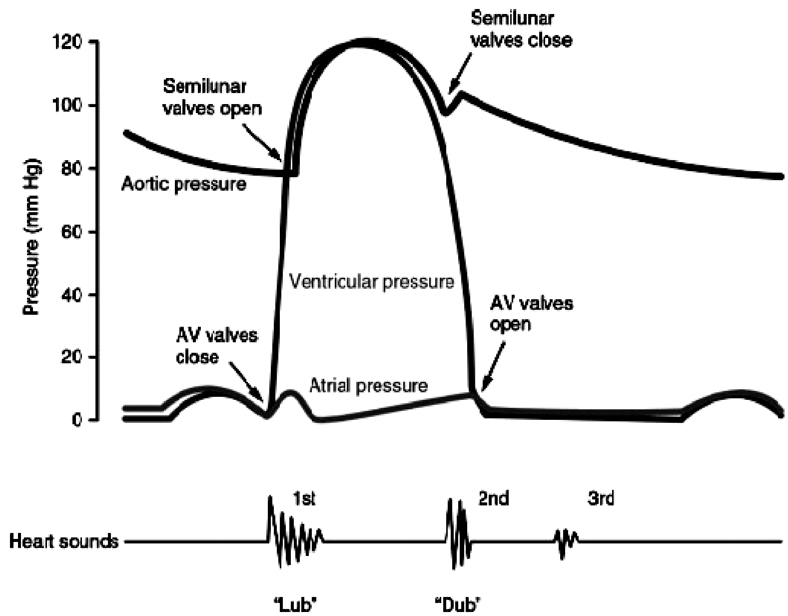

Fig.3.9 Heart Sounds (Lub and Dub)

Source: http://www.wikipedia.org

3.5.4 Cardiac output

Cardiac output is the amount of blood being pumped by the heart into the circulation in each beat of heart. In another words the cardiac output in the product of the heart rate (HR) or the number of heart beats per minute and the stroke volume (SV), which is the volume of blood pumped from the ventricle per beat (Fig.3.10), thus

Cardiac Output (CO) = Heart Rate (HR) X Stroke Volume (SV)

Values for cardiac output are usually denoted as "L/minute".

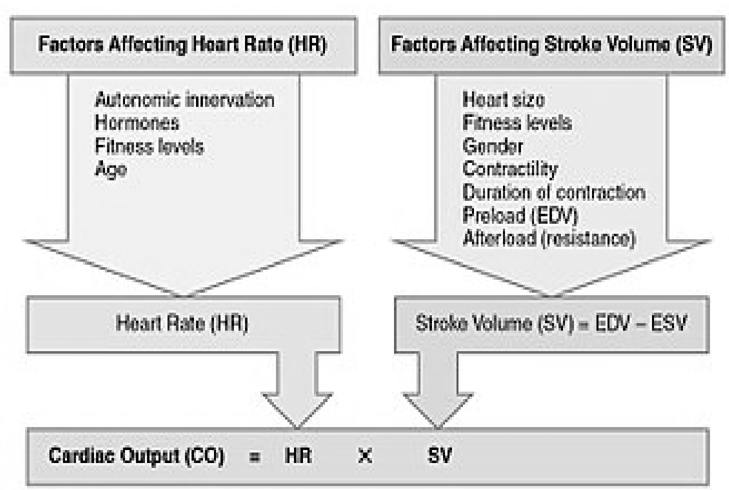

Fig.3.10 Factors of Cardiac Output

Source: http://www.wikipedia.org

Normal value of cardiac output:-

For a healthy adult person with body weight 70 kgm and heart rate in 72/ minute, the average stroke volume is 70 ml/beat & the minute volume about 5-6 liters.

In other words, the amount of blood expelled per ventricle per minute is approximately the same (i.e. 5-6 liters) as the total blood volume of the body.

The cardiac output is directly proportional to Age, body surface area, body weight, metabolic rate, gender and other factors.

3.6 Excitation of heart

The rhythmic contraction and relaxation of the cardiac muscles is known as the heart beat or cardiac excitation – contraction coupling. In other wards it describes the series of events, from the production of an electrical impulse (Action Potential) to the contraction of muscles in the heart & it allows for the heart to beat in a controlled manner at a rate between 60 to 100 beats per minute.

The cardiac conduction system is a group of specialized cardiac muscle cells in the walls of the heart that send signals to the heart muscle causing it to contract. The main components of the cardiac contraction system are the SA node, AV node, Bundle of His, Bundle branches & purkinje fibers (Fig.3.11).

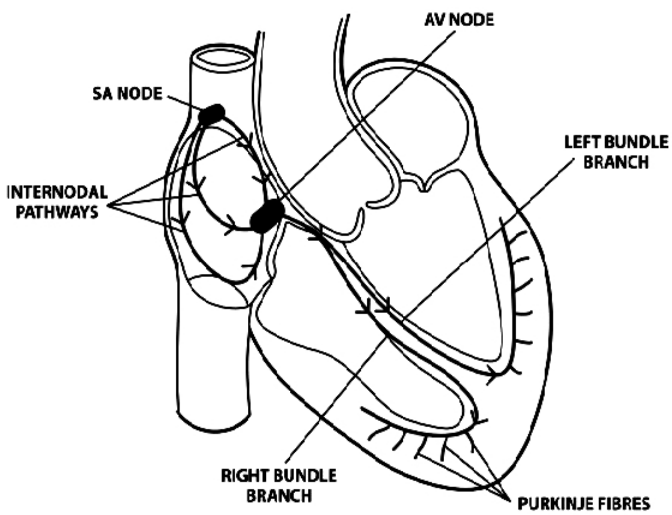

Fig.3.11 Conduction System of Heart

Source: http://www.wikipedia.org

3.6.1 The Sino-atrial node (SA-Node)

Contraction is initiated by a special patch of modified heart muscles, the Sino-atrial node (SA-node), situated in the wall of the right atrium near the opening of the superior Vena-Cava, the SA-node (Keith & flack 1907) is broader at the top and tapering below.

The SA node acts as a “Pace-maker” or “Pace-setter” of the heart because it is capable of initiating impulses which stimulate the heart muscle to contract. A tiny wave of current thus generated by the pace maker gradually sweeps over the entire heart muscles.

3.6.2 The Atrio-ventricular node

The wave of excitation from the SA-node passes first to the muscle fibres of right atrium (Bundle of Thoret) & then to left atrium (Bundle of Bachmann). Spreading along the muscles of the atria, it reaches the atrio-ventricular node (AV node), which is the part of cardiac conducting system that conveys stimuli from the atria to the myocardium of the ventricles. The AV node is located in the right Atrium at the posterior right border of the inter auricular septum.

It gives rise to the bundle of His, a muscular bridge that conducts stimulus from Atria to the ventricle.

In abnormal conditions when the SA node fails, the AV node generates the impulse (Nodal rhythm). It is capable of initiating impulses of contraction at the rate of about 45 per minute.

3.6.3 Purkinje fibres

On entering the ventricle along the interventricular septum, the initial portion of bundle of His divides into two branches one of which passes into the right ventricle (Right Bundle of His) and the other into the left ventricle (Left Bundle of His). The terminal branches of the conducting system are represented by a network of “Purkinje’s fibres” widely distributed in the subendocardial tissue. The impulse passes along all the branches of the conducting system, reaching the whole of the myocardium and causing it to contrast.

Thus, the impulse responsible for cardiac contraction arises in the SA Node, spreads along the contractile myocardium of the right and left atria & reaches the Atrio-ventricular (AV) Node, from these it posses along the bundle of His to the right & left ventricles & cause their systolic contraction.

The Heart beat may originate in one of the two ways – Neurogenically & Myogenically.

Origin of heart beat:- The beat of heart originate in one of two ways -

- **Neurogenic heart:-**

  The contraction of heart is initiated by a Nerve ganglion situated in the vicinity of the heart i.e. the heart beat originates by Nervous stimulation. A Neurohumour, Acetylcholine, secreted by the nerve endings accetesates the neurogenic heart beat.

  The heart of most orthopods and of some annelids like Arenicola and Lumbricus are Neurogenic.

- **Myogenic heart:-**

  In myogenic heart, contraction is initiated by a special node of modified heart muscle, the Sino-atrial (SA) node located in the Atrium & act as pace-maker. The rhythmic excitatory signals flashed by the pace-make travel away through the whole heart muscle over a special conducting system (e.g. Bundle of His and Purkinje fibres in Mammals).

  A myogenic heart thus exhibits an intrinsic beat, which doesn't require any External trigger for a start. The hearts of mollusks and vertebrates are of myogenic type.

3.7 Homeostasis mechanism

Human body include mechanisms that help regulate the body, His includes organs, glands, tissue & cells.

The main mechanisms of Homeostasis are body temperature, boy fluid composition, blood sugar, gas concentrations & blood pressure. Pressure by which the blood is pumped around the body is controlled by a homeostatic mechanism (Fig.3.12).

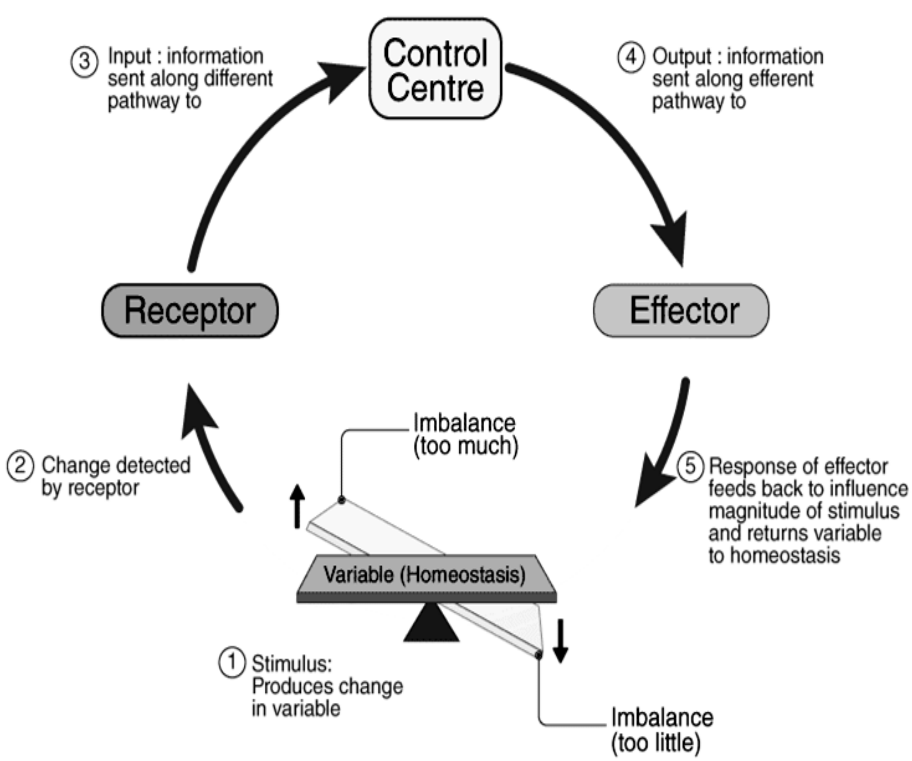

Fig.3.12 Homeostasis is a property of a human biological system. The regulation takes place in a defined internal environment.
Source: http://www.wikipedia.org

Regulation of body temperature:-

There are two types of heat regulation – Endothermic & Exothermic.

Endothermic is where a living thing can maintain their own core temperature and exothermic in where it gains the temperature of its surrounding environment living things that regulate its own temperature are detected by receptors in the skin & hypothalamus in the brain.

Below are some examples of what the body will do to regulate & maintain the body temperature.

Regulation of body fluids:-

Blood forms internal environment of the cell i.e. “Millieu Interieur” in terms of volume, composition, concentration pH & temperature, which is regulated to normal physiological limits with respect to minor changes in the body. The maintaining a balance in the body is the maintenance of body fluids dilute and watery solutions that contain dissolved chemical found inside walls and the surrounds of them. All the substances such as oxygen, nutrients, proteins and ions are needed to maintain life.

The composition of interstitial fluid changes as substances move back and for the between it and the blood plasma, thin occurs across the thin wall of the smallest blood vessels in the body, the blood capillaries.

Regulation of gas concentration:-

The cells in the body require oxygen, but also removing all carbondioxide as it is a waste product, so that sufficient energy can be produced. This is needed to be regulated & is controlled by the homeostatic mechanism those controls breathing.

3.8 Haemostasis

Haemostasis is a spontaneous arrest of bleeding by physiological process. Haemostatic mechanism includes –

(i) **Platelet adhesion:-** i.e. when a blood vessel is injured, platelets adhere to the exposed collagen, laminin, and Von-Willebrand factor in the vessel wall Constriction of Blood Vessels (BV) .

(ii) **Platelet activation:-** Platelets binding to exposed collagen initiate platelet activation, also produced by ADP and thrombin.

(iii) **Platelets aggregation (Coagulation Cascade): -** Is also increased by “Platelet activating factor” e.g. cytokine secreted from blood cells.

- Platelet aggregation along with platelet adhesion helps in formation of “temporary Haemostatic Plug”; this causes stoppage of bleeding from the injured blood vessel and maintains the integrity of the vascular tree.

- The loose aggregation of platelets in the temporary haemostatic plug is bound together and converted into "Definitive Hoemostatic Plug" by fibrin (Fig.3.13).

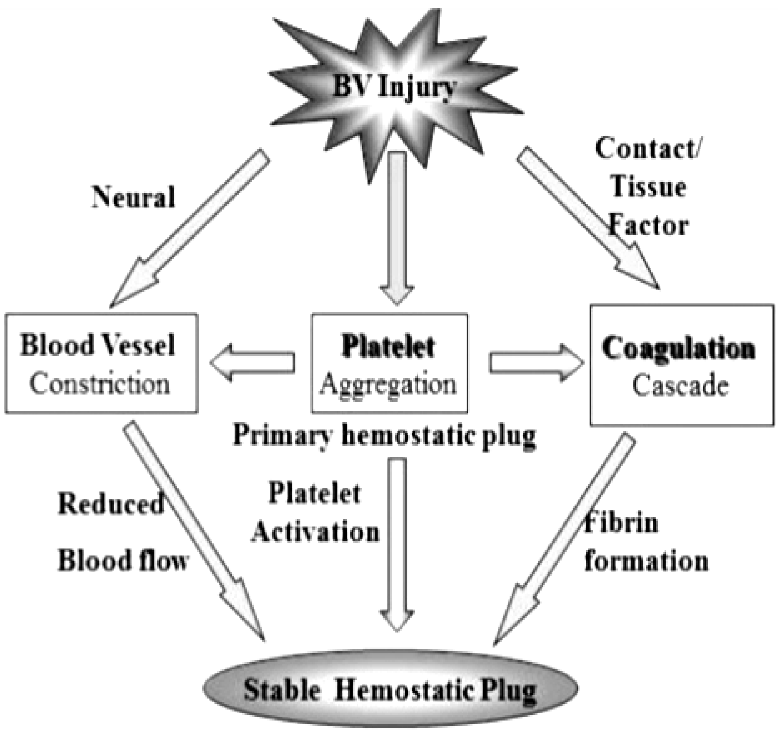

Fig.3.13 Haemostasis Mechanism

Source: http://www.wikipedia.org

3.9 Clotting mechanism

Haemostatic mechanisms like contraction of blood vessels & coagulation help to prevent blood loss during injury. Coagulation is a complex process and required four important substances. I.e. **Prothrombin**, **thromboplastin**. **Calcium** and **fibrinogen**. Except the Thromboplastin (which is a lipid or fat like compound containing phosphorus widely distributed throughout the tissue more in lungs & brain tissues).Others are present in circulating blood.

The thromboplastin is liberated from injured tissue and probably also from leucocytes of blood itself, which acting upon Prothrombin in the presence of calcium in an ionized form & converts it to active thrombin (Fig.3.14).

Thrombin acts upon inactive fibrinogen, which converted into insoluble fibrin, which is deposited as fine threads to form the framework of the clot.

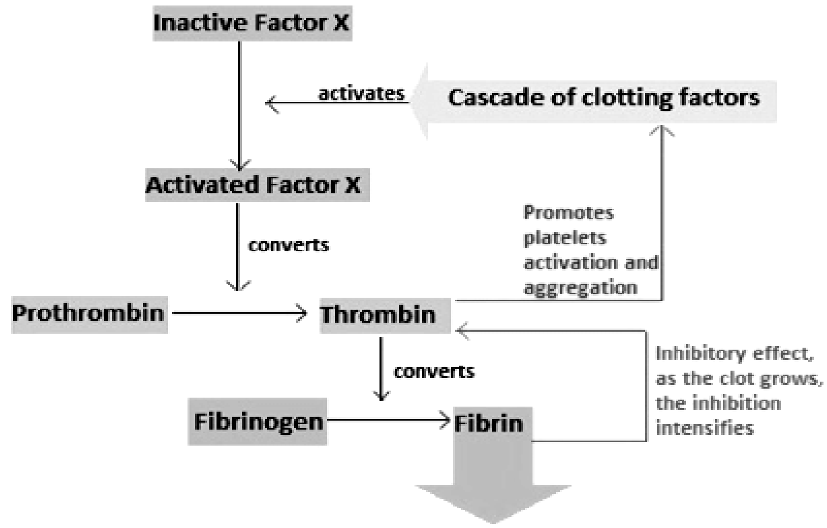

Fig.3.14 Clotting Mechanism

Source: http://www.wikipedia.org

Blood does not normally clot in the blood vessels because there is not sufficient free thromboplastin to convert the inactive Prothrombin to Active Thrombin.

A least 13 different plasma factors help in Blood clotting.

These are:–

Clotting Factors in Blood and Their Synonyms

Clotting Factor	Synonyms
Fibrinogen	Factor I
Prothrombin	Factor II
Tissue factor	Factor III; tissue thromboplastin
Calcium	Factor IV
Factor V	Proaccelerin; labile factor; Ac-globulin (Ac-G)
Factor VII	Serum prothrombin conversion accelerator (SPCA); proconvertin; stable factor
Factor VIII	Antihemophilic factor (AHF); antihemophilic globulin (AHG); antihemophilic factor A
Factor IX	Plasma thromboplastin component (PTC); Christmas factor; antihemophilic factor B
Factor X	Stuart factor; Stuart-Prower factor
Factor XI	Plasma thromboplastin antecedent (PTA); antihemophilic factor C
Factor XII	Hageman factor
Factor XIII	Fibrin-stabilizing factor
Prekallikrein	Fletcher factor
High-molecular-weight kininogen	Fitzgerald factor; HMWK (high-molecular-weight) kininogen
Platelets	

A deficiency of even one factor can delay or prevent clotting.

Coagulation of blood is inhibited by Heparin, a mucopolysaccharide that can be isolated from mammalian liver.

A cellular mesh work forms which help to close the wound. Contraction of muscles also helps in this process.

3.10 Summary

- The circulatory system is made up of blood vessels that carry blood away from and towards the heart.
- Arteries carry blood away from the heart and veins carry blood back to the heart.
- The heart has four chambers, the two bottom chambers are the right ventricle and the left ventricle. These pump blood out of the heart. A wall called the interventricular septum is between the two ventricles.
- The two top chambers are the right atrium and the left atrium. They receive the blood entering the heart. A wall called the inter-atrial septum is between the atria.
- The atria are separated from the ventricles by the atrio-ventricular valves.
- The tricuspid valve separates the right atrium from the right ventricle.`
- The mitral valve separates the left atrium from the left ventricle.
- The pulmonary valve is between the right ventricle and the pulmonary artery, which carries blood to the lungs.
- The aortic valve is between the left ventricle and the aorta, which carries blood to the body.
- One complete heart beat is made up of two phases. The first phase is called systole. The second phase is called diastole.
- Human body include mechanisms that help regulate the body, His includes organs, glands, tissue & cells.
- Blood does not normally clot in the blood vessels because there is not sufficient free thromboplastin to convert the inactive Prothrombin to Active Thrombin.

3.11 Terminal questions

Q. 1: Trace the origin & conduction of heart beat in mammals.

Answer:……………………………………………………………………….
………………………………………………………………………………
………………………………………………………………………………
………………………………………………………………………………

Q. 2: Describe the blood circulation in mammals.

Answer:……………………………………………………………………….
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………………………………………………………………………………
………………………………………………………………………………

Q. 3: Give an account of the cardiac cycle.

Answer:……………………………………………………………………….
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Q. 4: Differentiate between the systemic & pulmonary circulation.

Answer:……………………………………………………………………….
………………………………………………………………………………
………………………………………………………………………………
………………………………………………………………………………

Q. 5: Write short notes on – Pace maker, Cardiac output, Myocardium.

Answer:……………………………………………………………………….
………………………………………………………………………………
………………………………………………………………………………
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Q. 6: Describe the Homeostasis & Haemostasis mechanism.

Answer:……………………………………………………………………….
………………………………………………………………………………
………………………………………………………………………………
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Q. 7:

Describe the blood clotting in mammals.

Answer:……………………………………………………………………….
………………………………………………………………………………
………………………………………………………………………………
………………………………………………………………………….....

Multiple choice questions:-

1. **Blood circulation takes the following course in human heart:**

   (a) Left atrium → Left ventricle → Lungs → Right atrium → Right ventricle

   (b) Right atrium → Left ventricle

   (c) Left atrium → Left ventricle

   (d) Atrium → Right ventricle → Left atrium → Left ventricle

2. **Which set is correct for passage of the impulse of heart beat?**

   (a) S.A. node → Purkinje fibres → Bundle of his → Heart muscles.

   (b) A.V. node → Bundle of his → Purkinje fibres → Heart muscles.

   (c) S.V. node → S.A. node → Purkinje fibres → Heart muscles.

   (d) S.A. node → A.V node → Bundle of his → Purkinje fibres → Heart muscles.

3. **Heart beat in the vertebrates is:**

   (a) Neurogenic

   (b) Myogenic

   (c) Both

   (d) None

4. **All arteries carry oxygenated blood except:**

   (a) Systemic

   (b) Hepatic

   (c) Pulmonary

   (d) Cardiac

5. **Role of Pacemaker is:**

   (a) To increase heart beat

   (b) To decrease heart beat

   (c) To initiate heart beat

   (d) To control blood supply to heart

6. **First heart sound is:**

   (a) "Lubb" sound at end of systole

   (b) "Dub" or "Dup" sound at end of systole

(c) "Lubb" sound at beginning of ventricular systole

(d) "Dub" sound at beginning of ventricular systole

7. Heart beat is controlled by a nodal tissue made up of specialized cardiac muscles called:

(a) Myonemes

(b) Purkinje fibres

(c) Telodendrites

(d) None

3.12 Answers

1. – (c)

2. – (d)

3. – (b)

4. – (c)

5. – (c)

6. – (c)

7. – (b)

UNIT 4

Excretory System

Structure

4.12 **Terminal Question**

4.13 **Answer**

4.1 Introduction

The excretory system is responsible for the elimination of wastes, produced by homeostasis. It is a passive biological system that removes excess, unnecessary materials from the body. This system consists of specialized structures and capillary network that assist in the excretory process.

The human excretory system includes the kidneys and their functional unit, the nephron. The product of the kidney is urine, a watery solution of waste products, salt, organic compounds, and two important nitrogen compounds, uric acid and urea.

Uric acid results from nucleic acid decomposition, and urea results from amino acid breakdown in the liver. Both of these nitrogen products can be poisonous to the body and must be removed in the urine.

Excretion may be defined as the separation and elimination process of metabolic wastes from the body. The kidneys are bean-shaped organs approx 10 cm log, 5 cm wide and 2.5 cm thick. The right kidney is slightly lower than the left because of the considerable space occupied by liver.

Objectives:

- ➢ explain the structure and functions of kidney
- ➢ explain the importance of renal organs in homeostatsis.
- ➢ explain the osmotic pressure of urine.
- ➢ explain the characteristics of urine.
- ➢ discuss the detoxification in animals.

4.2 Structure of kidney (Vertical section)

1) The outer renal cortex – raddish in colour, the cortex contains the glomeruli and the proximal and distal tubules of the nephrons.

2) The inner renal medulla – inner medulla pale in colour.

- In the modullary region, the pelvis is surrounded by 4 to 14 conical structure these are called renal pyramids (Fig.4.1).
- These structure contain rich blood supply and contains the long loops (Henle's loop) of nephrons (functional units) and vasa recta (capillary network around these loops).

- Apex of each pyramid is called papilla each papilla is associated with a tubular structure called tubular structure, called calyx (calyces) these calyces open into renal papillae.
- Ureters are two long tubular structures urinary bladder, urethra (Fig.4.2)

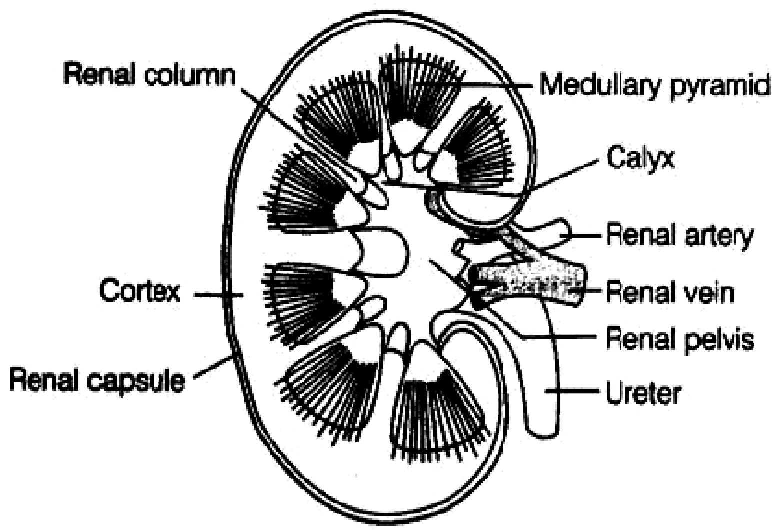

Fig. 4.1 L.S. of kidney

Source: http://www.wikipedia.org

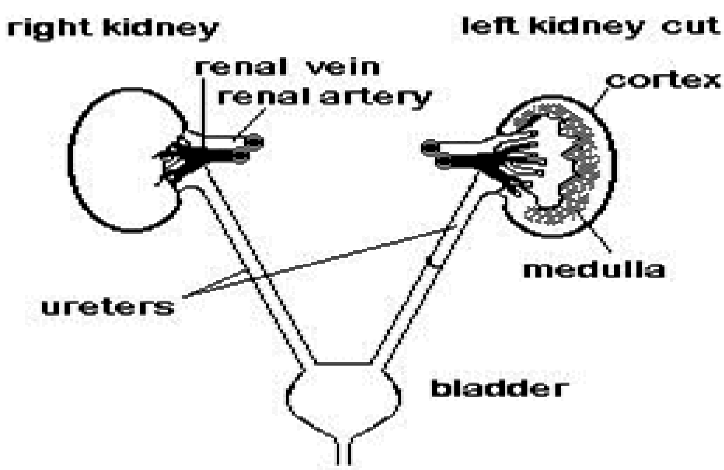

Fig. 4.2 Structure of urinary bladder,

Source: http://www.wikipedia.org

4.3 Types of nephrons

On the basis of their position in kidney, two main types of nephrons have been recognized.

1. **Cortical nephrons –** These nephrons are present in cortex region of the kidney. Under normal conditions these nephrons control blood volume.
2. **Juxtamedullary nephrons –** These nephrons are present at the junction of cortex and medulla. Their Henle's loop is penetrated deeply in the medulla. These nephrons helps to increase water retension.

4.4 Structure of nephron

Nephrons or uriniferous tubules is the functional unit of kidney. There are approximately 1-1.3 million nephrons in each kidney, which drain into the renal pelvis. A nephron consists of following parts. (Fig.4.3).

4.4.1 Renal or Malpighian Carpuscle

It consists of two Bowman's capsule and glomerulus.

(a) **Bowman's capsule:-** It has two layers-

- **(i)** Visceral layer – It is the inner layer
- **(ii)** Pariental layer – It is the outer layer.

Initial dilated part of the nephron, Bowman's capsule are made up of a single layer of flattered epithelial cells called podocytes.

Podocytes are less flattered cell which help in the ultra filtration of blood.

(b) **Glomerulus:-** It is network of capillaries which lies in the outer cavity (glomerular cavity) of Bowman's capsule.

- The capillaries are formed by the branching of afferent renal arteriole that supplies blood to nephron.
- The capillaries again join to form efferent renal arteriole that leaves the glomerulus cavity.
- From glomerulur capillaries ultrafiltration of blood takes place. Ultrafilteration is the first step in the formation of urine.

4.4.2 Proximal Convoluted Tubule (PCT)

- PCT lumen is continuous with that of Bowman's capsule.

- The cells of PCT are large columnar cells. These have heavy brush border, which greatly increases the surface area of the cell for reabsorption of substances from tubular lumen.
- The main function of PCT is the selective reabsorption of substance, like glucose, sodium, ions amino acids and water etc from tubular lumen.
- The small posterior part of PCT is straight, it is called pars recta. It open into Henle's loop.

4.4.3 Henle's Loop

This loop has two portions–

A. Descending limb.

B. Ascending limb.

(1) <u>Descending Limb:-</u>

- It is called descending limb, because in this limb the tubular fluid (filtrate) descends downwardly.
- It is very thin and permeable to water.
- The epithelial cells of this limb are flat and squamous type. These do not have microvilli, number of mitochondria in these cells is very low.

(2) <u>Ascending Limb:-</u>

- It is called ascending limb because in this limb the tubular fluid (filtrate) ascends upwardly.
- It is thick and impermeable to water.
- Its cells are cuboidal. These cells also don't have microvilli.
- Number of mitochondria in cells is comparatively high.
- In both these limbs the direction of fluid flow is opposite. Thus these two, along with blood capillaries, form a system, called counter current system.

4.4.4 Distal Convoluted Tubule:-

Thick ascending limb of (PCT) proximal convoluted tubule is continued as distal convoluted tubule. DCT opens into common tubule called <u>collective duct</u> which receives several nephron.

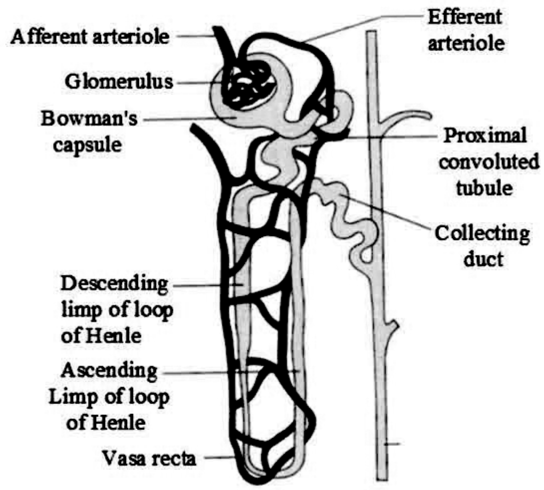

Fig. 4.3 Structure of nephrons

Source: http://www.wikipedia.org

4.5 Mechanism of urine formation

The glomerular filtration is the initial step in urine formation. The formation of urine involves three processes filtration, reabsorption and tubular secretion.

4.5.1 Ultrafilteration

The first step in the formation of urine. The plasma that transverses the glomerular capillaries is filtered by the highly permeable "glomerular membrane" and the resultant fluid, the glomerular filtrate is passed into Bowman's capsule.

The machenism of filtration depends on three factors -

- The pressure in the glomerulus (glomerular pressure) which is about 70 mm Hg. (the hydrostatic pressure gradient across the capillary wall)
- The osmotic pressure gradient across the capillary wall.
- The permeability of the capillaries and the size of the capillary bed.

  Thus the process of filtration is produced by the force of excess blood pressure in the glomerular capillaries over the osmotic pressure of the blood colloids.
- The hydrostatic pressure in the glomerular capillary is estimated about 70 mm Hg.

- The blood osmotic pressure is about 28 mm Hg. There is about back pressure.

  Therefore the back pressure intrarenal pressure of about 10 mm Hg.

- Thus effective glomerular filtration pressure is equal to about 32 mm Hg. [70-(28+10)] mm Hg.

4.5.2 Selective reabsorption

- The glomerular filtrate contains very useful substance like glucose, water and various ions. These substances are useful for the body. Therefore these are to be reabsorbed from the tubular lumen. This process of reabsorption of selected substances from tubular lumen to surrounding blood capillaries is called selective reabsorption. PCT, Henle's loop and even collecting duct, all contribute to reabsorption. But most of the reabsorption takes place in the PCT region.

- The walls of tubules are selectively permeable which readily allow water, sodium chloride, amino acids, glucose bicarbonates etc to pass into the blood. Substances which have to be excreted like uric acid, creatinine, phosphates, sulphates, however, don't pass through the tubular membrance. About 98-99% of the total water in the ultrafiltrate is absorbed.

- Most of reabsorption of water (80-90%) takes place in the proximal tubule. About 5% is absorbed in the thin part of loop of Henle and the rest in the distal tubule. The proximal tubule is also responsible for the reabsorption of glucose, phosphate, bicarbonate sodium, potassium and chloride are absorbed in the proximal tubule. All the proteins and amino acid are also absorbed in the proximal tubule. While water and some Nacl is absorbed in the distal tubule (Fig.4.4).

- The substances that are absorbed in large amount (water & glucose) are called **high threshold substances.**

- The urea, uric acid and certain salts are partly absorbed called low threshold substances and other that are not absorbed **called non-threshold.**

- The glomerular filtrate passes successively through the proximal convoluted tubules, loop or the Henle, distal convoluted tubular, collecting duct system and is finally drained into the pelvis of kidney from where it is finally eliminated as urine.

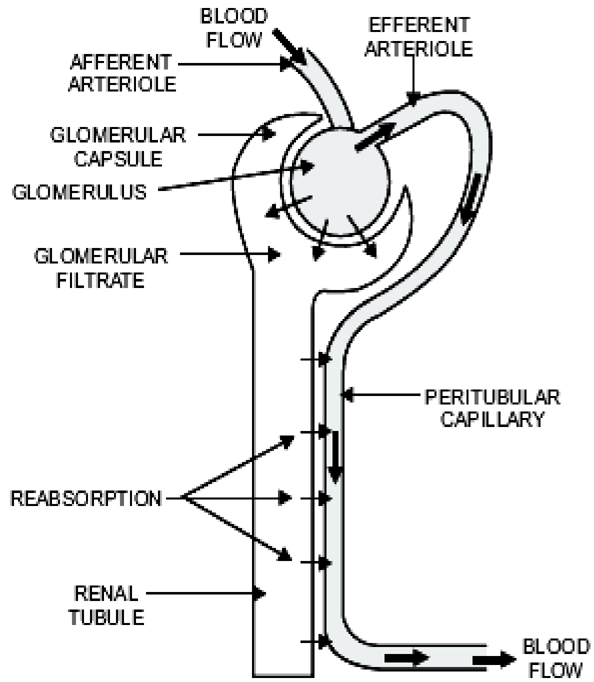

Fig. 4.4 selective reabsorption

Source: http://www.wikipedia.org

4.5.3 Tubular secretion

- The ultrafiltration in glomerulus does not filter all the impurities of the blood. The blood remaining the glomerular capillaries (after filtration) is sent to efferent arteriole, which divided into capillaries, forming PTCN still contains some impurities. These impurities must it pure. Hence these are poured (secreted) selectively into tabular lumen.
- The substances secreted by the tubular epithelium in man are **creatinine, K^+ and H^+ (ions).** The epithelia cells of distal tubule are cuboidal but have very few microvilli, Brush border is also not well-developed.

4.6 Water reabsorption

- Water movement across membrane is determined by hydrostatic and osmotic pressure gradient. Water is reabsorbed passively by diffusing along an osmotic gradient, about 99% of the filtered water is reabsorbed. Major amount of water is absorbed in PCT. Nephrons (Henle's loop) carries out a a **counter current system toa bsorbed more and more water from tubular filtrate.**
- Counter current mechanism for absorbing more and more water from tubular filtrate (in the Henle's loop region) to make the urine more concentrated.

4.6.1 Counter current system

- Counter current (counter-opposite, current-flow) is called so, because it involves descending and ascending limb of Henle's loop, in which the direction of flow of filtrate is opposite (Fig.4.5).

- In simple words counter current system only increases the concentration of salts (Na^+ and Cl^-) in the interstetium than tubular filtrate, the water comes out from the tubular lumen (by passive diffusion), into the interstetium thus more and more water is absorbed and urine becomes concentrated.

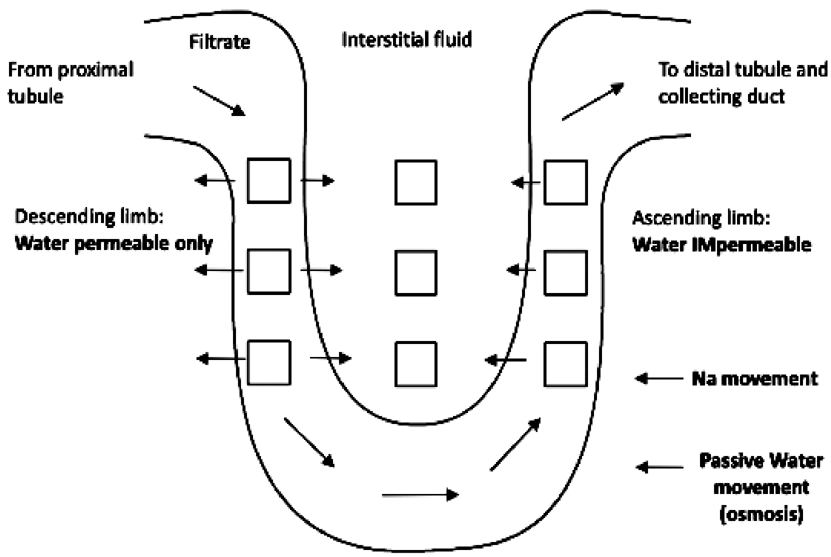

Fig. 4.5 Counter current system

Source: http://www.wikipedia.org

4.6.2 Osmotic pressure of Urine:-

- The urine is isotonic to plasma in the proximal tubule as it is an ultrafiltrate of blood.

- As the filterate flow into the descending limb of the loop of Henle it losses water and becomes hypertonic – In the descending limb is freely permeable to water, but not for electrolytes (Na^+ and Cl^{--}).

- In ascending limb is impermeable to water but highly permeable to electrolytes (Na^+ and Cl^{--}). Sodium is actively reabsorbed from the filterate, so that the urine becomes hypotonic.

- In the distal tubules also sodium is again actively reabsorbed in the blood so that the concentration of sodium become very high around the distal tubule.

- Passive reabsorption water in PCR, secondary to active reavsorption of Na^+ is called **obligatory reabsorption** of water.

- Reabsorption of water in the terminal DTC and CT under the influence of ADH (antidiuretic hormone), is called **facultative reabsorption** of water which varies according to the need of the body.

- Increased flow of urine is called diuresis, in which excess of glucose, salts and amino acids are excreted.

4.7 Composition of urine

- Water – 96%
- Urea – 2%
- Other dissolved sodid – 2%

(i) **Uric acid**– derived from the nucleic acid metabolism of body tissues.

(ii) **Creatinine –** an organic by product of muscle.

(iii) **Inorganic salts –** Chlorides, phosphates, sulphates and oxalates of sodium, potassium and calcium..

4.8 Characteristics of urine

(1) It is pale yellow in colour due to present of pigment urochrome, which is breakdown product of haemoglobin.

(2) Normally, Urine is acidic in reaction. But if it is kept open for some time. It becomes alkaline, because urea disintegrates to produce ammonia.

(3) After a heavy meal the fresh urine may also be alkaline.

Nitrogen excretion:

During the oxidative metabolism of carbohydrates, carbon dioxide and water are formed as excretory products. The bite pigments bilirubin and biliverdin that are formed in the liver by the breakdown of haemoglobin are excretory substances which pass out through the intestine.

The breakdown of proteins results in amino acid, the excess of which are excreted. While some aquatic animals excrete their extra nitrogen in the form of amino acids as such. Most of the animals degrade their excess amino acid to ammonia, uric or urea.

4.9 Regulation of kidney function

s

The kidney serves several essential regulatory roles. They are essential in the regulation of electrolytes, maintenance of acid-base balance, and regulation of blood pressure. They serve the body by filtering blood to remove wastes that are diverted to the urinary bladder for excretion.

4.9.1 Regulation of sodium & water

There are three major hormone that are involved in regulating Na^+ and water balance in the body at the level of the kidney.

Antidiuretic hormone (ADH) from the posterior pituitary acts on the kidney to promote water reabsorption, thus preventing its loss in urine. The most important variable in regulating ADH is plasma osmolarity. Reduced volume of extracellular fluid promotes secretion of ADH, but is a less sensitive stimulator of aldosterone secretion (Fig.4.6). Atrial natriuretic hormone (ANH) from the atrium of the heart acts on the kidney to promote Na^+ excretion to decrease intravascular volume. The main stimulus for ANH secretion is atrial distention.

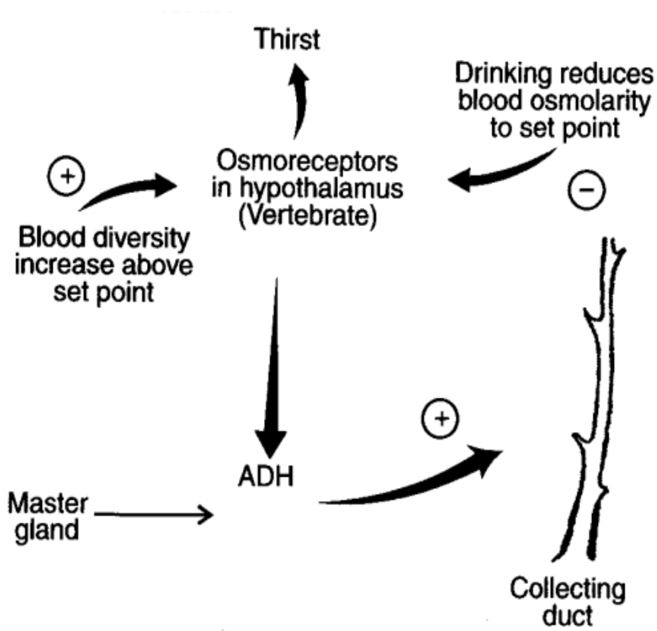

Fig. 4.6 Regulation of renal function, control by ADH

Source: http://www.wikipedia.org

4.9.2 Regulation of blood pressue:-

The cells of the juxta glomerulor node (macular derisa) situated at the junction of afferent and efferent arterioles and the distal convoluted tubule in each nephron, secrete a proteolytic enzyme, alled rennin. The **<u>rennin-angiotensin</u>** system (RAS) is a hormone system that regulates blood pressure and fluid balance. A decrease in mean arterial pressure induces juntaglomerular cell secretion of rennin. Renin is responsible for converting angiotensinogen to angiotensin I. Angiotensin converting enzyme (ACE) in the lungs converts **<u>angiotensin 1</u>** to **<u>angiotensin II</u>**.

Angiotensin II is a potent vasoconstrictor resulting in increased blood pressure. It also stimulates aldosteron release from the adrenal cortex that increases NA^+ and water reabsorption, increasing total effective circulatory volume.

Renin-angiotensin system is a "life saving system". It is very much useful in the Hypotension, dehydration, low blood pressure conditions. It act on brain to increase the

(i) Blood pressure (ii) Water intake (iii) secretion of vasopressin.

Renin-angiotensin system:-

Angiotensin

↓

efferent arteriole constriction

↓

decreased blood flow to peritubular capillary

↓

decreased pressure in peritubular capillary

↓

reabsorption of salts and water from tubule

4.10 Nitrogen excretion

4.10.1 Deamination

- The first stage in the breakdown of amino acid is the removal of their nitrogenous groups as ammonia. Removal of the amino groups (NH_2) which converts the amino acid into a keto acid is called deamination. Such deamination results from the action of a variety of enzymes, which are either oxidative or hydrolytic. Ammonia formed by the kidney tubule cells, mainly from glutamine, diffused into the lumen of the tubules and act as a hydrogen ion acceptor.
- The excess of ammonia which is formed by deamination and not used for reamination is converted into urea.
- Ammonia is very toxic to cells whereas urea is harmless even in very high concentrations. The liver is the only site of urea formation and that urea once formed is not destroyed in the body.
- Urea is formed in the liver from ammonia derived from amino acids.

- The first stage in the breakdown of amino acids is the removal of their nitrogenousl groups as ammonia. Removal of the amino group (-NH_2) which converts the amino acid into a keto acid is called deamination.

  Such deamination results from the action of a variety of enzymes, which are either oxidation or the amino acid enter the body of the animal through oxidative tran deamination.

(1) The amino gropus of the amino acid, aspartic acid is transferred to α-ketoglutaric acid converting it into glutamine acid (trans amination) during this process the aspartic acid is converted into oxaloacetic acid.

(2) The amino group of glutamic acid is remove in the form of ammonia (deamination) converting glutamic acid into α-ketoglutaric acid. At the same time there is also removal of a pair of hydrogen atoms from glutamic acid (oxidation). Thus the ammonia produced in the reaction actually comes from the amino groups of amino acid (aspartic acid).

(3) The hydrogen atoms produced by the oxidation of glutamic acid reduces NAD into NADH + H^+.

(4) The NADH and the oxaloacetic acid produced are oxidized in the mitochondria to CO_2 and H_2O generative ATP in the process.

Animals are classified into -

4.10.2 Ammonotelic Animals:-

Animals that excrete nitrogenous wastes in the form of ammonia. Most aquatic animals are ammonotelic. Ammonia is found as chief excretory product in the majority of primitice aquatic animals. Certain protozoa, polychaete annelids, crustaceans. Some molluscs and teleost fishes. It is also excrete by secondary aquatic animals such as larva of insects, aquatic teleost and turtles.

4.10.3 Uricotelic Animals

Animals which excrete their nitrogen predominantly in the form of uric acid are called uricotelic, insects, terrestrial, gastropods, terrestrial reptiles (snakes, lizards) and birds excrete mainly uric acid.

4.10.4 Ureotelic Animals

Animals which excrete urea as their major excretory product are said to be ureotelic. Urea is the useful product for a sem-terristrial animal that is not exposed to a scarcity of water. It is therefore the main product of some earthworms, adult amphibians and the semi-terrestrial tortoises and turtles. Elasmo-branch fishes and mammals are special cases that also excrete urea.

4.11 Summary

- The process of removal of nitrogeneous wastes from the body known as excretion.
- The nitrogenous metabolic wastes includes urea, uric acid & ammonia. These are produced mainly in liver.
- Urea is highly poisonous. Urea is excreted out through the kidney.
- The kidneys are two bean shaped organ approx 10 cm long, 5 cm wide.
- The right side kidney is slightly lower than the left.
- Nephron is the functional unit of the kidney.
- The glomeural filtration is the initial step in the urine formation
- Most of reabsorption of water takes place in the proximal tubule.
- Glucose, amino acid and Nacl are actively absorbed in the proximal tubules, while water and some Nacl is absorbed in the distal tubule.
- The glomerular filtrate passes successively through the proximal convoluted tubules, loop or the Henle, distal convoluted tubular, collecting duct system and is finally drained into the pelvis of kidney from where it is finally eliminated as urine.
- Animals that excrete nitrogenous wastes in the form of ammonia is called ammonotelic animals.
- Animals which excrete their nitrogen predominantly in the form of uric acid is called uricotelic animals.
- Animals which excrete urea as their major excretory product is called ureotellic animals.

4.12 Terminal question

Q. 1: Describe in detail the ultrafiltration and selective absorption.

Answer:…………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

Q. 2: Describe in detail the structure and function of kidney.

Answer:…………………………………………………………………………
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Q. 3: Explain the structure of nephrons in vertebrates.

Answer:……………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

Q. 4: Explain briefly in the role of loop of Henle in the formation of urine.

Answer:……………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

<u>Multiple choice questions:-</u>

1 Excretion means:

(a) Formation of useful substances in the body

(b) Removal of substances which have never been a part of body

(c) Removal of substances not required in the body

(d) All of the above

2 Urea is produced from ammonia in the human in

(a) Kidney

(b) c)Urinary bladder

(c) Liver

(d) Blood

3 Browman's capsules occur in

(a) Liver

(b) c)Kidney

(c) Adrenal gland

(d) Pancreas

4 Filteration of blood occurs in

(a) Browman's capsule

(c) Neck of nephron

(b) Loop of henle

(d) Renal papillal

5 Proximal and distal convulated tubules are part of a

(a) Nephron

(b) Caecum

(c) Oviduct

(d) Vas deferens

6 Filtration pressure is human kidneys is about

(a) 10 mm Hg

(b) c) 55 mm Hg

(c) 45 mm Hg

(d) 70 mm Hg

7 Active reabsorption of glucose occurs in the

(a) Distal tubule

(b) Loop of henle

(c) Proximal tubule

(d) Collecting ducts

8 Most toxic excretory product is

(a) Carbon dioxide

(b) Ammonia

(c) Aminoacids

(d) Urea

4.13 Answers

1.- (c)

2.- (d)

3.- (c)

4.- (a)

5.- (a)

6.- (a)

7.- (b)

8.- (c)

Uttar Pradesh Rajarshi Tandon
Open University

Bachelor of Science

UGZY-101

Animal Physiology

Block

2

Physiology-II

RIL-152

Course Design Committee

Prof. Ashutosh Gupta **Chairman**
Director, School of Science
UPRTOU, Prayagraj.

Prof. Paramhand Pathak **Member**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Prof. Ajay Singh **Member**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Prof. Rajendra Singh **Special Invitees**
Department of Zoology
Deendayal Upadhyay University,
Gorakhpur.

Dr. Deepa Chaubey **Member/Secretary**
Academic Consultant, School of
Science UPRTOU, Prayagraj.

Course Preparation Committee

Dr. Deepa Chaubey **Author**
Acadmic Consultant, School of Science
UPRTOU, Prayagraj.

Prof. G.S. Shukla **Editor**
Director, Health Science
UPRTOU, Prayagraj.

Dr. Deepa Chaubey **Coordinator**
Academic Consultant, School of
Science UPRTOU, Prayagraj.

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RIL-152

COURSE INTRODUCTION

- The term physiology originated from a greek word physiologikos meaning discourse of natural knowledge. Physiology deals with the normal functioning of the body. The functional unit of the body is the cell and a group of similar cells constitute a tissue, a group of tissues form a system. Physiology is about the functions of living organisms how they eat, breath, and move about, and what they do just a keep alive.

- In all aspects of physiology, it is important to appreciate the role of mechanisms that control bodily functions. A unique feature of this part is the correlation of function with the structure without the basic knowledge of anatomy; a student can't understand the biological function of the particular organ or system in the body. For example, if a student doesn't have an idea of the brush border, lining of a kidney tubule, he/she can't appreciate the wonderful mechanism of selective reabsorption of useful substances from the nephric filtrate. Similarly he/she will not understand the physiology of muscular contraction properly, is he/she is not quite familiar with the ultrastructure of a skeletal muscle.

- The basic principles and mechanism of physiology of animals form the theme of this course which throws light on the entire syllabus divded into Block I and Block II

Block I- Physiology I

Block II- Physiology II

- Block I has 4 units in which you are going to study physiology, digestion, respiration, circulation and excretion.

  Block II has 4 units in which you are going to study physiology of osmoregulation, nervous system, muscular system and endocrine system.

- In this course of Animal Physiology you will study about digestion, respiration, circulation, excretion, osmoregulation, nervous, muscular and endocrine system.

- We hope that you find this cause interesting and informative and it inspires you to develop further interest in Animal science

Block II (Physiology II)

- In this block we will deal with Physiology II of body. It is convenient to divide them broadly into osmoregulation, nervous system, muscular system and endocrine systems.

  - **<u>Unit 5</u> :-** It deals with the osmoregulatory processes in organs such as kidney, gills and salt glands. Osmoregulation is a process for maintenance of osmatic concentration of the body fluids. Prolactin, and antidiuretic hormones are the hormones involved in the osmotic regulation in vertebrates.

  - **<u>Unit 6</u> :-** It introduces some fundamental aspects of the nervous system, The structure and function of the basic unit is neuron. Hypothalamus is the higher centre for the autonomic nervous system.

  - **<u>Unit 7</u> :-** Muscle contraction is the most apparent and dramatic evidence of animal life. Movements are affected by muscles. They cover the bony parts of the skeletol in almost every part of the body, giving the organism its normal external shape.

  - **<u>Unit 8</u> :-** It deals with the second integrating system , i.e. the endocrine system

  - **<u>Objectives</u> :-** After studying this block you should be able to:

    1. Discuss the problems faced by aquatic and terrestrial animals while regulating their osmotic and ionic balance.

    2. Describe the physiological process involved in various modes of movement in mammals.

    3. Describe how nervous system and endocrine system integrate the various physiological functions.

UNIT-5

Osmoregulation

Structure

5.1 Introduction

Osmoregulation is a dynamic process which enables the animals to maintain a suitable internal medium by regulating the movement of water and salts between the body fluids and the external medium. Aquatic animals which have entered media of different salinities may be either poikilosmotic or homoiosmotic.

Osmoregulation is an energy consuming process. Animals live in different of environment and may live in fresh water, sea water or on land. There are various mechanisms in different animals for osmoregulation. The process of maintenance of osmotic concentration of the body fluids is called osmoregulation. Kidney is the major organ of osmoregulation in vertebrates.

Osmoregulation is the process of maintenance of across membranes within the body's fluids, which are composed of water plus electrolyte and non electrolytes. An electrolyte is a solute that dissociates into ions when dissolved in water. A non-electrolyte, in contrast, does not dissociate into ions during water dissolution. Both electrolytes and nonelectrolytes contribute to the osmotic balance.

Cells in hypotonic solutions swell as water moves across the membrane into the cell, whereas cells in hypertonic solutions shrivel as water moves out of the cell. Isotonic cells have an equal concentration of solutes inside and outside the cell.

The body is subject to a continual intake and loss of water and electrolytes. Excess electrolytes and wastes that result from osmoregulation and transported to the kidney and excreted. The process of excretion helps the body maintain osmotic balance.

Objectives:

- Explain the meaning of osmoregulation.
- Discuss the osmoregulation in the fresh water, Marine water and Terrestrial Animals.
- Discuss the mechanism of osmoregulation and osmotic problems.
- Discuss role of hormones in regulation water and electrolyte balance in the body fluids.

5.2 Functional principles of osmoregulation and membrane permeability

5.2.1. Poikilosmotic Animals

Most of the aquatic invertebrate animals are evolved with tissues.

An aquatic animal that is incapable of maintaining more or less constant osmotic pressure of body fluids, when there is a change in water salinity.

The bodily osmotic pressure in poikilosmotic animals is equal to or slightly greater than that of the surrounding medium such osmotically variable animals are called Poikilosmotic.

The different types of poikilosmotic animals are -

A) **Stenohaline :-** Poikilosmotic animals that can tolerate (only specific range of salinities) only slight changes in salinity are known as stenohaline.

For example :- Fresh water fish like gold fish are not able to survive in sea water because of the high content of salt. The some applies to fish that live in saline water, except they are unable to survive in fresh water.

Poikilosmotic animals include lower invertebrates, bivalve mollusks, many annelids and echinoderms.

B) **Euryhaline :-** Poikilosmotic animals which can able to adopt to a wide range of salinities. They are found in estuaries or river mouths or near sea shores where the salinity may fluctuate to great extent.

For example :- The sea mussel, Mytilus can tolerate the dilution of sea water upto 4% and lives unaffected.

Sipunculid worms such as phoscolosoma. Aurelia and Aplysia are also euryhaline.

5.2.2. Homoiosmotic Animals

They can regulate and maintain the osmotic concentration of their body fluid irrespective of the outside concentration. The he Humoi-osmotic Animals those fresh water invertebrates in which the osmotic pressure of the blood and tissue fluids is higher than the osmotic pressure of the surrounding medium, they maintained their osmotic pressure by discharging excess water from the body through the excretory organs.

Another example of homoiosmotic animals are living in fresh water adopts different methods for osmoregulation.

- Presence of impermeable cuticle.
- Development of excretory organs (nephridia or kidney) to produce hypotonic urine.
- Possession of special cells (on the gills, in the gut or in the kidney) to absorbe salts from the surrounding fluid.

5.3 Osmoregulation in invertebrates

- 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 is eliminated by the rhythmic pulsation of the contractile vacuole.
- **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 the urine by the antennary or green glands.
- **Mullusca:-** Fresh water mussels like unio and **Anodonta** carry on osmoregulation through kidneys. Osmotic pressure of these animals is higher than the surrounding aqueous medium and as such water diffuses into tissues. The water is eliminated by the kidneys during excretion.

5.4 Osmoregulation in aqueous environment

5.4.1 Fresh water Teleosts (Bony fishes)

Body fluid of fresh water teleosts is hypertonic. The fresh water is hypotonic. Hence endosmosis take place. Excess of water is removed in the form of urine by the glomerular kidney. Along with urine some amount of salt is also lost. The salt loss is made good by chloride cells present on the gill epithelium. These cells are capable of absorbing the small quantities of salts present in fresh water.

In some fresh water animals including fishes, reptiles, birds and mammals water uptake and salt loss are minimized due to the presence of the integument, which are less- permeable to water and salts. Fresh water animals other than reptiles, birds and mammals who have relatively impermeable integument do not drink excess of fresh water, reducing the need to expel excess water done by their cohabitants having integument permeable to water and salt (Fig.5.1).

Osmoregulation in fresh water teleosts. It is clear that fresh water fishes happen to face two problems.

(a) They gain water by endosmosis.

(b) They loose salts by diffusion.

The ionic regulation achieved by the following methods-

(i) The gill contains chloride cells. These cells transport actively salts from the freshwater into the body.

(ii) Fish obtains salts from the diet.

(iii) Kidney actively absorbs salts from the urine. For this tubular system is well-developed.

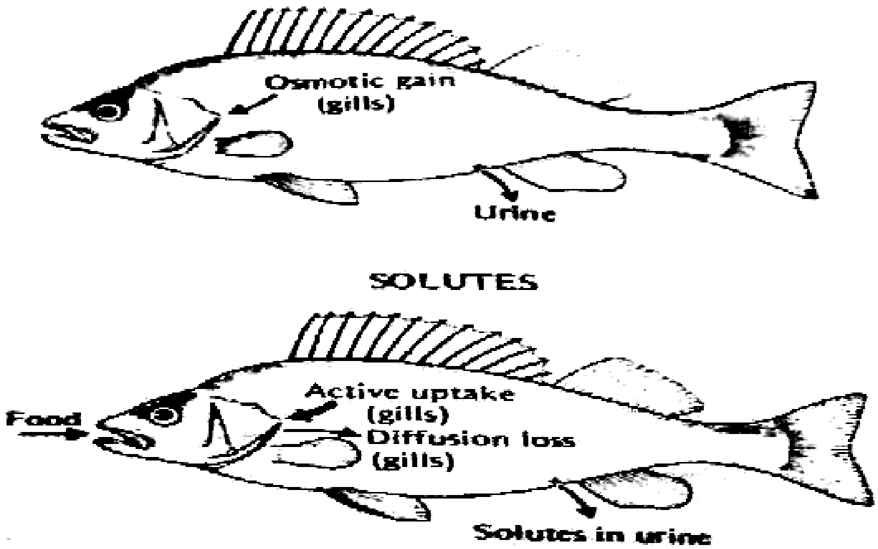

Fig. 5.1 Salt & water exchange in fresh water teleost

Source: Animal Physiology by Knut Schmidt-Nielsen

5.4.2 Osmoregulation in Marine Animals

- **<u>Osmoregulation in Marine Teleosts:-</u>**

In the Marine bony fishes e.g. <u>Opsanus</u> and <u>Lophius</u>, The body fluid of Marine teleost is <u>hypotonic</u> and the sea water is hypertonic. Hence exosmosis takes place. The loss of water is compensated by drinking the sea water (Fig.5.2).

As the sea water contains a large amount of salt concentration, the excess of salt from the body is secreted out by the chloride secretary cells of the gills.

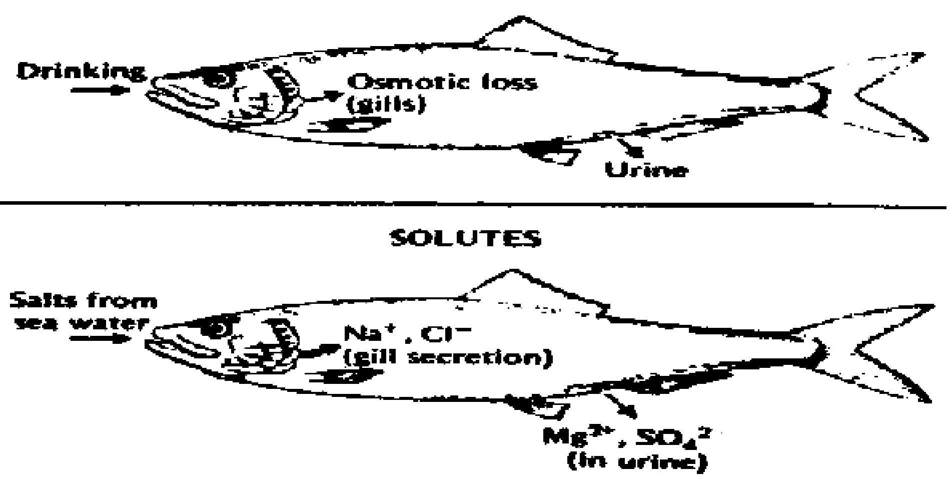

Fig. 5.2 Salt & water exchange in marine teleosts

Source: Animal Physiology by Knut Schmidt-Nielsen

- **Osmoregulation in migratory fishes:-**

Anadremous fishes **salmon** migrate from sea to fresh water for spawning, when it is in the sea water, the body fluid is hypotonic and the sea water is hypertonic. Hence exosmosis takes place. The loss of water is compensated by drinking of sea water (rich in salts).

- **Catadromous fishes:-**

Such fishes migrate from fresh water to the sea for spawning ex Eel (Anguilla anguilla).

When it is in the fresh water, the osmoregulation resembles that of fresh water teleost and when it is in the sea water, the osmoregulation resembles that of Marine teleost.

- **Osmoregulation in Marine Elasmobranchs:-**

The Marine elasmobranchs have developed a glomerular kidney. Marine cartilaginous fish such as Scoliodon have body fluid isotonic with sea water. In Marine elasmbranchs, the excess salts are removed by the rectal glands. The rectal glands of marine elosmobranchs are well developed but in fresh water species they are poorly developed.

- **Osmoregulation in fresh water elasmobranchs:-**

In few freshwater elasmobranchs, **Pristis Carcharias** gengeticus, body fluid is hypertonic and the fresh water is hypotonic. Hence they gain water by endosmosis and loose salts by diffusion. Kidney removes large quantities of dilute urine.

5.4.3 Osmoregulation in Amphibians

Amphibians lead most of their life time in fresh water. The body fluid is hypertonic and the fresh water is hypotonic. Hence endosmosis takes place. The excess of water is removed by the glomerular kidney in the form of urine. The salt loss is adjusted by –

(i) intake of food (ii) absorption through slimy skin (iii) reabsorption of salts from urine by uriniferous tubules.

In amphibian, the permeability of the skin to water is less in terrestrial than in aquatic species.

The aquatic food Xenopus laevis is normally ammonotelic. But after living in saline environment for 2 to 3 weeks, its blood urea increases, urine flow is reduced and it excretes urea instead of ammonia.

5.5 Osmoregulation terrestrial environment

5.5.1 Osmoregulation in reptiles

Reptiles are terrestrial in habit where scarcity of water prevails. The reptiles tend to loose water by evaporation.

Certain adaptation for water conservation are -

- These animals excrete uric acids. Uric acid excretion requires less water.
- When there is availability of water, these animals compensate the water loss by drinks of water.

5.5.2 Osmoregulation in birds

Majority of birds are terrestrial in habit. These birds tend to loose of water by evaporation. Hence the birds have developed certain important adaptation for water conservation.

- There is a coat of feathers, which prevents the evaporation of water from the body surface.
- Urine is in the form of semi-solid uric acid.

5.5.3 Osmoregulation in Mammals

The loss of water in mammals is through the skin, urine, breathing and faeces. The loss of water is mainly associated with the constant body temperature (homeothermy). The water loss takes place through the following methods.

- Increase in the rate of respiration produces maximum loss of water through the expired air.
- Water loss occurs through sweating.

Mammals conserve water by following methods -

(a) Nitrogeneous waster in the form of urea.

(b) Henle’s Loop is well developed for reabsorption of water by the counter current exchanger mechanism.

(c) Regulatory mechanisms prevent water loss.

5.6 Desert metatherian animals

It is a desert metatherian inhabiting where scarcity of water prevails. **Kangaroo, rats** (Dipodiomys) can survive without intaking water. The water conservation of the marsupial mammals are as follows -

- These remain in the burrows during day and come out during night.
- The possess no sweat glands.
- They live more on carbohydrate rich diet than on the protein rich diet.

The camel having large body can travel in the desert even in the scorching heat and cannot hide. It has developed the following mechanisms of water conservation.

(a) Output of urine is less.

(b) Camel produces highly concentrated urine.

(c) Camel's rumen (a chamber of stomach) contains fluid mixed with fermenting food. The hum contains pure fat, which is used for the formation of metabolic water.

(d) The water cells of rumen store metabolic water.

(e) The camel has an unusual tolerance to dehydration of the body.

5.7 Mechanism of osmoregulation

Actually osmoregulation is an energy consuming process. Animal remains alive, osmoregulation goes on. Once animals dies, osmoregulation stops.

Animals live in different of environment and may live in fresh water, sea water or on land. There are various mechanisms in different animals for osmoregulation. They carry out one or more of the following mechanisms for osmoregulation.

5.7.1 Removal of excess of salts

The excess of salt is removed from the body by any one of the following methods:

(A) The marine forms viz, fishes have chloride secretory cells in their gills. They secrete out the excess of salt present in the body fluid.

(B) In the case of the marine turtles and marine birds salt glands present in the head secrete out excess of salts.

5.7.2 Removal of excess water

In the case of fresh water animals, the body fluid is hypertonic (having more number of solutes). Hence endosmosis takes place.

For example –

Amoeba removes the excess of water by contractile vacuoles.

Crustanceans remove excess of water by the green glands.

Fresh water fishes remove excess of water by glomerular kidney.

5.7.3 Compensation of salt loss

When freshwater forms expel the excess of water, some amount of salt from the body is also lost. This lost salt is recovered by the following methods-

(A) Crustaceans and fresh water fishes have special kind of cells in the gills, called chloride cells. They absorb salts from the freshwater and add it to the body fluid.

(B) The kidney of the fresh water fishes is capable of reabsorbing some salts from the urine.

5.7.4 Compensation of water loss

In the case of marine animals, the body fluid is actually hypotonic and the sea water is hypertonic. Hence exosmosis occurs in the marine forms of animals.

As a result the marine animals are dehydrated. The loss of water is compensated by drinking sea water and by getting water from marine food. This is the reason that's why marine fishes drink the sea water.

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

5.8 Problems of osmoregulation

The problems of osmoregulation are a process for the maintenance of osmotic concentration of the body fluids. The animals living in marine, environment do not have the problem of osmoregulation, because their body fluids are isotonic to their external environment, the sea.

But the animals living in fresh water and terrestrial environment have the problem of osmoregulation because their body fluids are hypertonic to their external environment. Thus these animals have adopted various physiological and behavioral adaptations in order to maintain homeostasis with their respective external surroundings. This is done by osmoregulatory organs. An animal possessed by osmoregulatory organs maintains an osmotic steady state even in the variations in osmotic balance. The intake and outflow of water and salts are equal. Such osmotic homeostasis is maintained with the help of metabolic energy, obtained from ATP.

There are two different types of osmotic exchanges that take place between an animal and its environment.

These are obligatory exchanges and regulated exchanges.

(1) Obligatory exchange.

(2) Regulatory exchange.

In obligatory exchange osmotic exchanges occur mainly in response to physical factors over which the animal has little or no physiological control.

Whereas in regulated exchanges, the osmotic exchanges are physiologically controlled and it.

Serve to aid in maintaining internal homeostasis. Regulated exchanges generally serve to compensate for the obligatory exchanges. The animals that maintain osmolarity of their body fluids constant irrespective of the medium in which they live are termed osmoregulators, while those do not actively control the osmotic condition of their body fluids but conform to the osmolarity of the medium in which they live are termed **osmoconformers**.

For example – Most vertebrates except **elasmobranches** and **hagfishes** are strict osmoregulators, maintaining the composition of body fluids within small osmotic range. Marine invertebrates are in osmotic balance with sea water (Fig.5.3).

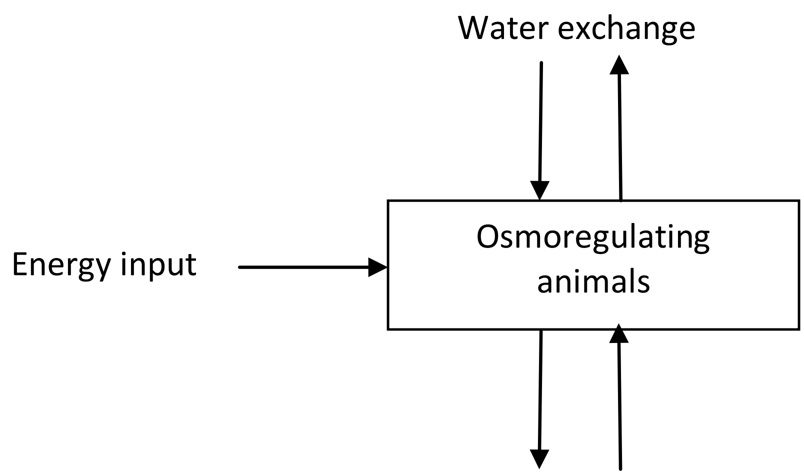

Fig.5.3 Regulation of nature of urine:

5.9 Hormones in water and electrolyte regulation

Mechanism of hormonal control of osmoregulation in both invertebrates and vertebrates.

- **Invertebrates**

Regulation of water and ions in invertebrates is done by neuroendocrine mechanism. It operates at the level of malpighian tubules and the rectum in insects. A neurosecretory substance termed, **diuretic hormone** inhibits water reabsorption from the rectum and also stimulates water uptake by the **malphighian tubules**. Another neurosecretory hormones termed chloride transport stimulating hormone is known to regulate electrolyte balance in insects.

- **Vertebrates**

In terrestrial vertebrates hormones such as prolactin, antidiuretic hormone and adreno-cortical steroid are known to control water and salt balance.

- **Prolactin**

Prolactin is secreted by the pituitary gland. In fishes, some amphibians, birds and mammals it acts on the organs concerned with the water and electrolyte balance. In migratory fishes prolactin secretion promotes the physiological changes.

- **Anti-diuretic Hormones (ADH)**

It is also called vasopressin **ADH** aids in retention of water. It is synthesized in the neuosecretory cells of the hypothalamus and stored in the neurohypophysis.

ADH increases the permeability of the collecting ducts.

The ADH system represents a very important feedback control system for controlling the NA^+ concentration and the osmotic concentration of the body fluids, when the NA^+ and osmotic concentration become very high, increased secretion of ADH cause water retention in the body and thereby dilutes their concentration. When the concentration of NA or other osmotic elements becomes highly low, decreased secretion of ADH cause to be lost from the fluid, and their concentrations rise back towards normal level.

Infact, ADH makes the collecting tubule highly permeable to water.

- **Adreno-cortical steroids**

The adrenal cortex secretes two types of steroid hormones.

(i) **Glucocorticoids** – Concerned with regulation of glucose.

(ii) **Mineralocorticoids** – Concerned with salt regulation.

In general the action of corticosteroids is adoptive. Salt output or retention is altered in accordance with environmental demands.

5.10 Summary

Osmoregulation is a process for the maintenance of osmotic concentration various physiological and behavioural mechanism.

- Marine invertebrates are in osmotic equilibrium with sea water, but can regulate their ionic composition.
- Marine elasmobranchs have a low salt content, but are in osmotic equilibrium with sea water because they are capable of retaining urea in their blood.
- Marine teleosts are hypotonic and make up for the lost water by drinking sea water and excreting the excess salts by the gills.
- Morine reptiles for example, crocodile, sea snake and marine birds like the marine teleosts do not produce urine which is hyperosmotic to their body fluids. Instead they have specialized

organs for the secretion of salts known as salt glands, located the cranium of animals.

- ❖ Fresh water invertebrates are hypertonic to absorbing salt from the very low concentration in fresh water.
- ❖ Fresh water fishes and amphibians are in a similar situation and also absorb salt from the water.
- ❖ Reptiles, birds and mammals are all terrestrial and have impermeable integument and some other devices for the conservation of water.
- ❖ Marine mammals such as sea lions, whales, seals have no external salt secreting organs. But the kidneys of these animals are capable of producing a very hypertonic urine.
- ❖ Hormones such as diuretic hormones, antidiuretic hormone, chloride transport stimulating hormone play a vital role in the regulation of water and electrolyte balance in invertebrates.
- ❖ Prolactin, antidiuretic hormone mineralocorticoids are the hormones involved in the osmoionic regulation in vertebrate.

5.11 Terminal questions

Q. 1: Explain briefly how do migratory fishes cope up with the problem of osmoregulation.

Answer:……………………………………………………………………
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Q. 2: Explain briefly the osmoregulation in Marine Animals.

Answer:……………………………………………………………………
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Q. 3:Explain briefly the osmoregulation in fresh water and Terrestrial Animals.

Answer:……………………………………………………………………
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Q. 4:Explain briefly role of the ADH hormones.

Answer:……………………………………………………………………
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Q.5: Describe the mechanism of osmoregulation in different vertebrates.

Answer:……………………………………………………………………
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Match the term given in column I with their definitions given in column II.

(a)	Obligatory exchange	**(i)**	Animals that maintain an internal osmolarity different from the medium in which they live.
(b)	Regulatory exchange	**(ii)**	Physiologically controlled osmotic exchange to maintain internal hormones
(c)	Osmoregulators	**(iii)**	Animals that do not actively control the osmotic condition of their body fluid, and instead conform to the osmolarity of the medium in which they live.
(d)	Osmoconfermers	**(iv)**	Osmotic exchanges that occur mainly in response to the physical factors over which the animals have no physiological control

5.12 Answers

(a) IV

(b) II

(c) I

(d) III

UNIT-6

Nervous System

Structure

6.1 Introduction

The nervous system is the major controlling, regulatory, and communicating system in the body, like other system in the body, the nervous system is composed of organs, principally the brain, spinal cord, nerves and ganglia.

These, in turn, consist of various tissues, including nerve, blood and connective, tissue.

Together these carry about the complex activities of the nervous system.

In mammals all 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 tissue, while indirect control is exercised through the endocrine glands and the circulatory system.

Objectives:

After studying this unit you should be able to –

- Describe the structure of nervous system & nerve cell.
- Classification of synapse.
- Transmission of nerve impulses & action potential.
- Neural circuit

6.2 Nervous System

Brain, the most complex part of the body communicates with each and every other body parts through a well-developed and essential electrical wiring known as nervous system which includes both the central nervous system (CNS) and the peripheral nervous system (PNS). The central nervous system is the main integration and command centre of body and is made up of the and spinal cord where PNS connects the CNS to different effector organs of body and is divided into two subdivisions, somatic nervous system (SNS) and autonomic nervous system (ANS) (**Fig.6.1**). Along with that recent researches also revealed the importance of enteric nervous system (ENS) or intrinsic nervous system as one of the major divisions of the nervous system. It includes a mesh-like system of neurons that mainly governs the function of the gastrointestinal tract. The ENS again includes two plexuses, the submucosal and the myenteric with their own functions.

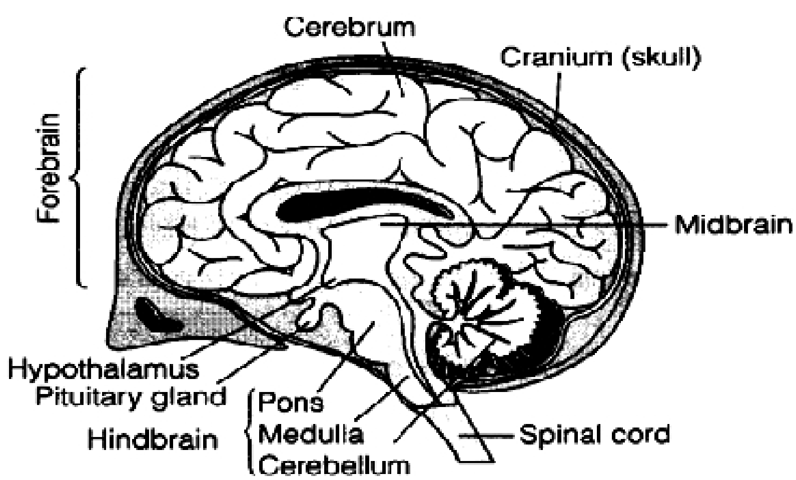
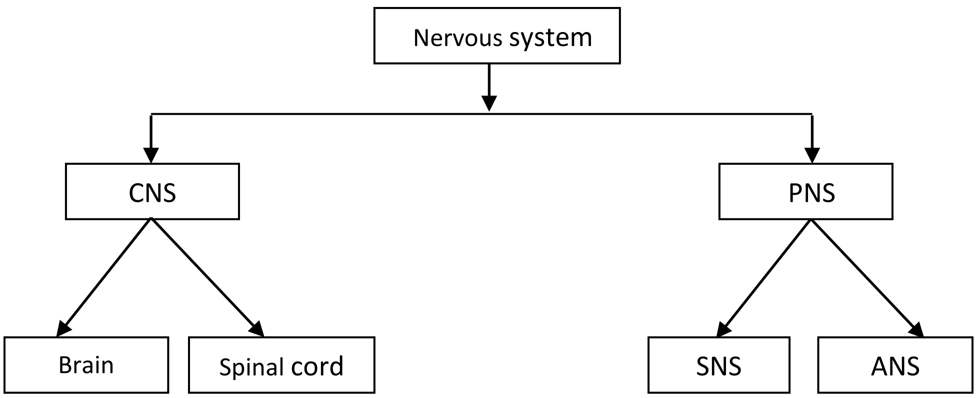


Fig.6.1 Human Brain
Source: http://www.wikipedia.org

The cellular building blocks of the entire nervous system are nerve cells, called neurons, and supporting cells called glial cells. The human brain is composed of almost 100 billion of electrically excitable neurons and 10 times as many glial cells. Neurons are specialized for electrical and chemical signaling over long distances. Glial cells, in contrast to nerve cells, are not capable of transmission of electrical signaling; thereby the neuron is the only functional unit of the nervous system. Current evidences indicate that the supporting glial cells play an important role in modulation of neuronal activity and developmental processes.



Organisation of the Nervous System: CNS: Central Nervous system, PNS: Peripheral Nervous System, SNS: Sympathetic Nervous System, ANS: Autonomic Nervous System. Source: Self Drawn

6.3 Structure of nerve cell

The nerve cells have a cell body which encloses a cytoplasm containing a nucleus. The cell body gives off a number of processes. There is usually a single axon and a variable number of dendrites. The primary components of the neuron are the cell body. A typical cell body is rounded or polygonal in shape. It contains a nucleus with large nucleolus. Special bodies called nisslgranules are also present in this, these are composed of ribonucleoproteins.

Axon:-

The axon, a long slender protection that conducts electrical impulses away from the cell body.

Dendrites:-

Dendrite (tree like structure) that receive message from other neurons. They conduct nerve impulses to the cyton and synapses (specialized junction between neutrons).

- The flow of information moves in the following direction dendrite to cell body (soma) to axon to terminal button to synapse.
- It has all the organelles like other cell, only centrosome is absent because nerve cell have lost the ability to divide (Fig.6.2).

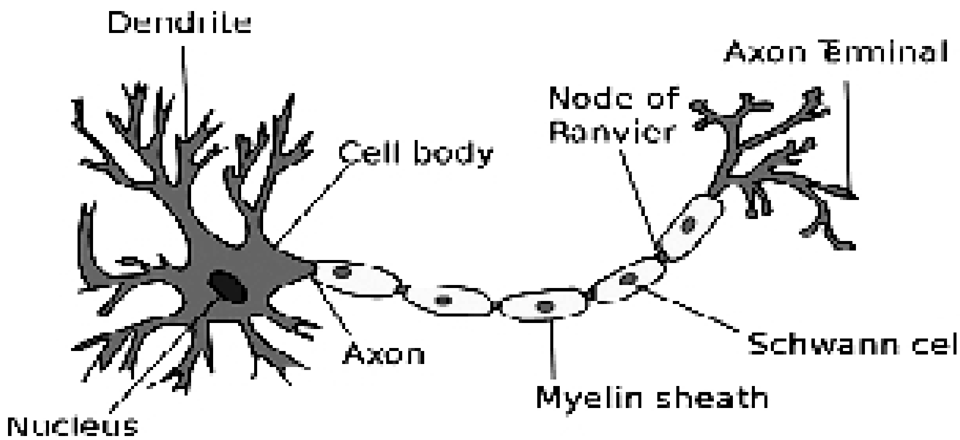


Fig.6.2 Nerve fibres:-

Source: http://www.wikipedia.org

An axon and its sheath are commonly called a nerve fibres.

The main types of nerve fibres are –

(i) Myelinated nerve fibres.

(ii) Non-myelinated.

(1) Myelinated nerve fibres:-

- In most neurons, the axon is surrounded by a insulating sheath, known as myelin sheath. The white matter of central nervous system, cranial and spinal nerves consists largely of myelinated fibres.
- It has composed of three elements – axis cylinder, myelin sheath or medullary sheath and neurolemma.
- The axis cylinder is central and is the direct continuation of the protoplasm of the nerve cells.The unspecialized cytoplasm of an axon is called axoplasm.
- The surface membrane of the axoplasm is known as axolemma, which is directly concerned with the transmission of nerve impulse.
- The myelin sheath is composed of lipoprotein.
- The myelin sheath is surrounded by the cytoplasm of special types of cell called Schwann cells, which are always closely associated with nervous tissue.
- The myelin sheath provided both mechanical support and electrical insulation to the axon.
- The myelin sheath is broken at regular intervals along the lengths of the axon.
- The places where the myelin sheath is discontinuous are called nodes of Ranvier.

- The structure is very important in the conduction of impulses through myelinated nerve fibres.
- The axon is covered by a structure less membrane called neurilemma. The Schwann cells lie within this membrane (sheath of Schwann).
- The axon end is telodendrite, which terminate minute knob known as synaptic knob.

(2) <u>Non-medullated fibres:-</u>

The post ganglionic fibres of the autonomic nervous system belong of this type.

These fibres are very much smaller and do not possess a myelin sheath.

6.4 Synaptic transmission

<u>Synaptic transmission:-</u>

Synapses are junctional complexes between presynaptic membranes (synaptic knobs) and post synaptic membranes (effectors).

So, presyhaptic is the transmission side (synaptic knob) and post synaptic is the receiving side (dendrite, soma or effects).

Synaptic knob contain many membrane – bounded synaptic vesicle, synaptic vesicles contain the neurotransmitter (Fig.6.3). Synaptic knob also contains mitochondria, microtubules and other organelles.

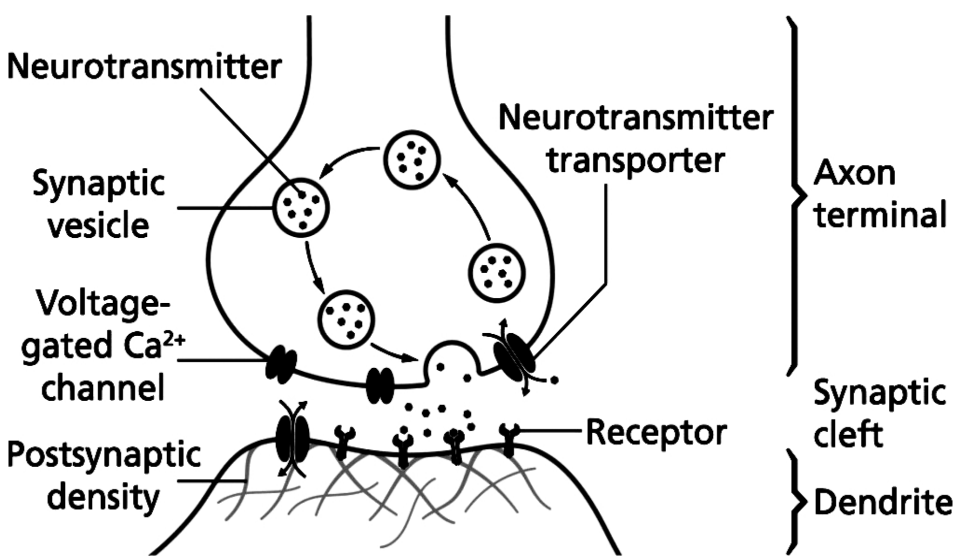


Fig.6.3 Synaptic Transmission,

Source: http://www.wikipedia.org

<u>Mechanism of synaptic transmission:-</u>

Synapses are point of contact between one neuron and other. The synapses can be of two types- **Electrica**l and **Chemical transmission**.

6.4.1 Electrical transmission

Electrical synapse is defined as a gap junction-mediated connection between neighbouring neurons. It is found in all nervous systems, including human nervous system. Electrical synapse conduct nerve impulses at a much faster rate than that of chemical synapse

The electrical synapses pass on the electrical activity from one cell to another by passage of ions

The electrical synapse does not release neurotransmitters in the synaptic cleft instead there is a direct transfer of electrical signal from one cell to the other via opening of fluid channels that conduct electricity. Special tubular structures comprised of small proteins are formed called as gap junctions which connects the interior of one cell to the next allowing free movement of ions. An example of the electrical synapse is the way by which action potentials are transmitted between smooth muscle fibers.

6.4.2 Chemical transmission

Chemical synapse is defined as a specialized biological junction through which neurons signal to each other or to non-neuronal cell via secretion of chemical messenger. It is the most common type of synapse in the nervous system. Human nervous system is composed of a huge number of chemical synapses;

On the other hand, in the chemical synapse the message is passed on by transmission of neurotransmitters released by the **pre-synaptic membrane** which act on the **post** the mechanism of neurotransmitter release across the chemical synapses. It is essential to note that the chemical synapses **are "unidirectional"** i.e. there is a one-way conduction of signals. That is from the *presynaptic neuron* from where the signal is generated and neurotransmitter is released to the *postsynaptic neuron* which has receptors to which the transmitter binds and executes its effect (Fig.6.4).

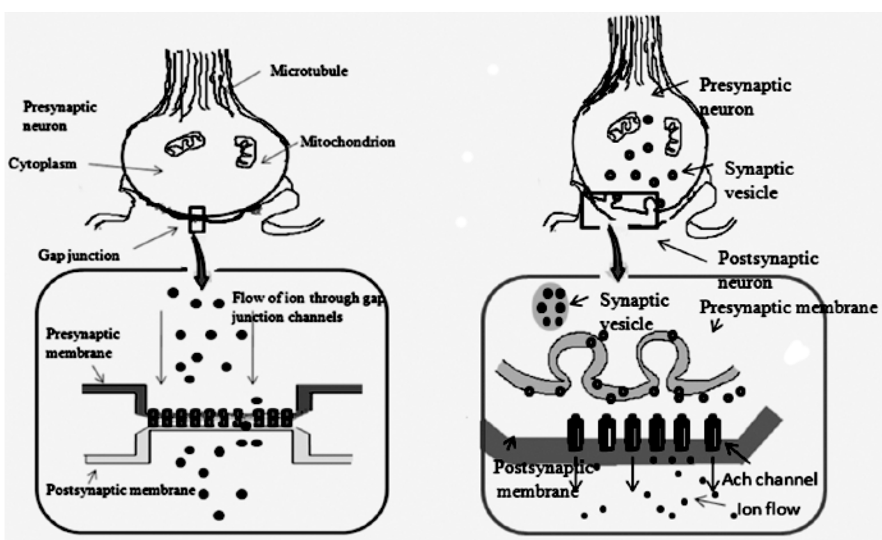


Fig.6.4 Electrical synapse & Chemical synapse
Source: http://www.wikipedia.org

6.5 Classification of synapse

Synapses are divided into four types -

6.5.1 Axodendritic synapse

Axodendritic synapse refers to the synapse between the axon terminal of presynaptic neuron and the dendrites of postsynaptic neuron. It is the most common type of synapse present in the nervous system. Axodendritic synapse is a kind of chemical synapse as the impulse is transmitted by chemical components named neurotransmitter.

6.5.2 Axosomatic synapse

Axosomatic synapse refers to the junction between axon terminal of presynaptic neuron and the cell body of postsynaptic neuron.

6.5.3 Dendrodendritic synapse

Dendrodendritic synapse refers to the junction between two different neurons. It is also one type of chemical synapse that receives depolarizing signal from incoming action potential and causes influx of calcium ions

that intern leads to release of Neurotransmitter molecules to propagate the signal the post synaptic neuron. Signaling mechanism in this kind of synapse utilizes Na+ and Ca2+ pumps (Fig.6.5).

6.5.4 Axoaxonic synapse

Axoaxonic synapse refers to the synaptic junction of axon terminal of one neuron with either the initial axon segment or an axon terminal of another nerve cell.

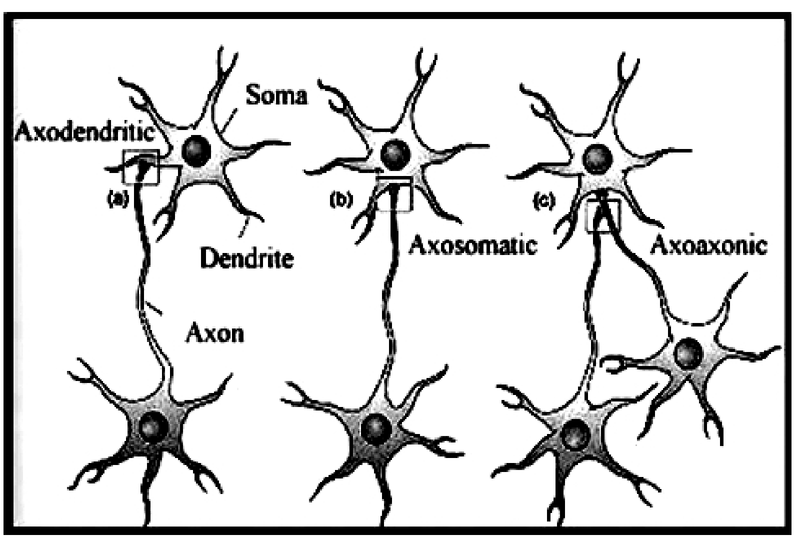


Fig.6.5 Anatomical Classification of Synapse

Source: http://www.wikipedia.org

6.6 Neurotransmitters

Referred to as the body's chemical messengers the first neurotransmitter to be discovered was a small molecule called acetylcholine.

It plays a major role in the peripheral nervous system, where it is released by motor neurons and neurons of the autonomic nervous system. It also plays an important role in the central nervous system.

A neurotransmitter influences a neuron in one of three ways.

Excitatory, inhibitory or modulatory.

An **excitatory transmitter** promotes the generation of an electrical signal called an action potential in the receiveing neuron, while an **inhibitory transmitter** prevents it. Whether a neurotransmitter is excitatory or inhibitory depends on the receptor it binds to.

Neuromodulators are a bit different, as they are not restricted to the synaptic cleft between two neurons, and so can affect large numbers of neurons at once.

- A terminal nerve endings there are many mitochondria and minute vesicle (synaptic vesicles) which contain small packets of chemical transmitter, acetyl-choine (A-ch) responsible for synaptic transmission.
- Nerve membrane which is in close with the muscle membrane, is known as presynaptic membrane, while the muscle membrane is called post synaptic membrane. The space between these two membrane is called synaptic cleft.
- The nicotinic A-ch receptors are found on the post-synaptic membrane near the junction folds. They are so called because they are stimulated by both nicotine and A-ch, and inhibited by curare.
- An enzyme specific acetyl-cholinesterase is found in high concentration in post synaptic clefts, which destroys (hydrolyzes) the A-ch.

6.6.1 Synthesis of A-ch

A-ch is synthesized within the mitochondria from choline in the presence of enzyme. Choline Acetyltransferase. In addition, it requires acetyl coenzyme A, ATP and glucose.

A-ch once formed is temporarily stored in minute vesicles (synaptic vesicles).

Nerve impulse causes fusion of vesicles with membrane of terminal nerve fibres by increasing permeability of Ca^{+}.

Freecholine + Acetyl coenzyme A + ATP + Glucose

← present in mitochondria →

↓ **Choline acetyl transferees**

(Acetyl–choline (A-ch)

↓ **Acetyl cholinesterase**

Choline + Acetate

6.7 Transmission of nerve impulses & action potential

The Na+-K+ pump transports three Na+ ions outside the cell for every two K+ ions in the cytosol. The unequal transport of these Na+ and K+ ions through Na-K pump separates the charges across the membrane, in which outside of the cell becomes relatively more positive and cytosol becomes relatively more negative. However, this active transport of Na+ and K+ ions only separates enough charges to generate a negligible membrane potential of -1 mV to -3 mV out of total -70 mV resting membrane potential in a typical neuron. The major membrane potential occurs due to the passive diffusion of Na+ and K+ down the concentration gradients (Fig.6.6). Therefore, Na+-K+ pump indirectly help in producing membrane potential, through its contribution to maintain the concentration gradients which is directly responsible for the ion movements that generate most of the potential.

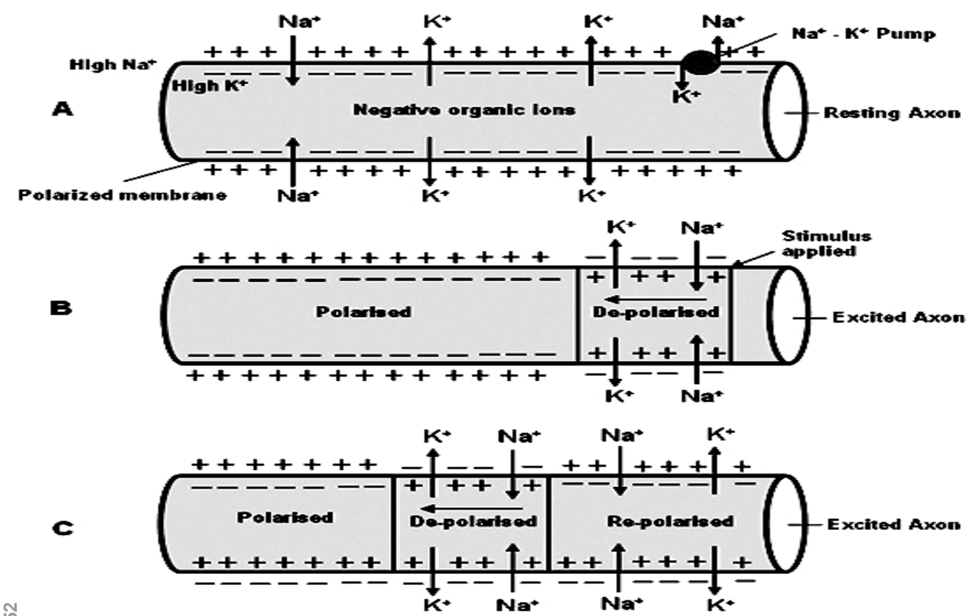


Fig.6.6 Transmission of Nerve impulses and Action Potential

Source: http://www.wikipedia.org

Temporary changes in the membrane potential from its resting potential generate electrical signals that are processed and transmitted by the nerve cells. These signals can be divided into two forms called as **graded potentials and action potentials**. The graded potential is important in transmitting the signaling over short distances, whereas action potentials are transmitted to the long-distance by nerve and muscle membranes. The direction of changes in the membrane potential from the resting potential is described by the terms depolarization, repolarization, and hyperpolarization The resting membrane potential is said to be polarized which denotes differences in the net charge between outside and inside of a cell. The membrane depolarization occurs when its potential is less negative or close to zero than the resting level. Overshoot describes a reversal of the membrane potential polarity. In other word, when cytosol of a cell becomes positive with respect to the outside of the cell. Repolarization is returning of depolarized membrane towards the resting potential. The membrane is said to be hyperpolarized when the membrane potential becomes more negative than the resting potential.

1. Nerve impulse (action-potential) reaches presynaptic nerve ending.
2. As it reaches presynaptic membrane, it causes release of A-ch into the synapse (synaptic cleft).
3. A-ch after its release, diffuses within very short distance to the post synaptic membranes ie. Motor end plate.
4. A-ch attaches to nicotinic A-ch receptors on motor and plate surface and increases the permeability of motor end plate to Na^+ and other positive ions (Ca^{2+}).
5. Increased permeability of Na^+ causes depolarization at the post synaptic membrane, causing generation of local potential, called end plate potential.
6. Resting membrane potential (RMP) in skeletal muscle membrane is – 90 mv. When 30 – 40 mv, it depolarizes the surface membrane of the muscle and results in generation of action (spike) potential.
7. Spike potential thus sets up a propagated muscle action potential which can travel in both directions along the muscle membrane. Once it reaches the muscle cell (muscle fibre) then the muscle gives mechanical response by contraction.

1. <u>Resting potential</u> :-

During resting (polarised) state, the inside of nerve is negative and the outside of nerve is positive and the resting membrane potential in most of neurons is – 70 mv (extracellular fluid has a high concentration of Na+ and Cl^- and the intercellular fluid a high concentration of K^+)

2. <u>Depolarization</u> :-

During activation of the membrane deplarization means reduction in the membrane potential from its negative value towards zero Na+

quickly moves in, this movement results in a positive charge on the inside of the cell as compared with the outside.

This reverses of electric charges is called depolarization.

3. **Repolarization :-**

K^+ ion with their positive charge, now begin to flow out faster than the $Na^=$ flow in, when these positive charger are moved to the outside of the cell they initiate the process of repolarization (return to the resting stak) and inside of the cell again becomes negative.

4. **Metabolic pump :-**

The active transports of Na+ out of the cell and at the same time also moves potassium back into the cell (inside) against concentration gradient called sodium potassium exchanges pump.

5. **The action potential :-**

As Na+ rushes into the fibre, the outside of the fibre briefly becomes negatively charged at that point. Adjacent to this point, a part of the fibre remains positively charged. This difference in potential between the two areas is called the Action Potential. Since opposite charges attract one another, positive charges move towards the negative changes on both sides of the membrane causes depolarization of the membrane (Fig.6.7).

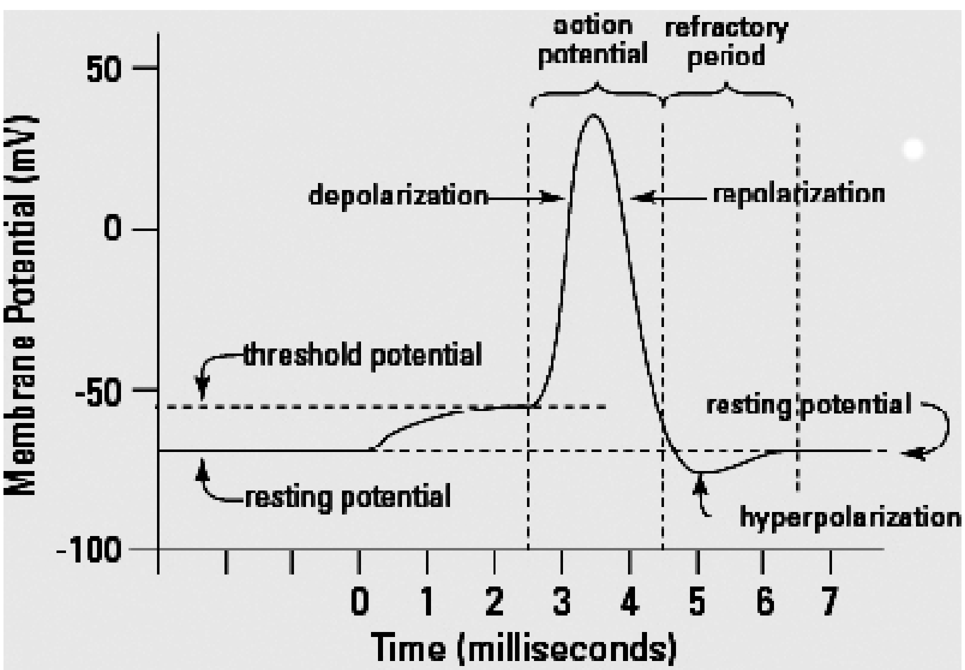


Fig. 6.7 Action Potential

Source: http://www.wikipedia.org

This depolarization causes the membrane to become more permeable.

As a result Na+ rushes into the cell.

Thus action potential may be defined as a self propagating depolarization of nerve membrane.

The entire phenomenon of action potential can be summarized as follow-

(1) Impulse is a beginning depolarization of the membrane after an initial 15 mv of depolarization, the rate of depolarization increases.

(2) The point at which this charge in rate occurs is called the firing level.

(3) Thereafter, the tracing on the oscilloscope rapidly reaches and overshoot (spike) the isopotential (zeropotential) line to approximately +35 mv.

(4) It then reverses and falls rapidly towards the resting level.

(5) When repolarization is about 70% completed, the rate of repolarization decreased and the tracing approaches the resting level more slowly.

(6) The sharp rise and rapid falls are the spike potential of the axon, and slower fall at the end of the process is the after depolarization.

(7) After reaching the previous resting level the tracing overshoots slightly in the hyperpolarizing direction to form the small and prolonged after hyperpolarization.

(8) The after depolarization is sometimes called the negative after – potential and the after hyperpolarization the positive after potential.

(9) Inflamed fat the nerve has been conducting repetitively for a length of long time, the after hyperpolarization is usually quite large. These potential represent recovery process in the neuron rather than the events responsible for the spike portion of the action potential.

6.8 Conduction of nerve impulses

The propagation of action potential can be divided into two types:

(1) Continuous conduction: This type of conduction involves step by step depolarization of membrane followed by repolarization of adjacent segment of the plasma membrane facilitated by different voltage-gated channels. The action potential propagation described so far in this module is called **continuous conduction**. It occurs in the unmyelinated axons of the neuron and also in muscle fibers.

(2) Saltatory conduction: This type of conduction occurs along the myelinated axons of the nerve fiber (Figure 9). Myelin sheath acts as an insulator which prevents the flow of charges between intracellular and extracellular fluid compartments. There are only few voltage-gated channels present on the axolemma that is covered by myelin sheath.

However, at the nodes of Ranvier, where myelin sheath is absent, axolemma bears large number of voltage-gated sodium and potassium channels that carried current across the membrane at the nodes. Therefore, instead of moving on the whole membrane, action potentials on myelinated fiber propagate through jumping from one node to another and for this reason such type of conduction is called **saltatory conduction**. The propagation of action potential through saltatory conduction is much faster as compared to continuous conduction on the axon of same diameter because only few charges are able to leak out through the myelinated sheath of the axon membrane.

6.9 Reflex Arc

Reflex is an involuntary response to a stimulus which depends on integrity (Completeness) of reflex pathway i.e. the reflex arc.

<u>The Reflex Arc:-</u>

- It forms the function unit of nervous system and consists of receptor, an afferent neuron, an efferent neuron and an effector organ.
- The number of synapses (connection between afferent and efferent neurons) varies from one to many hundred. These synapses are located in the brain or spinal cord.
- The afferent neurons enter via the dorsal roots are cranial nerves and have their cell bodies in the dorsal root ganglia. The efferent fibres leave via the ventral root are corresponding motor cranial nerves (Fig.6.8).
- Since the connection between afferent and efferent neurons is usually present in the CNS, therefore, activity in the reflex arc is modified by the multiple inputs converging on the efferent neurons.

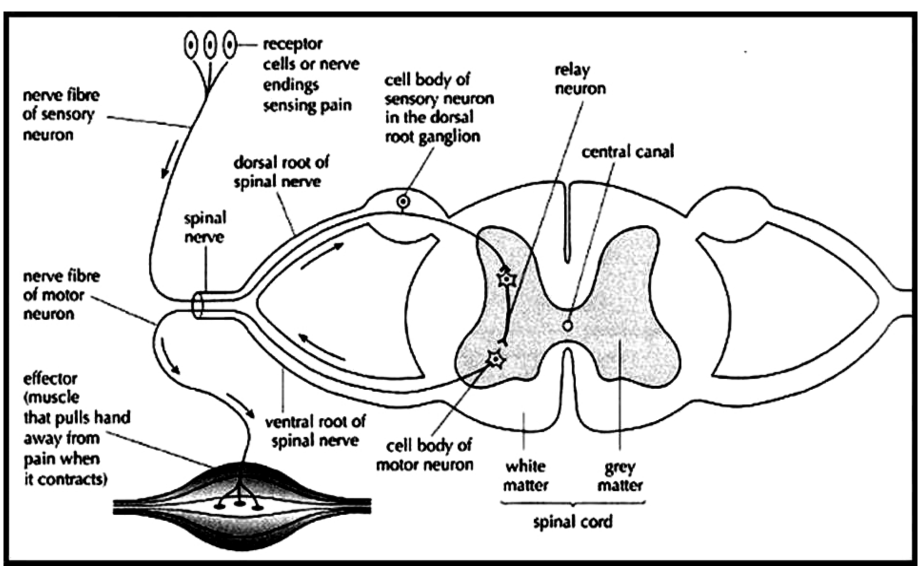


Fig. 6.8 Reflex arc, Source: http://www.wikipedia.org

- **Unipolar neuron:** Unipolar neurons have a single axon but contain no Dendron. Unipolar neurons are commonly seen in insect's brain, where the cell body of the neuron is located at the peripheral region of brain and is inactive. Another is pseudounipolar type that contains an axon which has two branches. Pseudounipolar neurons are actually variations of bipolar neurons in that initially they have two processes which fuse during their development into one short common axon. Primary sensory neurons, located in the dorsal root ganglions of spinal nerves and the semilunar ganglions of the trigeminal nerves are the major examples of pseudounipolar neuron.

- **Bipolar neurons:** Bipolar neurons have an axon and a single dendrite. Bipolar cells mainly act as sensory neurons in the transmission of special senses like olfaction, taste and hearing.

- **Multipolar neuron**: Multipolar neurons contain several dendrites. It is the most common type of neurons present in CNS and includes interneurons and motor neurons. A special type of multipolar neuron, known as pyramidal neuron is found in some areas of brain including hippocampus, cerebral cortex and the amygdale (Fig.6.9). The main structural features of the neuron include conic shaped cell body, after which the neuron is named. Pyramidal neurons are majorly present in the corticospinal tract.

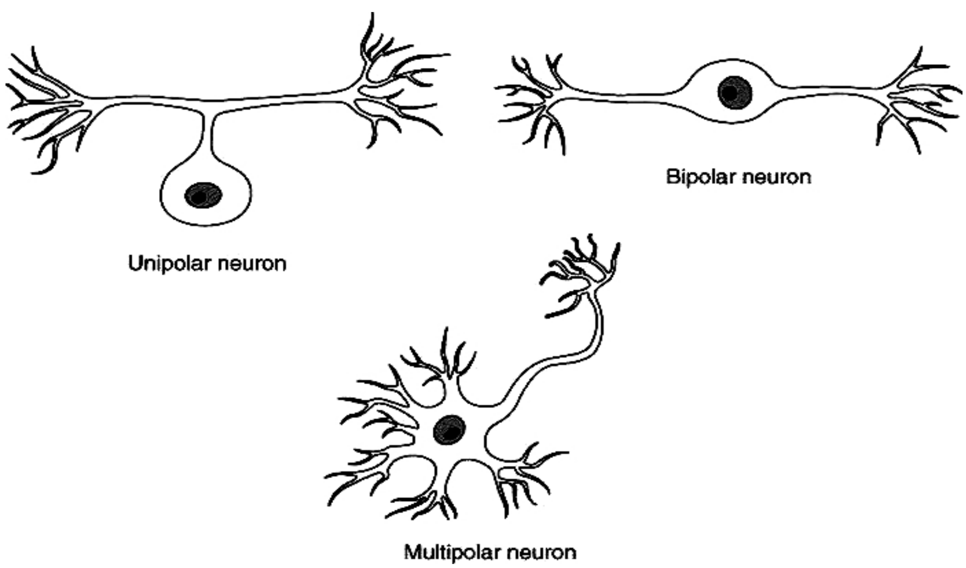


Fig.6.9 Multipolar Neurons

Source: http://www.wikipedia.org

- **Sensory neuron or afferent neuron:** Sensory neurons are cells of nervous system responsible for converting external stimuli from the organism's environment into internal electrical impulses as sensory information (e.g. the dorsal root ganglion cell). In response to a sensory input, peripheral sensory neuron (a first-order sensory neuron) conducts an electrical impulse that travels down the nerve fiber to the central nervous system. In sensory neurons an external stimulus may alters the permeability of cation channels present in the nerve endings, that in-turn generates a depolarizing current (receptor potential). Receptor potential if sufficient in magnitude, generates action potential in the sensory neuron. The axon diameter of a particular sensory neuron determines the

conduction speed of action potential. A first order sensory neuron may activate a second- or third-order neuron or a motor neuron. The sensory division carries sensory information to the CNS that includes "special senses" of touch, smell, hearing, taste and sight. It also carries senses of pain, body position (proprioception) and a variety of other visceral sensory information. The neurotrophins family of polypeptide growth factors are very much important in regulation of development of sensory neurons GDNF promotes the survival of parasympathetic, sympathetic, proprioceptive, enteroceptive, and cutaneous sensory neurons.

- ***Motor neuron or efferent neuron**: Motor neuron* (or motoneuron) is the nerve cell along which electrical impulses pass from the brain or spinal cord to a gland, muscle or any other target area (for example neurons in the autonomic nervous system). Motor neurons are classified in three major types, somatic motor neurons (that send their axon to skeletal muscles), special visceral motor neurons (which innervate branchial muscles) and general visceral motor neurons (that innervate cardiac muscle and smooth muscles). According to position motor neurons are again classified into two major group, upper motor neuron and lower motor neuron. Electrical impulse in the upper motor neuron travels from the cerebral cortex to the spinal cord. Nerve impulse then travels in the lower motor neuron that carries it from the spinal cord to the neuromuscular junction. Acetylcholine acts as a major neurotransmitter in motor neuron signaling.

- **Interneuron**: Interneurons are the neurons that connect various neurons within the brain and spinal cord and are very much important in neural circuits. Oscillatory activity of neuron and adult brain neurogenesis is dependent on interneurons present in the circuit. GABAergic interneurons with their axons present near the subgranular zone (SGZ) neurogenic niche can potentially exert functional impact on neurogenesis of adult brain (Bergström et al. 2014.).

6.10 Summary

- The nervous system is the human organ system that coordinates all of the body’s voluntary and involuntary actions by transmitting signals to and from different parts of the body.

- The nervous system has two major divisions, called the central nervous system (CNS) and the peripheral nervous system (PNS).

- The CNS includes the brain and spinal cord, and the PNS consist mainly of nerves that connect the CNS with the rest of the body.

- The PNS also has two major divisions the somatic nervous system and the autonomic nervous system.

- The somatic system controls activities that are under voluntary control.
- The autonomic system controls activities that are not under voluntary controls.
- Signals sent by the nervous system are electrical signals called nerve impulses. They are transmitted by special nervous system cells called neurons or nerve cells. Nerve impulses can travel to specific target cells very rapidly.
- Dendrites of a neuron receive nerve impulse from other cells.

6.11 Terminal questions

Q. 1: Describe the structure & function of the neurons.

Answer:……………………………………………………………………
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Q. 2: Describe the transmission of nerve impulses & action potentials.

Answer:……………………………………………………………………
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Q. 3: Give detailed structure of nervous system.

Answer:……………………………………………………………………
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Q. 4: Describe the synaptic transmission & classification of the synapse .

Answer:……………………………………………………………………
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Q. 5: Describe the neurotransmitters.

Answer:……………………………………………………………………
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…………………………………………………………………………
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Q. 5: Describe the neurotransmitters substances.

Answer:……………………………………………………………………
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Q. 6: Describe the neural circuit in detail.

Answer:……………………………………………………………………
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<u>Multiple choice questions:</u>

(1) System of the body which co-ordinates and controls its activity is known as -

(a) Organ system

(b) Nervous tissue

(c) Muscular system

(d) Nervous system

(2) Which of the following is not the component of the PNS?

(a) Elastic connective tissue

(b) Cranial nerve

(c) Spinal nerve

(d) Ganglia

(3) Name the basic structural and functional unit of the nervous system.

(a) Neuroglia

(b) Glial cells

(c) Neurons

(d) Perikaryon

(4) Which of the following cells supports, nourishes, and protect the neurons ?

(a) Nissl bodies

(b) Perikaryon

(c) Ganglia

(d) Glial cells

(5) What are Nissl bodies?.

(a) Golgibodies

(b) Lysosomes

(c) Cluster of rough ER

(d) Mitochondria

(6) Name the multipolar neuron which is located entirely within the central nervous system.

(a) Motor neuron

(b) Efferent neuron

(c) Afferent neuron

(d) Inter neuron

(7) Out of the following, which one does not affect the speed of conduction of nerve impulses?.

(a) No. of ganglia

(b) Myelin sheath

(c) Axon diameter

(d) Temperature

(8) Chemicals which are released at the synaptic junction are called ?.

(a) Hormones

(b) Neurotransmitters

(c) Cerebrospinal fluid

(d) Lymph

6.12 Answers

(1) – (d)

(2) – (a)

(3) – (c)

(4) – (d)

(5) – (c)

(6) – (d)

(7) – (a)

(8) – (b)

UNIT-7

Muscular System

Structure

7.1 Introduction

In the previous unit you have learnt about the nervous system of vertebrates. In this unit you will learn briefly about the structure and functions of muscular system. The muscular system is composed of specialized cells called muscle fibres. The muscular system is responsible for functions such as maintenance of posture, locomotion, and control of various circulatory systems. The three kinds of muscles in mammals are:

1. Slow muscles, also called nonstriated muscles (viscera muscles, smooth muscles, involuntary muscles) These are associated with the visceral organs like alimentary canal, bladder etc.
2. Fast moving muscles called striated muscles (voluntary muscles, striped muscles or skeletal muscles) which are associated with the skeleton
3. Medium-fast muscles called cardiac muscles, associated with the heart.

Objectives:-

After studying this unit you should be able to:

- Describe the skeletal, cardiac and smooth muscles
- Different types of contractile filament
- Sarcotubular system of cardiac muscle
- Sliding filament theory of muscle contraction

7.2 Types of muscles

The body muscles are divided into three types (Fig.7.1) -

(1) Skeletal muscle
(2) Cardiac muscle
(3) Smooth muscle

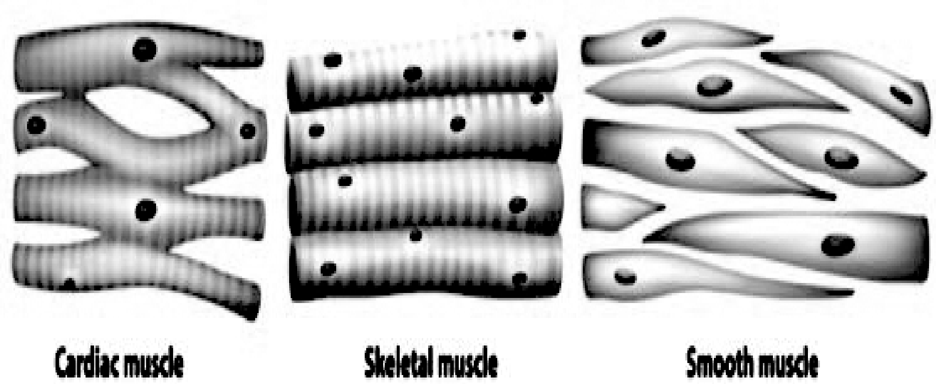


Fig.7.1 Types of Muscles

Source: http://www.wikipedia.org

7.2.1 Skeletal muscle

The skeletal muscles are attached to the skeleton and form somatic musculature also called the striated muscle. Generally under voluntary control.

The term muscle fibre is attributed to a muscle cell

Each muscles fibres are multinucleated cylindrical structure which tapers at both ends.

The cell membrane of muscle fibre called sarcolemma and its cytoplasm called the sarcoplasm.

Each muscle fibres are made up of many fibrils called myofibrils/

The protoplasm of muscle fibres called sarcoplasm, contains numerous mitochondria are termed sacrosomes, smooth surface endoplasmic reticulum term as sarcoplasmic reticulum.

Sarcomeres is the basis functions unit of the muscle fibre.

Bundle of myofilaments are known as myofilaments.

The myofibrils are composed of actine & myosine filaments.

The filaments are chiefly made up of four contractile protein – actin, myosin, tropomyosin and troponin.

A single fibril is made up of many myofilaments and the myofibrils are collectively called the contractile elements of the muscle.

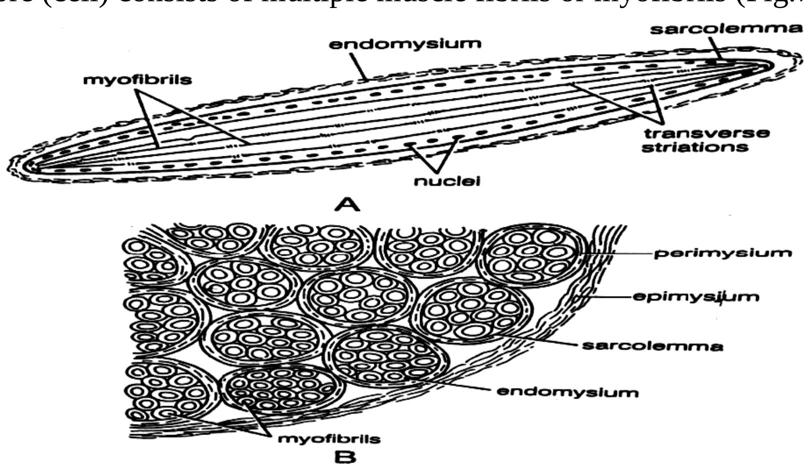
The muscle fibre is enclosed in a sheath of connective tissue which is termed as endomysium. Such muscle fibres are arranged in bundles known as fascicule.

Each fascicule are enclosed within a sheath of connective tissue **known as epimysium**.

Like other muscles, the skeletal muscle is also supported by various connective tissues.

Epimysium, the connective tissue coat, is the outer most covering for each whole skeletal muscle bulk. The whole muscle bulk is divided into smaller bundle, the Fasciculi, bounded by the perimysium.

Now again each fasciculus consists of muscle fibres which is enclosed in a delicate areolar connective tissue jacket, the endomysium. Each muscle fibre (cell) consists of multiple muscle fibrils or myofibrils (Fig.7.2).



RIL-152

Fig. 7.2 Muscle Fibres, Source: http://www.wikipedia.org

In electron microscopy appearance that the filament are of two types –

- The thick filaments are mostly composed of the protein myosin and hence are also known as myosin filaments.
- The thin filaments are mostly composed of the protein actin filament.
- Each myofibril is composed of number of alternating bands called light band or isotropic band (I band) and dark band or anisotropic band (A band).
- The A band (dark band) contains the myosin filaments and a part of actin filaments from the two sides in an interdigital manner.
- The I band contains only the actin filaments.
- The middle region of the A band has a lighter area which is called H (Hensen's) disc.
- The I band is bisected by a very dense and narrow Z (Zwis chenscheibe) line.
- The lighter zone surrounded a dark thin strip called M line (Fig.7.3).

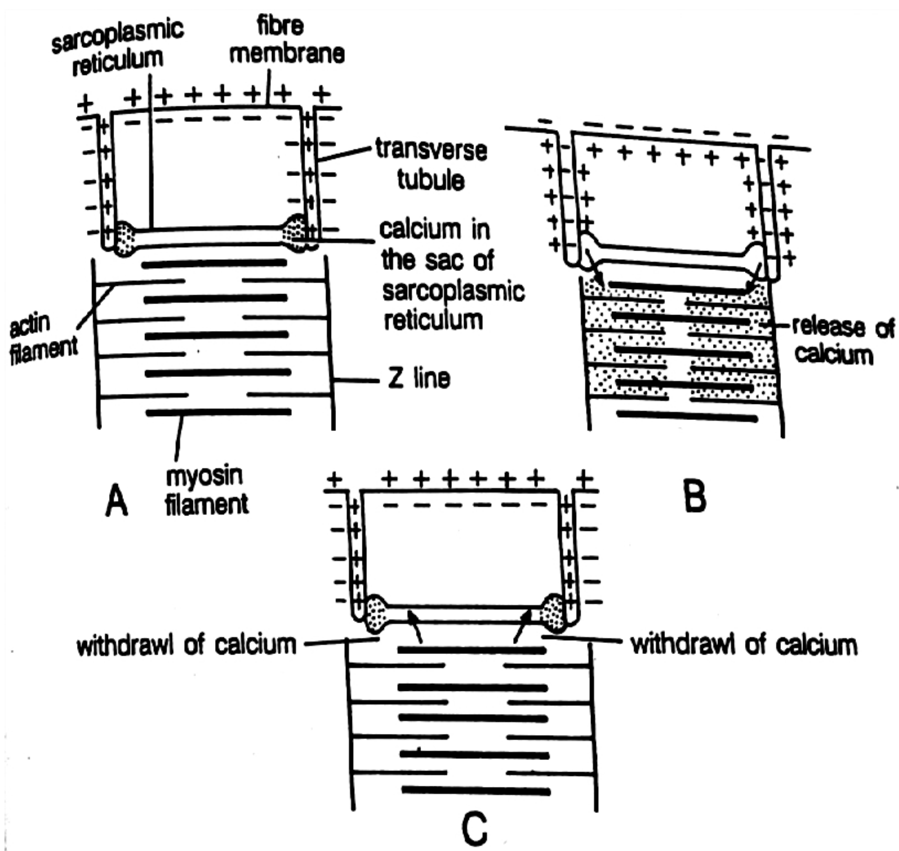


Fig.7.3 electron microscopy appearance of the filament

Source: Human Physiology by C.C. Chaturjee

7.2.2 Cardiac muscle

Striated involuntary muscle contracts rhythmically and automatically, present in the muscle layer of heart. Vertebrate cardiac muscles are composed of branched cells. In electron microscope studies that the heart muscles are made up of distinct individual cells, which appear like a syncytium because adjacent membranes are in very close contact with each other through special membranes, called the intercalated discs. The cardiac muscle fibres are smaller in size than the skeletal muscle fibres.

The functional properties of cardiac muscle differ from the skeletal muscle.

- The spontaneous nature of contraction and rhythmicity which is not subject to voluntary control.
- The fibres are not simple cylindrical but they bifurcate and come in contact with that of the neighbouring fibres and ultimately form a three dimensional network.
- The nucleus is single and placed deep in the sarcoplam more or less at the centre (Fig.7.4).

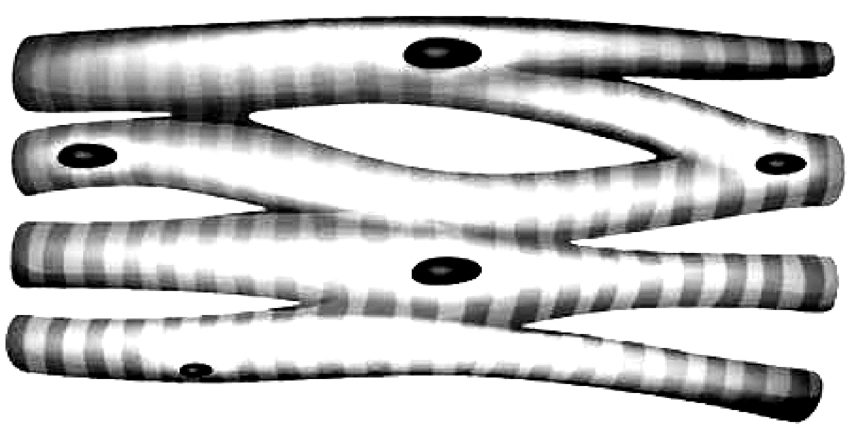


Fig.7.4 Cardiac Muscle

Source: http://www.wikipedia.org

7.2.3 Smooth muscle

Mostly in hollow viscera lacks cross- striations, therefore also called plain muscle. Involuntary in nature. Also called non striated smooth involuntary muscle smooth muscles are small and spindle shaped each muscle has a single nucleus. These muscles are present in all hollow viscera eg. gastro-intestinal tract, ducts of the glands, blood vessels, respiratory, urogenital and lymphatic system of the body (Fig.7.5).

These muscles are also present in the dermis, ciliary body and iris of the eye.

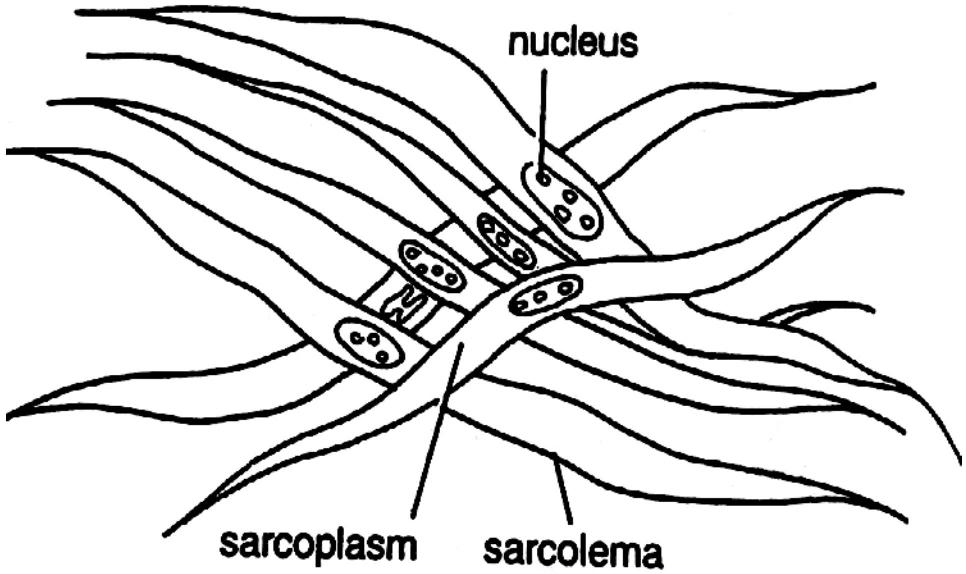


Fig.7.5 Smooth Muscle

Source: Animal Physiology by A.K.Berry

7.3 Sarcotubular system (T system)

The T system is the tubular invagination of the sarcolemma of the cardiac muscle. Initation for contraction involving a system of tubules called sarcoplasmic reticulum.

7.3.1 T-system

This T-system is the tubular invagination of the sarcolemma of the cardiac muscle and is larger in diameter than that of the skeletal muscle. The T-tubules are present at the Z lines in the cardiac muscle fibres, but the same are at the A-I junction in case of the mammalian skeletal muscle.

These tubules also increase the surface for metabolic exchange in between the interior of the cardiac muscle fibres and the intercellular space.

Over and above they function for quick propagation of impulse from the cell surface to the interior.

7.3.2 Sarcoplasmic reticulum

The sarcoplasmic reticulum is identical with the endoplasmic reticulum of other cell type but with the difference that its membrane does not possess ribosomes.

They are consisted of longitudinal interconnected tubules which are expanded into small terminal sacs at the Z lines (Fig.7.6).

There are no well-developed transverse cisternae in the cardiac muscle.

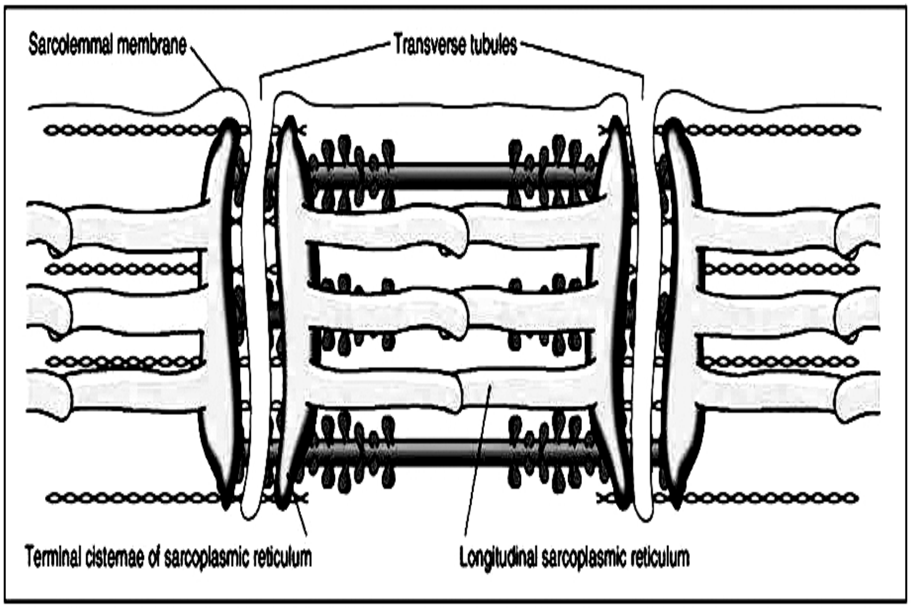


Fig.7.6 Sarcotubular System

Source: Physiology 3E www.studentconsult.com

7.4 Transmission of impulse & mechanism of contraction

The mechanism of contraction in the cardiac muscle is essentially same as that of the skeletal muscle. Impulse originated in the pace-maker area is transmitted through different conducting tissues and ultimately reaches the cardiac muscle fibres, and from which the impulse is transmitted rapidly from cell to cell, through different surface. From the cell surface the impulse is transmitted to the contractile elements of the myofibrils through the sacroplasmic reticulum.

Following stimulation the impulse is transmitted to the myofibrils by the T-System and the depolarization causes the release of calcium from the sarcoplasmic reticulum, which in turn activates the myosin ATPase (Fig.7.7).

- This activated ATPase breaks the ATP to ADP and the ADP to AMP with the release of certain amount of energy which is required for the process of contraction
- At the end of the contraction, the Ca^{++} ions returns to the sacroplasmic reticulum and relaxation occurs.
- Firstly myosin reacts with ATP to form myosin-ATP complex.

- Further, in the presence of k^+ and F-actin, Actomyosin ATP complex is formed.

$$Myosin-ATP \xrightarrow[F-actin]{K^+} Actomyosin-ATP$$

- This complex in the presence of Ca^{++} and ATPase splits the ATP to inorganic phosphate and actomyosin ADP.

  Thus, now it is known that the muscle contraction is turned on by the release of Ca^{++}ion and the hydrolysis of ATP of actomyosin – ATP complex provides the necessary energy.

- Relaxation of the muscles fibre results from the recovery of calcium ion back into the sarcoplasmic reticulum. This is done by an ATP dependent Ca^{++}ion pump. Decrease in the concentration of Ca^{++}ion dissociates Ca^{++}ion from troponin and then tropomyosin inhabits contraction.

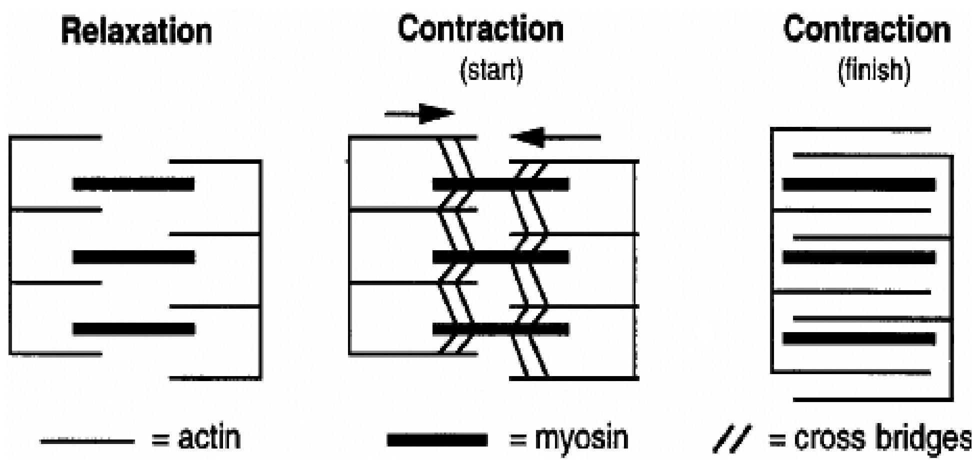


Fig. 7.7 Mechanism of Contraction

Source: Human Physiology C.C.Chaterjee

7.4.1 Sliding filament theory of muscle construction

The sliding filament mechanism of muscle contraction was discovered by **Huxley**.

- The process by which the shortening of the muscle is brought about sliding of actin filament over the (thick) myosin filaments.
- When a muscle is in the resting state, it remains extended because actin and myosin components of the actomyosin-ATP complex.
- When a nerve impulse arrives at the junction between the nerve ending and the muscle, the **sarcolemma** of a muscle fibre is deploarized, Subsequently, the deplorization of sacrolemma is transmitted to the interior of the muscle fibre by a plexus of channels the **sarcoplasmic reticulum**.

- The action potential deploagizer the muscle membrane here, It causes the sarcoplasmic reticulum to release large quantities of Ca^{++}ion.
- Ca^{+}ion activate the contraction process.
- The released calcium binds to the TPC subunit of the troponin complex, producing conformational changes which are transmitted to tropomyosin and then to actin protein of the thin filament, so actin interact with myosin with resultant muscular contraction
- Intact myosin has the activity of enzyme ATPase which hydrolyzes ATP and ADP, releasing the energy for activity
- The thick and thin filaments interact by cross bridges.
- The sliding during muscle contraction is produced by breaking and reforming of cross bridge (cross linkage) between actin and myosin.
- The width of 'A' band is constant where as the Z lines move closer together when the muscle contracts and farther apart when it is stretched. As the muscle shortens filaments apparently overlap (Fig.7.8).

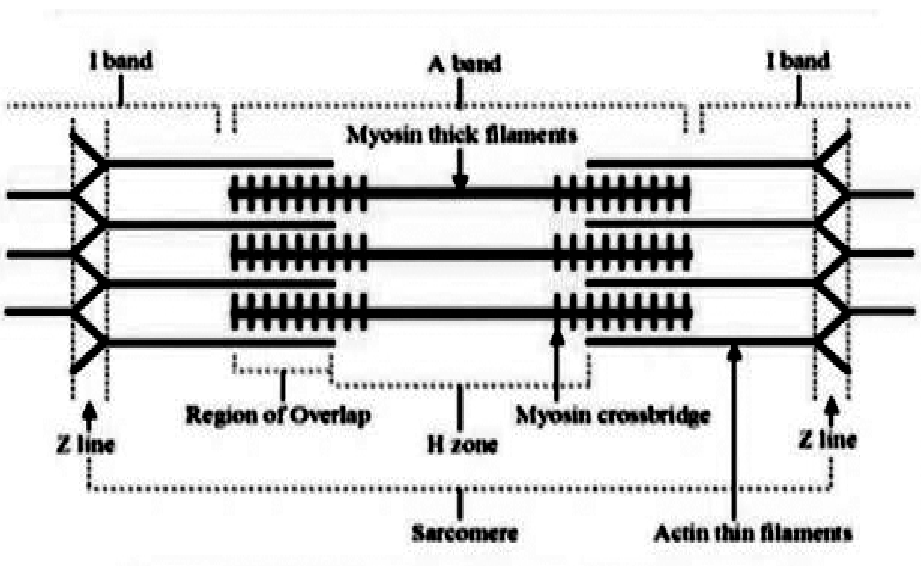


Fig.7.8 Sliding Filament Theory

Source: http://www.wikipedia.org

7.5 Nervous control of muscles

Muscles are supplied both with sensory and motor fibres. The sensory nerves, sent information regarding the 'stage' of the muscle (pain, fatigue etc.) to the central nervous system. Motor nerves accordingly control the activity of the muscle. Special motor nerves which prevent muscles from contracting are called inhibitory nerves. Nerves which control the activity of automatically contracting muscles, like visceral and heart muscles are called regulatory nerves. Regulatory nerves can be both inhibitory and excitatory. The point at which the axon makes contact with the muscle is called myoneural junction or motor end plate.

- When a single axon divides into several terminals before supplying a muscle fibre it is termed mononeural multiterminal.
- When a muscle fibre receives stimuli from several axons it is called polyneuronal innervated by it is called a motor unit. If a large number of motor units are present in a muscle, the muscle can contract in a finely graded manner.

7.6 Proteins in muscles (contractile filament)

The filaments are chiefly made up of four contractile protein - **actin, myosin, tropomyosin and troposin**. A single fibril is made up of many myofilaments. Myofibrils and myofilaments are collectively called the contractile filaments of muscle.

7.6.1 Myosin

- Myosin binds to the polymerized form of actin, the major constituents of the thin filament. It is composed of about 200 myosin molecules, each having molecular weight of 4,80,000.
- Myosin is composed of six polypeptide chains (hexamer). It contains one pair of heavy chains and two pairs of light chains.
- The two heavy chains coil around each other to form a double helix
- One end, of each of these chains, folded into a globular protein mass called head of the myosin, other end of helix is called the tail.
- The four light chains are also part of myosin heads, two to each head.
- These light chains aid to control the function of the head during the process of muscle contraction
- The myosin molecule is composed of two parts : one part is called light meromyosin and the other part is called heavy meromyosin
- The head fragment is globular in shape, this protein called the heavy meromyosin (HMM) heavy meromyosin, contains the fibrous and globular proteins of myosin.
- The heavy meromyosin has two chemically different active sites.
- The tail fragments of myosin molecules are called light mermomyosin (LMM). It is a rod like structure consisting of two alpha helices coiled around each other like a two-stranded rope.

- At one site binding to actin molecule and at the other hydrolysis of ATP occurs.
- The globular subunit of myosin has two active sites, one for actin and other for ATP.
- In the cross bridging cycle, the globular head binds ATP and splits it to ADP + Pi in the presence of Mg^{2+}, but does not release the ADP and Pi.
- These energy released is stored in the myosin ADP complex.
- This complex then binds actin, forming actin – myosin – ADP – Pi - complex.
- In the next step, ADP and Pi are released by myosin and the myosin head changes the conformation, pulling the attached actin towards the middle of the myosin filament.
- The myosin head then binds to a new ATP, triggering its release from actin subsequently, the new ATP is hydrolysed, blocking the myosin head in position to bind another actin molecule.
- Tropomyosin and Troposin are cross-linking proteins found in association with actin (Fig.7.9).

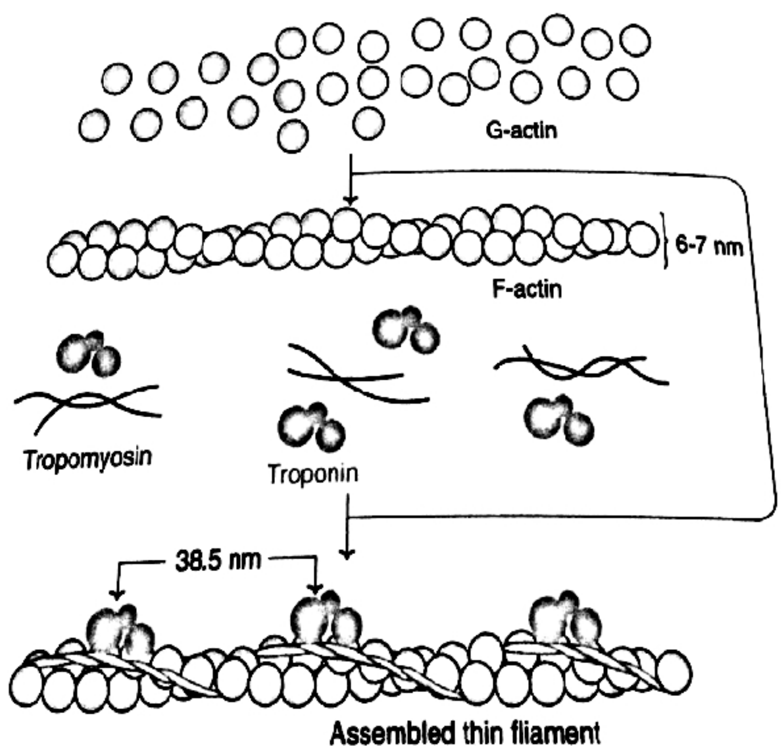


Fig. 7.9 Diagrammatic representation of the thin filament of a sarcomere

Source: Human Physiology and Biochemistry by Prof. A.K.Jain

7.6.2 Tropomyosin

- Tropomyosin is a long protein coiled along the groove between the chains of actin filament.
- Tropomyosin composed of two chains, attaches to F-actin in the grooves.

7.6.3 Troponin

- Troponin is also found on the actin filament.
- It is a protein molecule. It is attached to each tropomyosin molecule forming Troponin-Tropomyosin complex.
- Troponin has got a deep affinity for Ca^{++}. The calcium ions bind to troponin & bring about conformational changes in both troponin & tropomyosin molecules. This effects induces the movement of tropomyosin to uncover the binding sites & allow cross bridges of myosin to bind to actin filament. Thus calcium ion acts as the physiological regulation of muscle contraction (Fig.7.10).
- Troponin consist of three Polypeptide chains, according to its functions -
  - Troponin T (TPT binding to tropomyosin).
  - Troponin I (TPI, that inhibits F-actin myosin interaction)
  - Troponin C (TPC, calcium binding polypeptide)

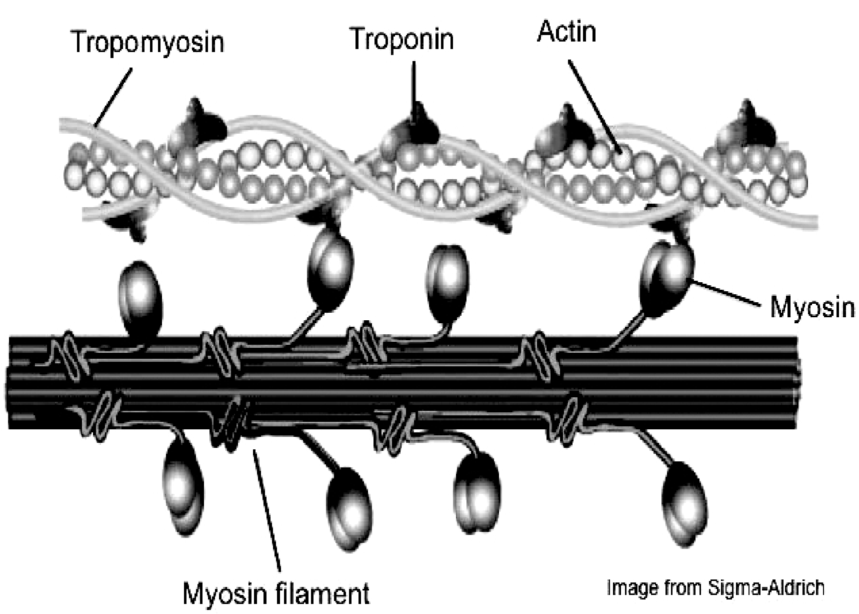


Fig. 7.10 Attachment Tropomyosin, Troponin and Actin Filaments
Source: Image from sigma-Aldrich

7.6.4 Actin

Actin is a major constituents of thin filaments of sarcomere. It exists in two forms -

(a) Monomeric - G-Actin (globular actin).

(b) Polymeric - F-actin (filament actin).

G-actin polymerizes to form an insoluble double helical F-actin

- The backbone of actin filament is a double stranded helix of F-actin protein molecule
- Each strand of F-actin is composed of polymerized G-actin molecule
- To each one of G-actin molecule is attached one molecule of ADP
- These ADP molecules are the active sites on the actin filaments with which the crossbridges of the myosin filaments interact to cause the muscle contraction.

7.7 Summary

- Muscles is the single largest tissue of the human body (30-40%) of the body weight). It is composed of fibre cells into which myofibrils are embedded.
- Each myofibril contains alternating A and I bands.
- Sarcomere is the functional unit of muscle.
- Actin, myosin, tropomyosin and troponin are the major contractile proteins found in the muscles. The muscle contraction and relaxation occur due to the active involvement of these proteins.
- ATP is the immediate source of energy for muscle contraction.
- Nerve impulse is transmitted via a motor nerve to motor end plate.
- Nerve impulse crosses the neuromuscular junction by causing release of Acetylcholine. Acetylcholin depolarizes sarcolemma.
- Impulse is conducted into T-tubules and to the sarcoplasmic reticulum.
- Sarcoplasmic reticulum releases large quantities of calcium ions into sarcoplasm. Calcium ions activate the contraction process.
- Calcium ions combine with troponin which pushes tropomysin away from actin receptor sites.
- Myosin crossbridges interact with actin receptor sites

- As each sarcomere shortens, the whole muscle fibre contracts.
- Calcium ions are reabsorbed by the sarcoplasmic reticulum.

7.8 Terminal questions

Q. 1: Give a detail account of various types of muscles.

Answer:……………………………………………………………………….
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Q. 2: Describe the role of myosin in muscle contraction.

Answer:……………………………………………………………………….
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Q. 3: Enumerate the important structural and functional differences between three types of muscles in a vertebrate

Answer:……………………………………………………………………….
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Q. 4: Explain the role of calcium in the regulation of muscle contraction.

Answer:………………………………………………………………………
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❖ **Short answer type questions:-**

(1) Myosin filament

(2) Actin filament

(3) Skeletal muscles

(4) Cardiac muscle

(5) Visceral muscle

❖ **Describe the following in brief:-**

(1) Sarcotubular system

(2) Sources of energy for muscular contraction

(3) Role of Ca^{++} in muscle contraction

OBJECTIVE QUESTIONS

❖ **(A) Multiple choice questions:-**

(1) What is a given to the cytoplasm of the myofibril:

(a) Ectoplasm

(b) Endoplasm

(c) Sarcoplasm

(d) Sarcomere

(2) Sliding filament theory of muscle contraction was given by:-

(a) Huxley

(b) Landsteiner

(c) Cori

(d) A.S. Gyorgi

(3) One of the following element is essential for contraction of muscles:-

(a) Na^{+}

(b) Mn^{++}

(c) K^{+}

(d) Ca^{++}

(4) Junction between muscle fibres and motor nerve is known as:-

(a) Synapse

(b) Neuromuscular junction

(c) Axon

(d) Neuromotor junction

(5) Dark anisotropic band in muscle fibre is known as:-

(a) M-band

(b) H-band

(c) Z-band

(d) A-band

(6) The sarcomere is the area between two:-

(a) M-band

(b) H-band

(c) Z-band

(d) A-band

(7) Sarcolemma is the membrane which covers:-

(a) Nerve fibre

(b) Visceral fibre

(c) Muscle fibre

(d) Collagen fibre

(8) Cardiac muscles have properties of:-

(a) Straited muscles

(b) Unstraited muscles

(c) Both (a) and (b)

(d) None of the above

(9) Energy source for muscle contraction is:-

(a) Actin-Tropomyosin

(b) ATP

(c) Lactic acid

(d) Nicotinamide

(10) End plate potential is characterized by:-

(a) Hyperpolarization

(b) Normal polarity

(c) Depolarization

(d) None of the above

❖ **(B) State whether True or False:**

(1) Troponin has got a deep affinity for Ca++

(2) Smooth muscles are present in all hollow viscera

(3) Sarcomere is the functional unit of muscle fibres

(4) The association of axon terminals with motor end plate forms neuromuscular junction

(5) Skeletal muscle doesn't exhibit a refractory period

7.9 Answers

❖ **(A)**

(1)	(c)	(6)	(b)
(2)	(a)	(7)	(c)
(3)	(d)	(8)	(c)
(4)	(b)	(9)	(b)
(5)	(d)	(10)	(c)

❖ **(B)**

(1) - True

(2) - True

(3) - True

(4) - True

(5) - False

UNIT-8

Endocrine System

Structure

8.1 Introduction

The word endocrine is derived from the **Greek terms endo meaning within and 'krine' meaning to separate or secret**. The endocrine system acts through chemical messages called hormones that influence growth, development and metabolic activities. The nervous system releases neurotransmitters or neuro-hormones that regulate neurons, muscle cells and endocrine cells. Because the neurons can regulate release of hormones, the nervous and endocrine system works in a coordinated manner to regulate the body's physiology.

The term 'hormone" for the first time was given by Bayliss and starling in 1902. Hormone is a chemical substance, which is secreted internally by certain specific glands and acts upon a target organ in the body.

Objectives:

- explain the meaning of endocrine.
- discuss the different types of glands in vertebrates.
- discuss the hormonal control system.
- discuss the anterior & posterior pituitary hormones.
- discuss the thyroid & parathyroid glands.
- explain the pheromones.

8.2 Different types of glands in vertebrates

In general three types of glands are found in vertebrate's body.

(i) Exocrine glands.

(ii) Endocrine glands.

(iii) Mixed glands.

8.2.1 Exocrine glands

These are specialized glands which secrete their secretions in body cavity with the help of duct.

These glands are provided with ducts and therefore these are also called as ductile glands. These include – mammary glands, sebaceous glands. salivary glands, enzyme, bile and mucous secreting glands of alimentary canal etc.

These glands do not secrete hormones.

8.2.2 Endocrine glands

These glands are ductless glands.

These glands together form the endocrine system of the body.

Ex. Pituitary gland, thyroid gland, endocrine part of the pancreas, adrenal gland, gonads etc.

8.2.3 Mixed glands

These are duct glands whose major part is exocrine, but some endocrine cells or tissue also occur. Pancreas is well know example of such a gland.

8.3 Chemical nature of hormones

Hormones can be classified in to three groups on the basis of their chemical nature –

- Peptide (protein) hormones.
- Steroid hormones.
- Tyrosine derivative hormones.

8.3.1 Peptide hormones

- These hormones are composed of one or more polypeptide chain and therefore these are protein in nature.
- Important peptide hormones are – Growth hormone, Insulin, Vasopressin (ADH), Oxytocin, TSH, FSH, LH and Prolactin etc.

8.3.2 Steroid hormones

- These hormones are steroids.
- These hormones are lipid in nature and directly or indirectly derived from cholesterol, which is the main steroid in our body, (cholesterol is not a hormone),
- Example of steroid hormones include testosterone, estrogens, progesterone, cortisol, cortisone and calcitriol etc.

8.3.3 Tyrosin derivatives hormones

- These hormones are derived from an amino acid, called tyrosine.
- Important tyrosine derivative hormones are thyroxin tri-iodo thyronin or T3,
- tetra-iodo-thyronin or T4, epinephrine, nor-epinephrine etc.

8.4 Hormonal control mechanism

Regulation of secretion of hormones is brought by two mechanisms direct and nervous control.

8.4.1 Direct control

Some of the hormones secretion is regulated by the blood concentration of the substances which are directly controlled by the hormones themselves.

For example – Insulin secretion from pancreatic.

β-islets of Langerhans is promoted by a rise in blood glucose level and glucagon secretion from α-cells by a fall in blood glucose level.

These responses keep the blood glucose levels within narrow limits inspite of variations in carbohydrates intake in the diet, since insulin lowers and glucagon rises blood glucose.

8.4.2 Nervous control

Hormones secretion from endocrine glands is largely controlled by the CNS. Most of the neurotransmitters are concerned with rapid transmission of stimulation or inhibition over short distances. The CNS contains neurons which synthesize and release peptides.

The highest concentrations of such neurons are found in the hypothalamus where they release peptide hormones.

Thus the term neurosecretion refers to the actions of all neurons which act by release of chemical agents, as neurotransmitter.

Neural control of endocrine glands occurs by three mechanisms.

8.4.3 Neural control of endocrine glands

8.4.3.1 Direct innervations via ANS (for example)

- Pancreatic islets of langerhans have a post-ganglionic parasympathetic innervations.
- Adrenal medullary cells innervations by pre-ganglionic symphathetic fibres.

8.4.3.2 Neurosecretory neurons control of the posterior lobe

Neurons control of the posterior lobe.

Depolarization of neurosecretory cells of the posterior pitulitary by Ach released at synopses on the cell bodies of these neurons causes release of ADH and oxytocin.

8.4.3.3 Neurosecretory neurons control of the anterior lobe

Neurons control of the anterior pituitary.

The hypothalamic regulation of the anterior pituitary is achieved through peptidergic neurons which synthesize and secrete specific releasing factors. They enter the hypothalamic – hypophysial portal system and stimulate or inhibit the secretion of anterior pituitary hormones into systemic blood.

In addition to control by the CNS the secretion of anterior pituitary hormones is regulated by 'feedback' control effects of the hormones secreted by the target organs, the feedback control mechanism are of two types **– Negative and Positive**.

In the negative feedback control the response is opposite to the original stimulus, it is important for survival.

In the positive feedback control, the response is the same as that of the original stimulus.

8.5 Endocrine system

8.5.1 Hypothalamus

Hypothalamus is the part of forebrain.

8.5.1.1 Location and structure

It forms the floor of diencephalon. Therefore, it lies below the thalamus.

From the lower part, a nerve stalk arises. It is called infundibulum.

In this way, hypothalamus serve to connect brain and endocrine system. In other words it is the main centre of body's neuroendocrine system.

8.5.1.2 Endocrine function

- Hypothalamus plays a number of roles as a part of nervous system.
- As the centre of neuro-endocrine system, it serves to detect the changes in body's homeostatic environment.
- For this hypothalamus itself secrete various stimulatory / inhibitory chemicals (hormones) which reach the pituitary through hypophyseal portal system.

8.5.1.3 Hormones of hypothalamus

The neuro-secretory cells (neurons) of hypothalamus secrete certain chemicals, called neuro-hormones (Fig.8.1), which are mentioned below.

- **Growth hormone releasing hormone (GHRH):-**

  It is a 44 amino acid containing hormone. It stimulates somatotroph cells of anterior lobe of pituitary gland to release its growth hormones.

- **Thyrotropin releasing hormone (TRH):-**

  It is a tripeptide hormone. It stimulates thyrotroph cells of the anterior lobe of the pituitary gland to secrete its thyroid stimulating hormones.

- **Adrenocorticotropin releasing hormone (ACRH):-**

  It stimulates corticotroph cells of the anterior lobe of the pituitary gland to secrete its adreno-corticotropic hormone.

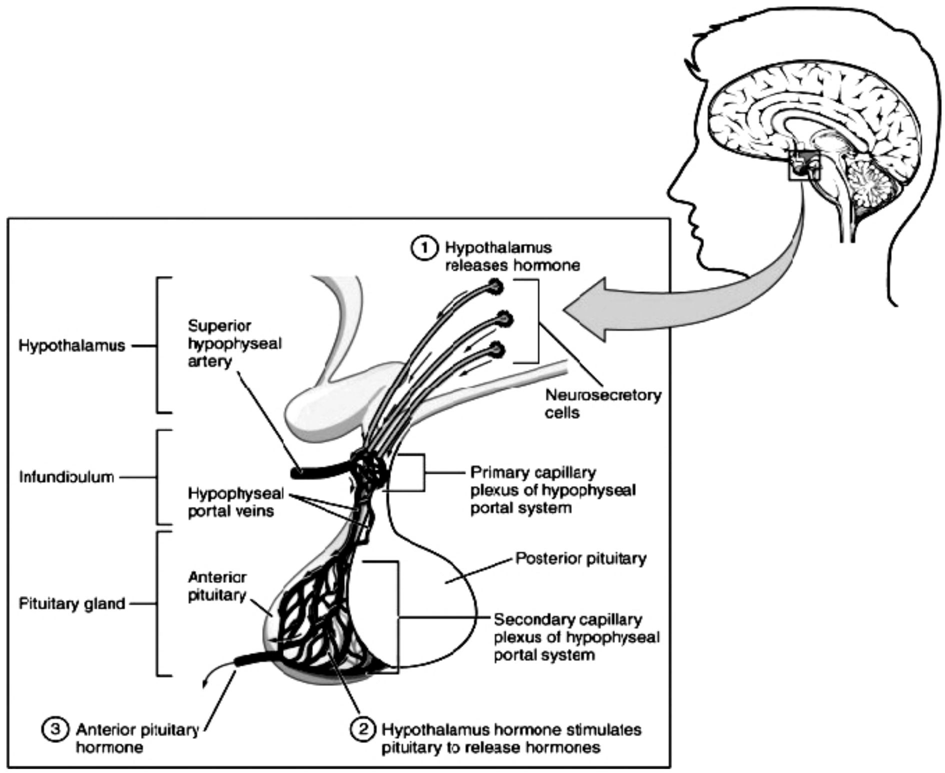


Fig. 8.1 Hormones of hypothalamus

Source: http://www.wikipedia.org

Hormones secreted by the Hypothalamus & Anterior Pituitary Gland

Hypothalamus		Anterior Pituitary
GHRH *(GH-releasing)*	→	GH *(growth hormone)*
SS *(somatostatin, GH-inhib)*	→	"
CRH *(corticotropin-rel)*	→	ACTH *(adrenocorticotropic)*
GnRH *(gonadotropin-rel)*	→	LH *(luteinizing hormone)*
"	→	FSH *(follicle-stimulating)*
PRH *(PRL-releasing)*	→	PRL *(prolactin)*
PIH *(PRL rel-inhibiting)*	→	"
TRH *(thyrotropin-rel)*	→	TSH *(thyroid stimulating)*

- **Growth inhibiting hormone (GIH):-**

  This hormone is also called somatostatin. It inhibits the secretion of growth hormone from the anterior lobe of the pituitary gland.

- **Gonadotrophin releasing hormone (GnRH):-**

  It stimulates gonadotroph cells of the anterior lobe of the pituitary gland to secret its follicle stimulating hormone, Luteinising hormone in ovaries and to secrete its interstitial cells stimulating hormone in testes.

- **Prolactin releasing hormone (PRH):-**

  It stimulates lactotroph cells of the anterior lobe of the pituitary gland to secret its prolactin.

- **Prolactin inhibiting hormone (PIH):-**

  It inhibits the secretion of prolactin from the anterior lobe of pituitary gland.

- **Melanocyte releasing hormone (MRH);**

  It stimulates the intermediate lobe of the pituitary gland to secrete its melanocyte – stimulating hormone (MSH).

- **Melanocyte inhibiting hormone:-**

  It inhibits the secretion of melanocyte stimulating hormone from the intermediate lobe of the pituitary gland.

8.5.2 Pituitary Hormones

Pituitary gland produced many hormones that influence many part of the body called the master gland of the body (Fig.8.2).

8.5.2.1 Anterior lobe or hormones of Adenohypophysis.

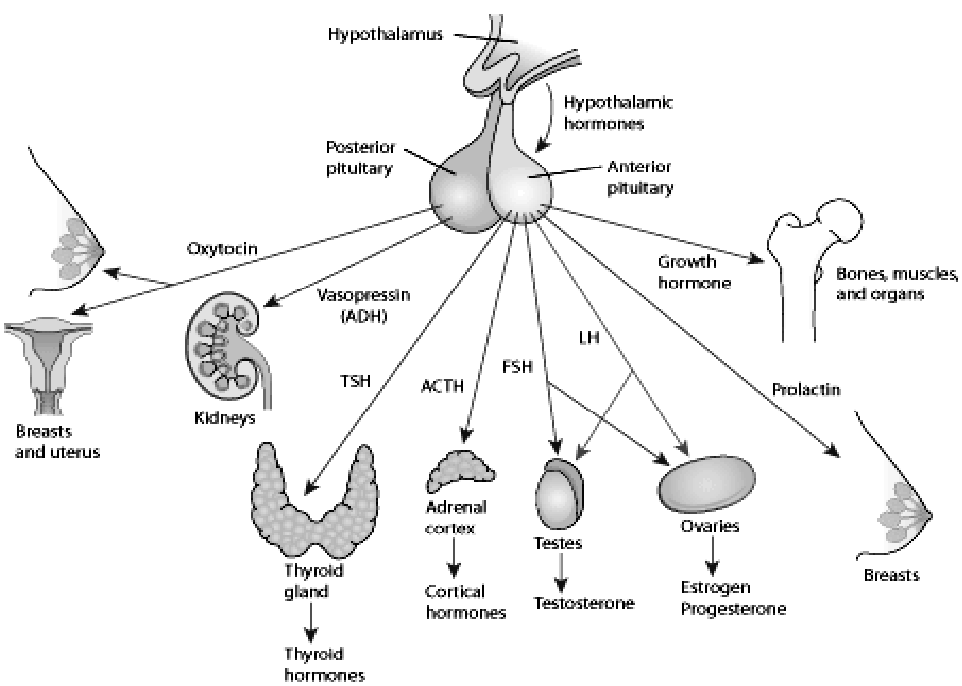


Fig. 8.2 Pituitary hormones, Source: http://www.wikipedia.org

- **TSH (Thyroid stimulating hormones):-**

  The release of TSH by the anterior lobe of the pituitary gland. It there is an excess secretion there is an increase in size of thyroid gland. But excess of secretion is prevent by thyroxine.

  The major action of this hormone is to stimulate the thyroid gland. It control the growth and activity of the thyroid gland.

- **ACTH (Adrenocorticotrophic hormones):-**

  Is regulates the development and secretion of adrenal cortex.

- **FSH (Follicle stimulating hormone):-**

  In the female, it stimulates the development maturation of the ovarian follicle and estrogen and stimulates it to secrete estrogens (female sex hormone). In the male, it stimulates the testis for spermatogenesis.

- **LH (Luteinizing hormones):-**

  In the female, LH is involved in the further development of egg cell and it release by rupturing the ovarian follicle. It secrete female sex hormones progesterone, similarly in male LH stimulating the interstitial cell of testis and as a result produce testosterone (Principal male sex hormone).

- **PRL (Prolactin Hormone):-**

  In mammals this hormones induces the mild secretion (lactogenesis) in the mammary gland of the mother shortly after giving birth.

- **MSH (Melanocytes stimulating hormones):-**

  They stimulates the melanin pigment granules in the epidermal cells of the skin (especially present in animals).

- **GH Growth hormones:-**

  This hormone is a protein.

  The growth hormones stimulates growth of all the body cells including the skeletal and muscular tissues.

  It promotes glycolysis (glycogen to glucose). So, it slightly increases blood glucose level.

  GH inhibits lipolysis (breakdown of fats in adipose tissues).

  Under secretion of the GH during dwarfism – over secretion of GH in adult causes in gigantism. Gigantism causes excessive growth of long bones. In adults excessive growth hormones secretion causes acromegali.

- **<u>Acromegali causes –</u>**
    - Over growth of jaw.
    - Heads are large, elongated with prominent jaws.
    - Abnormal growth of the body such as hands and feet which enlarged and spade like.
    - Skeletal abnormalities induce arthritis.
    - Soft tissues of the body overgrow resulting enlargement of spleen, liver, pancreas, kidney and thyroid.

8.5.2.2 Hormones secreted by posterior pituitary (neuro-hypophysis)

Posterior pituitary gland consists of nerve fibres and neurogloialcells, which connected to brain, Neurohypophysis release two hormones.

These are –

(i) Anidiuretic hormone (ADH) or Vasopressin

(ii) Oxytocin

(1) **<u>Antidiuretic hormone</u>:**

<u>Function</u>:- The most important and fundamental function of ADH is to reabsorb as much water as possible from the DCT of nephrons. For this it increases the permeability of the epithelial cells of DCT (distal convulated tubules) for sodium ions and water.

- The absorption of sodium ions from DCT also increases the reabsorption of water (under the effect of osmotic gradient).

(2) **<u>Oxytocin:</u>**

<u>Function</u>:- The most important effect of oxytocin is to stimulate the breast to eject the milk out. Therefore it is also called milk ejecting hormone.

- During parturition (delivery time) in a women, the secretion of oxytocin is at its maximum. After the birth of body, ‘oxytocin’ squeezes the lactiferous ducts. It’s secretion is mainly a reflex mechanism.
- Oxytocin also plays an important role in the birth of body. At the time of parturition, it initiates contraction in the uterine muscle, which creates labour pain, this helps to propel the child towards vagina and helps in the coming out of the body from mother’s body.

8.5.3 Steroid hormones

Steroid hormones are produced by adrenal cortex and gonads (testis and ovaries) as well as by the placenta during pregnancy because the different steroid hormones are closely related with each other. The most commonly occurring animal steroid is cholesterol. Cholesterol is in fact a major constituent of all normal tissue.

Cholesterol and steroid Hormones:-

Group	**Prinicipal compound**	**Principal source**
Sterol	Cholesterol	All tissue and cells.
Estrogen	Estradial	Ovary, follicles.
Androgens	Testosterone	Testis – interstitial cells
Progestogen	Progesteron	Ovary – Carpus luteum
Mineralocarticoid	Aldosteron	Adrenal cortex – zona glomerulosa
Glucocorticoid	Aldosteron cortisol	Adnrenal cortex – zonafascicularis

The estrogens are steroids produced by the developing ovarian follicles.

The androgens are produced by the interstitial cells of the testes. Testosteron is the principal androgen in mammalian testes. The principal representative of progestogen is progesterone. It is formed by the corpus luteum.

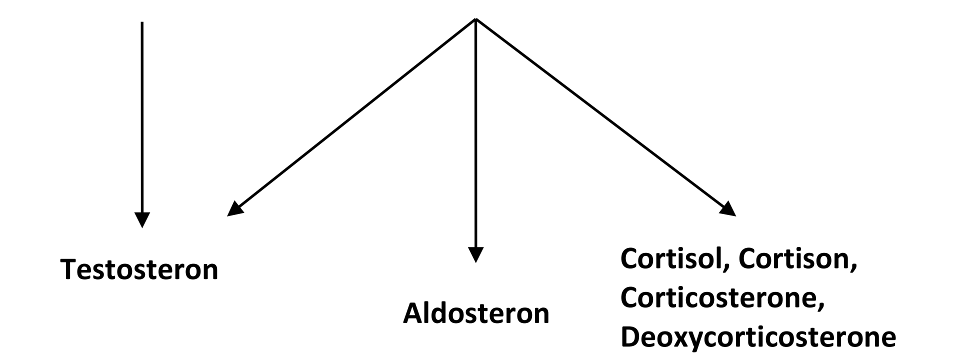
The adrenocortical steroids are basically progesterone derivatives. The names mineralocorticoid and glucocorticoid given to adrenal steroids refer to the two distinctive type of biochemical activity.

Cortisol is the most prevalent natural glucocorticoid. Aldosteron, on the other hand, is a principal mineralocorticoid.

Biosynthesis of steroid hormones -

(By R. Schoenheimer, D. Rittenberg and K. Birch)

Acetate → Cholesterol → Pregnenolone → Progesterone



The testosterone biosynthesis is from cholesterol through pregnenolone or progesterone.

Estrogen formation proceeds primarily from androgens. Therefore, numerous tissues including the ovary, placenta and adrenals have the ability to convert testosterone to estrogenic derivatives. The adrenal steroid also origate from cholesterol via pregnenolone and progesterone.

8.5.4 Thyroid hormones

- ❖ Thyroid is a largest endocrine gland.
- ❖ It is bilobed organ. The two lobes are connected by a narrow structure called the isthmus, situated in front of the neck just below the larynx.
- ❖ The thyroid gland secretes three hormomes, namely, thyroxine (T4), trilodothyronin (T3) and calcitonin.
- ❖ T4 and T3 are collectively known as thyroid hormones.
- ❖ Iodine is an essential component of both T4 and T3 (Fig.8.3).

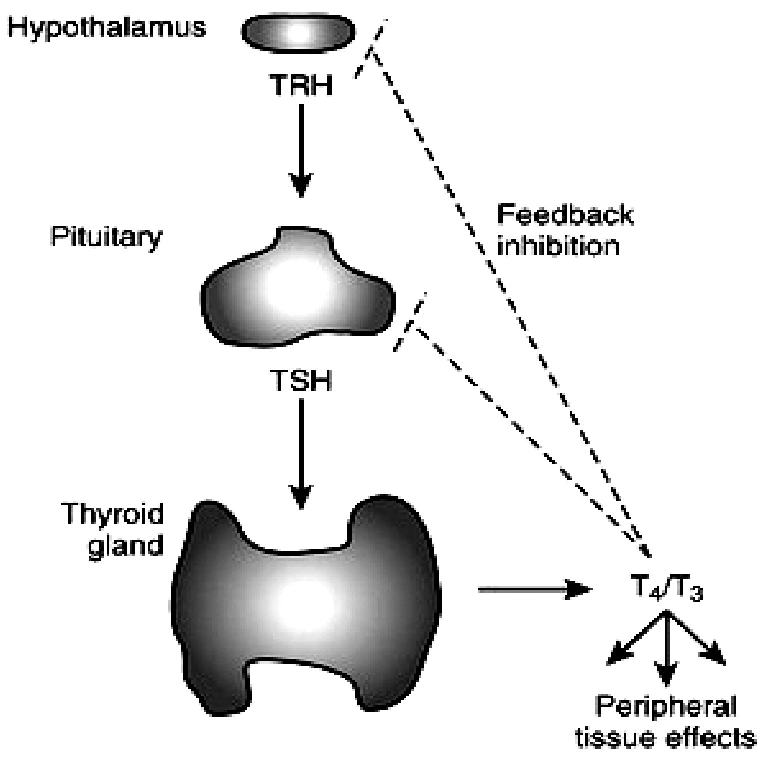


Fig. 8.3 Functions of the thyroid hormones

Source: http://www.wikipedia.org

(1) <u>Metabolic action:-</u>

Thyroid hormones stimulate the rate of oxygen consumption or oxidative metabolism and resulting heat production of various cells and tissues of the body the metabolic action of the thyroid hormones is directly related to the regulation of body temperature in mammals.

(2) Regulatory role:-

Thyroid gland also has a second important function, namely a regulatory role, in general process of growth and development of all cells and tissues.

These include the sexual development, maturation of bones and teeth, mental development and energy metabolism etc.

(3) Metamorphosis:-

Apart from carrying out metabolic and regulatory functions, the thyroid hormones also controls some development process.

These hormones stimulate tissue differentiation. In lower vertebrates, they help in metamorphosis (convert larvas into adults). For instance, if thyroid gland of the tadpole larva) is removed the larva fails to change into an adult.

8.5.4.1 Disorder of thyroid secretion

Hypersecretion of T3 and T4 causes Graves disease (exophthalmic goiter). In this condition, the level of thyroxin in blood becomes very high. The thyroid gland swells up, leading to goiter.

- The thyroid secrete excessive amount of thyroid hormones. The condition is characterized by exophthalmia (protrusion of eyeballs).
- Hyposecretion of thyroid hormones in children leads to cretinism. It is characterized by slow body growth reduced metabolism and poor mental development.
- Hyposecretion in adult caused myxedema. It characterized by puffy appearance due to accumulation of fat in the subcutaneous tissue, mainly in throat region.

8.6 Calcitonin

This hormone is secreted by ‘C’ cells of (Parafollicular cells) of thyroid gland.

It is a peptide hormone, containing 32 amino acids.

Function: - The main function of calcitonin is to lower the level of calcium in blood. It can be done in two ways –

- Increasing the deposition of calcium in bones.
- Increasing the excretion of Ca^{2+}ion with urine.
- But calcitonin may help in raising the blood phosphate level.

- ❖ Calcitonin works opposite to parothormoune, which is secreted by parathyroid gland. Both these hormones togenterh regulate the level of calcium and phosphrus in the body.

8.6.1 Parathyroid Glands

These glands are located on the posterior surface of the lobes of the thyroid gland.

They are composed of cords of secretory epithelial cells, separated by small number of fat cells.

The secretory epithelial cells are composed of two types of cells.

(i) Chief cells - which secrete parathyroid hormone and rich in glycogen.

(ii) Oxyphil cells - are rich in mitochondria but lack glycogen.

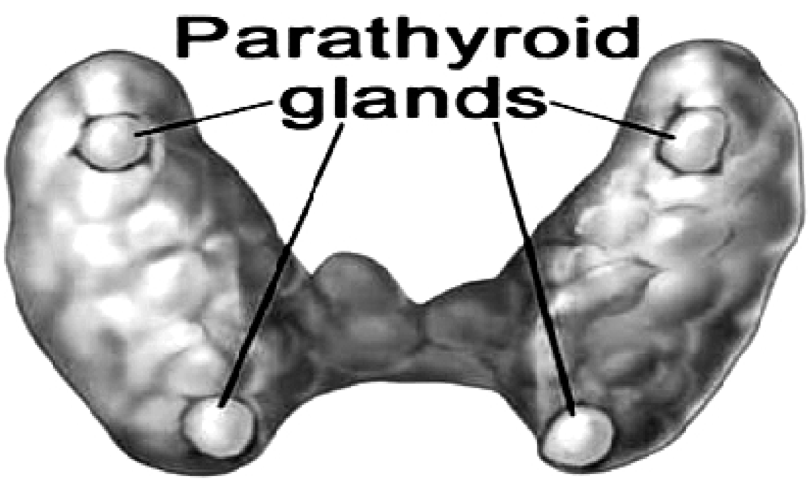


Fig. 8.4 Parathyroid glands

Source: http://www.wikipedia.org

8.6.2 Hormone of parathyroid gland:-

The hormone secreted by parathyroid gland is called parathormone. It plays a central role in calcium metabolism in the body.

<u>Function:-</u> The most important function of Ca^{++} . This hormone helps to regulate the metabolism of calcium and certain other minerals ion in blood plasma.

8.6.3 PTH disorders

(1) <u>Hypoparathyroidism:-</u>

Hyposecretion of PTH results in the lowering of blood calcium level. This increases the excitability of nervous and muscles.

(2) Hyperparathyroidism:-

Since one of the effects of parathormone is to remove calcium from bone, the excess may result in osteoporosis (Fig.8.5).

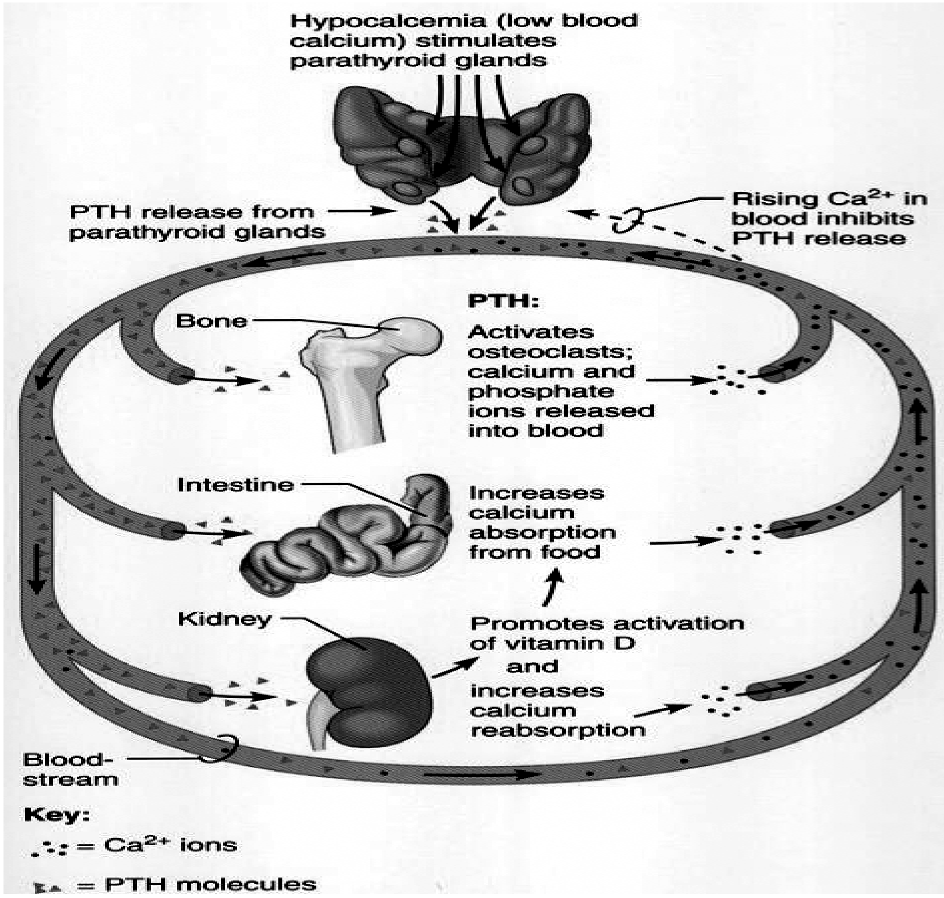


Fig. 8.5 Function of parathyroid gland,
Source: http://www.wikipedia.org

8.7 Pheromones

The term pheromone was coined by Karlson and Luscher (1959) for intraspecific semiochemicals. Semiochemicals are the chemical substance which carry or spread the information. There are three types of semiochemicals.

(1) Pheromones.

(2) Kairomones.

(3) Allomones.

Pheromones:-

Pheromones may be defined as a chemical or mixture of chemicals that are released into environment by an organism and that cause specific behavioural and physiological response in the recepient of the same species.

Important difference between pheromones and hormones

Sl.No.	Pheromones	Hormones
1.	Externally secretory product.	Internally secretory product.
2.	Act between the individuals of colony.	Act with in the individual.
3.	These are species specific.	Not species specific.
4.	Release into the environment.	Release into body fluid.
5.	Released through exocrine glands.	Released through endocrine glands.
6.	Spread out through air into the surrounding	Hormones are transported through the blood.

8.8 Summary

- The brain exerts executive control over the endocrine system via the hypothalamus.
- There are several classes of steroid hormones estrogens, androgens and corticosteroids.
- Estrogens levels are generally higher in females and andgogens higher in makes.
- Hormones of the endocrine system coordinate and control growth, metabolism, many other functions.
- Growth hormone deficiency causes dwarfism while its excessive production results in gigantism (in children) or acromegaly (in adults).
- Cushing's syndrome is due to overproduction of ACTH that results in the increased synthesis of adrenocorticosteroids.
- Deficiency of ADH causes diabetes insipidus, a disorder characterized by excretion of large volumes of dilute urine.
- Thyroid hormones directly influence Na^+, K^+ ATP pump which consumes a major share of cellular ATP.

8.9 Terminal questions

Q. 1: Describe the thyroid and parathyroid glands.

Answer:…………………………………………………………….……
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………………………………………………………………………………
………………………………………………………………………………

Q. 2: Write an essay on hypothalamus.

Answer:……………………………………………………………………..…
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Q. 3: Describe the regulations of anterior pituitary hormones.

Answer:……………………………………………………………………..…
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Q. 4: Describe the regulation of posterior pituitary hormones.

Answer:……………………………………………………………………..…
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Q. 5: Describe the hormonal control mechanism.

Answer:……………………………………………………………………..…
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Q. 6: Describe the structure & function of the thyroid hormones.

Answer:……………………………………………………………………….
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Q. 7: Discuss in detail the steroid hormones.

Answer:……………………………………………………………………….
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Multiple choice questions:-

1. **Which one of the following is called pituitary body:**

   (a) Hypothalamus + Brain

   (b) Hypothalamus + Pituitary gland

   (c) Pituitary gland alone

   (d) Pituitary gland + Brain

2. **Hypothalamus controls and regulates most body activities by integrating the function of:**

   (a) Nervous system

   (b) (b) Endocrine system

   (c) (c) a + b

   (d) (d) Circulatory system

3. **The hypothalamus communicates with anterior pituitary by means of:**

   (a) Axons of neurosecretory cells.

   (b) Infundibulum

   (c) Hypothalamo-hypophyseal portal vein

   (d) All the above

4. **Regulation of adenohypophyseal hormones is under control of:**

   (a) Brain

   (b) Cortex

   (c) Medulla

   (d) Hypothalamus

5. **Master gland of body is:**

   (a) Liver

   (b) Pancreas

   (c) Pituitary

   (d) Thyroid

8.10 Answers

1 – (b)

2 – (c)

3 – (c)

4 – (d)

5 – (c)

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