

05

Animal form and function

Relate the Structure of Animal Tissues to their function

There are four major types of animal tissues : Epithelial tissue, Connective tissue, Muscle tissue and Nervous tissue.

1. Epithelial tissue: -

Characteristics

It covers external or internal free surfaces and organs. The cells of the tissues are closely packed. Cells of epithelial tissue have both apical and basal surfaces where apical surface remains free and the basal surface attached to the basement membrane. No blood vessels in the tissue. Tissue gets nutrients and oxygen from the underneath connective tissue.

Functions-

- Protection (e.g. barrier against mechanical injury, pathogens, barrier against fluid loss)
- Secretion (e.g. enzymes, hormones, mucus, sweat)
- Absorption (e.g. nutrients, respiratory gases)

There are two general types according to the number of cell layers on the basement membrane.

- Simple epithelia – Single cell layer (e.g simple squamous, simple cuboidal, simple columnar and pseudostratified)
- Compound epithelia – several cell layers (e.g. stratified squamous, transitional)

Simple squamous epithelium –

It is a single layer with plate like cells. This type of epithelium is thin and leaky. They are found in places where materials exchange by diffusion.

e.g: blood capillaries, alveoli,

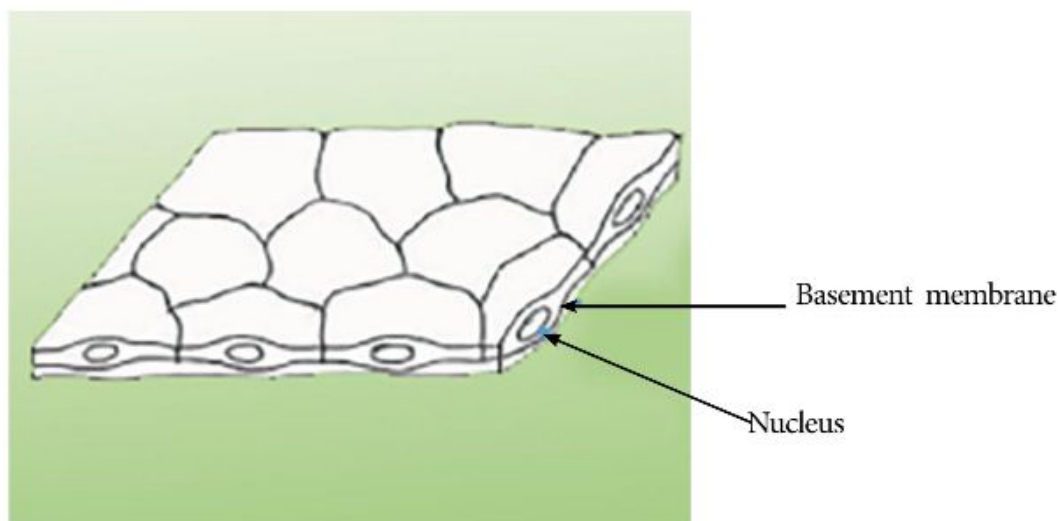


Fig 5.1: simple squamous epithelium

Simple cuboidal epithelium –

It is a single cell layer with dice shaped cells specialized for secretion. It is found in kidney tubules, many glands such as thyroid glands and salivary glands

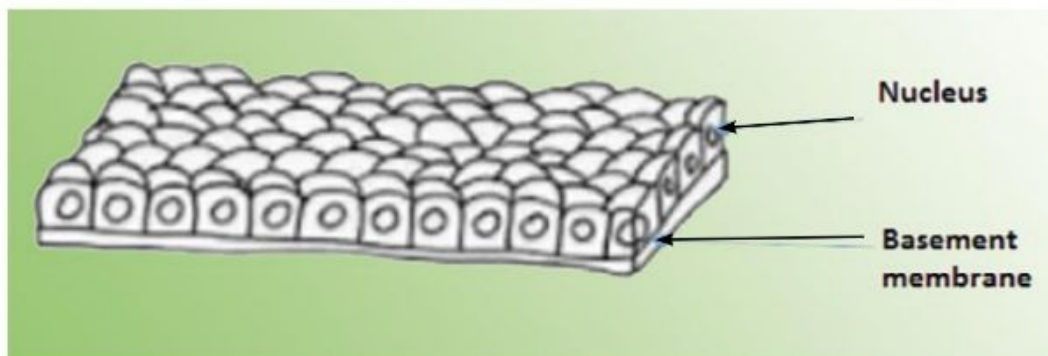


Fig 5.2: simple cuboidal epithelium

Simple columnar epithelium

It is a single layer with large and brick-shaped cells. It is often found in places where secretion or active absorption is important. e.g. intestinal lining

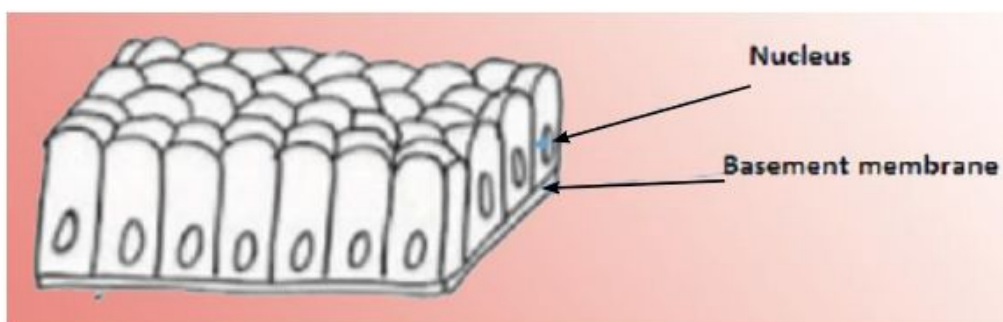


Fig 5.3 : simple columnar epithelium

Pseudostratified columnar epithelium

This tissue consists of a single cell layer. Cells are not of equal height. Nuclei of cells are located at different level. Appear as several layers. In many vertebrates this epithelium has ciliated cells that form a mucous membrane and the cilia help to sweep the mucous along the surface. e.g. nasal passage, trachea.

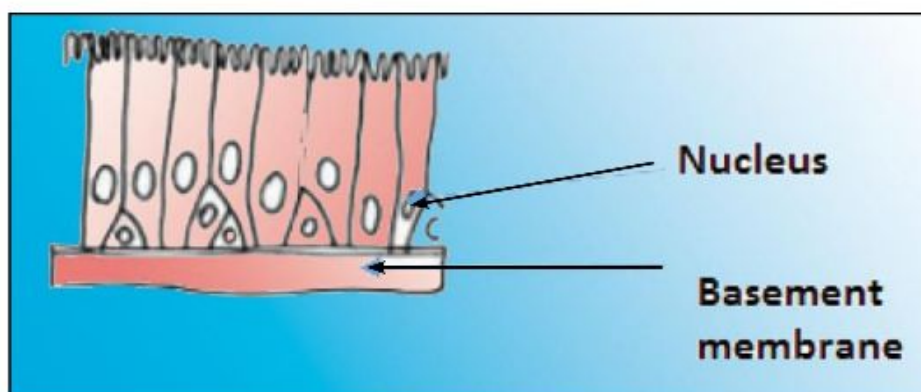


Fig 5.4 : Pseudostratified squamous epithelium

Compound epithelia –**Stratified squamous epithelium:**

This tissue is composed of a number of layers of cells. This epithelium regenerates rapidly. Cell division produces new cells near the basement membrane. The old cells are sloughed off and replaced by the new cells. This epithelium is found on surfaces where they are subjected to abrasion such as outer skin, lining of mouth, anus, vagina

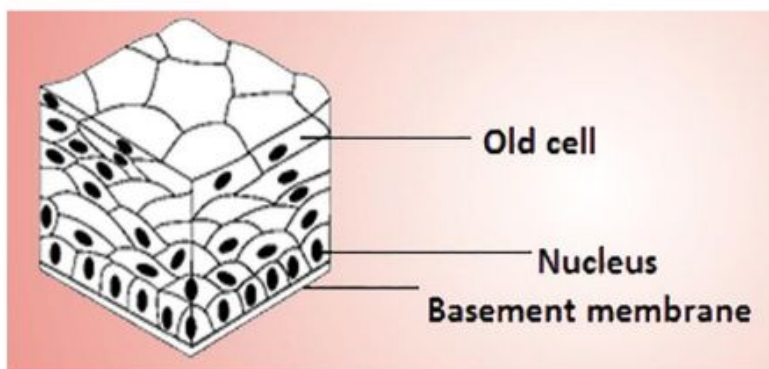


Fig 5.5: Stratified squamous epithelium

2. Connective tissue**Characteristics**

Connective tissues are the most abundant tissues in the body that help to connect organs and tissues together structurally and functionally. These types of tissue consist of different types of cells scattered in a large amount of extracellular matrix containing different types of fibres. Matrix may be a semisolid (Jelly-like), liquid or

solid (dense and rigid). Different types of cells can be found in the matrix such as fibroblasts (secrete fiber proteins), macrophages (engulf foreign particles or any cell debris by phagocytosis) and mast cells (secrete heparin and histamine) in addition fat cells (storage and insulation) and leukocytes (protection) are found in some connective tissues.

There are three different types of fibers. They are collagen fibers (provide strength and flexibility), reticular fibers (join connective tissues to adjacent tissues) and elastic fibers (make tissue elastic).

Functions

- Binding and structural support
- Protection
- Transport of materials
- Insulation

There are different types of connective tissues. They are loose connective tissue (Areolar tissue), Fibrous connective tissue (Dense connective tissue), adipose tissue, blood, cartilage and bone .

Loose connective tissue (Areolar Tissue)

This tissue is the most widely distributed connective tissue type in the vertebrate body. This can be considered as the generalized type of connective tissue. Types of cells in this tissue are fibroblasts, macrophages, mast cells, leukocytes and fat cells.

All three types of fibres are found in this tissue. Fibers are loosely arranged and wavy in nature. This tissue binds epithelia and the underlying tissue. Therefore this holds organs in place. This tissue is found under the skin and throughout the body.

Fibrous connective tissue (Dense connective tissue)

This tissue is densely packed with collagen fibers. Therefore the matrix is relatively reduced and contains fewer cells (fibrocytes). This tissue is found in tendons (attach muscle to bones) and ligaments (connect bones and joints) where tensile strength is required.

Adipose tissue

This tissue is packed with adipose cells. Each adipose cell contains a large fat droplet. This is a specialized type of loose connective tissue which pads and insulates the body and stores fuel as fat molecules. For instance, it is found under the skin where it act as a thermal insulator and energy store.

Blood tissue

It is a specialized connective tissue where the matrix is not secreted by the cells and fibers are formed only during blood clotting process. The extracellular matrix of the blood is liquid. It is called as plasma. The blood plasma contains salts, water and dissolved proteins. Red blood cells (transport respiratory gases), white blood cells (defense) and platelets (blood clotting) are suspended in the blood plasma. Main functions of blood tissues include transport of materials, protection, and osmoregulation. (For further details refer pg 195)

Cartilage

This tissue consists of a matrix composed of chondroitin sulphate which is a rubbery protein-carbohydrate complex. Collagen fibers and chondrocytes are embedded in the matrix. Chondrocytes secrete chondroitin sulphate and collagen fibers. This tissue provides support and flexibility in places such as trachea, intervertebral discs.

Bone

It is a mineralized connective tissue. Matrix consists of collagen fibres and inorganic salts. Inorganic salts are Calcium, magnesium and phosphate ions. Cells are osteoblasts (bone forming cells) and osteocytes (mature bone cells that maintain bone tissue). Osteocytes are enclosed within lacunae. The mammalian hard bone has repeating units called osteons. Each osteons has a concentric layer of mineralized materials. At the centre of the osteon is a central canal containing blood vessels and nerves. This tissue forms the endoskeleton of most vertebrates and provides support and strength to the body.

3. Muscle tissue

Muscle tissue is responsible for movement. The cells in the muscle tissue are composed of actin and myosin proteins. This tissue is able to contract and relax. There are three basic types of muscle tissues found in the vertebrate animal body. They are smooth muscle, skeletal muscle and cardiac muscle tissues.

Smooth muscle tissue

The cells of the smooth muscle tissue are spindle shaped and uninucleated. Cells lack striations. This tissue is responsible for involuntary body functions (e.g. churning of stomach, constriction of arteries). This tissue is found in digestive tract, urinary bladder, arteries and other internal organs.

Skeletal muscle tissue

They are composed of bundles of long cells with multi nuclei. Cells are striated. The contractile units of this muscle cells are called sarcomers. This gives the striated appearance to the muscle cells. The arrangement of the sarcomere gives the striated appearance. The muscles are generally attached to the skeletal system and helps mainly in voluntary body movements.

Cardiac muscle tissue

They are composed of uninucleated cells which are interconnected via intercalated discs. Cells are striated with sarcomeres. Cardiac muscle tissue is responsible for involuntary heart contractions. Intercalated discs help relay signals from cell to cell and synchronize heart contraction. Cardiac muscle tissue is only found in the wall of the heart.

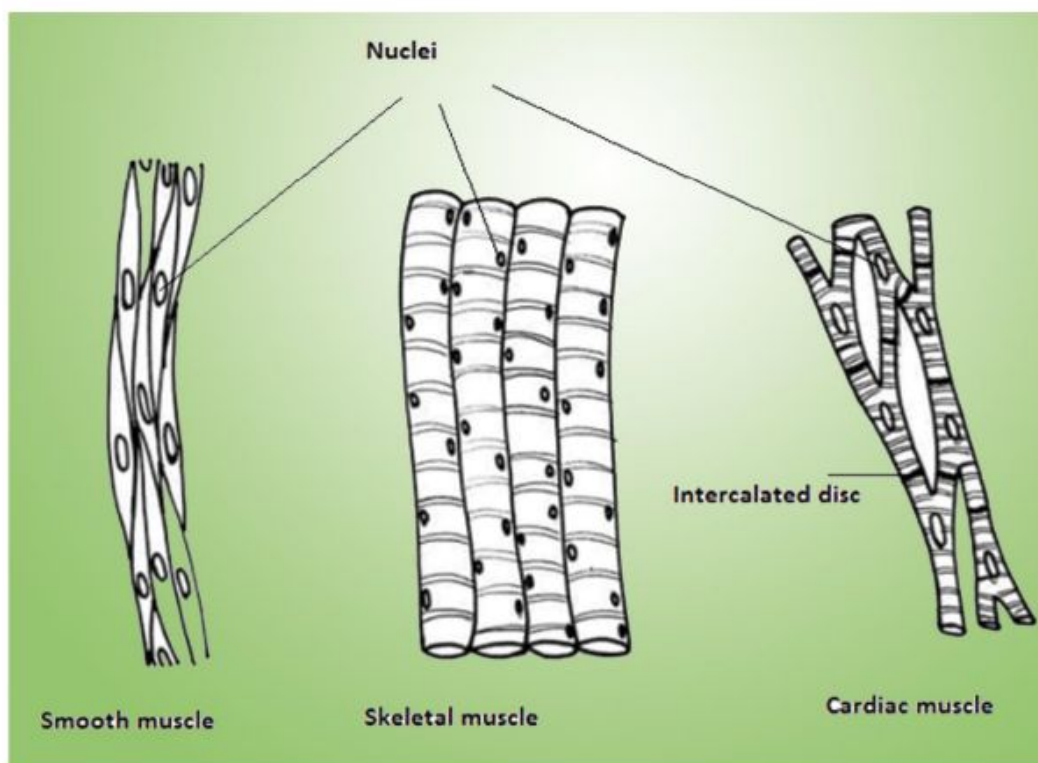


Fig 5.6: Muscle tissue

4. Nervous tissue

Nervous tissue contains neurons and glial cells. Neurons receive, process and transmit nerve impulses. Neuroglia (Glial cells) support the neurons.

Neurons: A neuron has cell body, dendrites and axon. The basic structural unit of the nervous system is the neuron. Dendrites and cell body is used to receive nerve impulses from other neurons. Axon is used to transmit impulses to other neurons, cells or muscles. Axons are bundled together into nerves.

Neuroglia (Glial cells): Neuroglial cells are supportive cells of neurons. Their functions include nourishment of nerve cells, insulation of nerve cells, replenishing neurons and sometimes modulate neuron functions.

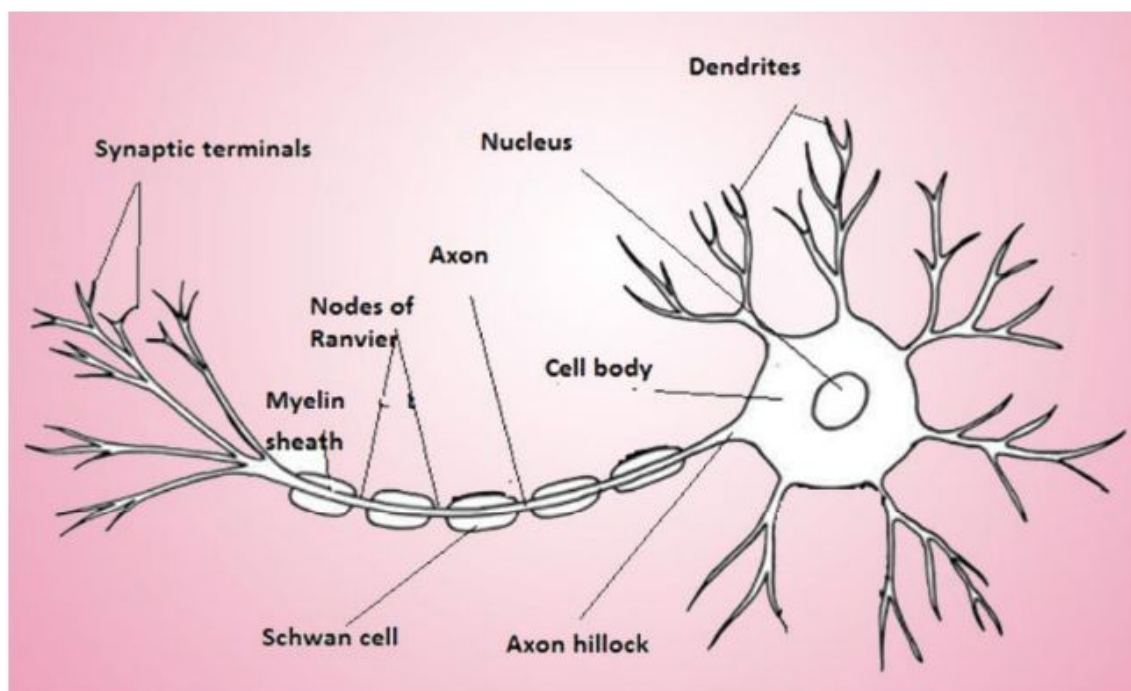


Fig 5.7: The structure of the Motor neuron

Nutrition in animals

Animal nutrition is the process by which food is taken in for make use in different body functions. Typically food is broken into smaller molecules and absorbed prior to utilization. Animals are heterotrophs.

Heterotrophic nutrition is the process by which the organisms obtain organic food molecules by ingesting other organisms or by substances derived from other organisms. Other than animals, fungi and majority of bacteria are heterotrophs. There are two type of heterotrophic nutrition namely, holozoic nutrition and symbiosis.

Holozoic nutrition

Most animals are holozoic where they ingest food into their alimentary canal. This mode of nutrition consists of five main stages: Ingestion, digestion, absorption, assimilation and elimination/ Egestion.

Main stages in holozoic nutrition

- **Ingestion:** This is the first stage where the act of eating or feeding happens. Food sources differ among animal species and they possess different modes of ingestion according to the diet or environment.
- **Digestion:** Food is broken down into molecules small enough to pass through the membranes and enter the cells of organisms. Digestion could occur mechanically (by teeth or muscle contractions) and chemically (by enzymes). During mechanical digestion, food is broken down in to smaller fragments thus increase the surface area for efficient chemical digestion. During chemical digestion enzymes break bonds in large molecules into small molecules.

The last two stages of food processing occur after the food is digested.

- **Absorption:** In this stage, the animal's cells take up small molecules. e.g. simple sugars, amino acids
- **Assimilation:** Assimilation is the process of utilization of absorbed nutrients for various functions of the body.
- **Elimination:** In this process undigested materials are passed out from the alimentary canal.

Feeding Mechanisms of animals

- **Filter feeders:** They strain suspended food particles from the surrounding watery medium. They use several mechanisms such as capturing, trapping, etc.
e.g. - clams and oysters - feed on small pieces of food in the water that passes over their gills. Cilia in the gills sweep the food particles to the animal's mouth in a film of mucus.

- **Fluid feeders:** They suck nutrient rich fluid from a living host using well adapted mouth parts.
e.g: Mosquitoes-suck human blood, Aphids- suck phloem sap of plants, Bees and humming birds suck -honey from flowers
- **Substrate feeders:** These animals live inside their food source or on the food source eating its way through the food.
e.g. The leaf miner caterpillar - eating through the soft tissues of a leaf
Maggots (fly larvae) - burrow into animal carcasses
- **Bulk feeders:** Animals which eat comparatively large pieces of food. These animals have different types of adaptations to tear the food or to capture the prey (e.g. jaws, teeth, tentacles, claws, poisonous fangs).
e.g. - Most animals including human

- **Symbiosis**
This is an ecological relationship between organisms of two different species that live closely together. It is divided into three groups such as Mutualism, Parasitism and Commensalism

- **Mutualism:** It is a close association between two living organisms of different species which benefits both partners.
e. g. - Cellulose digesting microorganisms in Ruminants and Termites

- **Parasitism:** It is a close association between two living organisms of different species which is beneficial to one (parasite) and harmful to the other (host). Parasites live either within or on the host and derive its nourishment
e.g. –Tape worm and humans, Lice and humans

- **Commensalism:** It is a close association between two living organisms of different species which is beneficial to one and does not affect the other (neither harmful or beneficial)
e.g.- Barnacles attached to whales

Human Digestive system

Structure and function of the human digestive system

Human alimentary canal is a long tube/ tract which connects with external environment and can fulfill steps of holozoic mode of nutrition. Human digestive system consists of alimentary canal and associated glands. The alimentary canal consists of the following parts: oral cavity, pharynx, esophagus, stomach, small intestine, large intestine, rectum and anus. The associated glands include salivary glands, pancreas and liver.

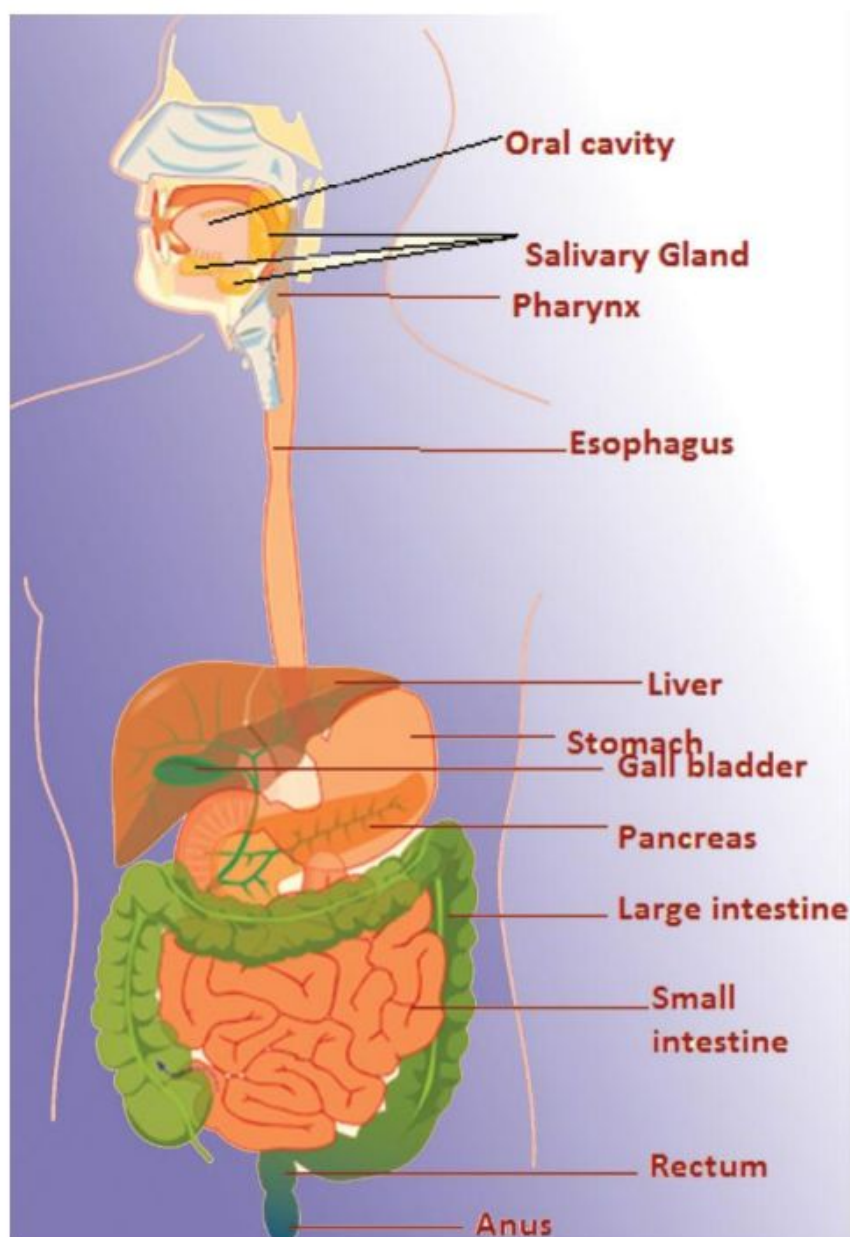


Fig 5.8 :- Structure of the Human Digestive tract

Mouth/ Oral cavity: Oral cavity consists of the tongue, teeth and salivary glands. Ingestion and initial steps of digestion are carried out in the oral cavity. In the mouth both mechanical and chemical digestion is carried out. There are four types of teeth in the mouth: incisors, canines, premolars and molars. Food is cut, mashed and ground by different types of teeth with different shapes. This makes it easier to swallow food and increase the surface area for digestion.

Salivary glands release saliva into the oral cavity through ducts. Releasing saliva into the oral cavity occurs when food enters the oral cavity due to a nervous reflex. Saliva is also released into the mouth before food is ingested due to various other stimuli. e.g. sight, odor of food, etc.

Saliva contains water, amylase, mucus (a viscous mixture of salts, cells and slippery glycoprotein called mucins). In addition to that, saliva composed of buffers and anti microbial components.

Functions of the saliva

- Salivary amylase: Chemical digestion of polysaccharides (e.g. starch) into smaller polysaccharides and disaccharide maltose.
- Water: Liquefy food and provide watery medium for chemical digestion. Aids in taste reception.
- Mucus: Lubrication of food which makes it easier for swallowing. Clean the mouth and protects the lining of the mouth from abrasion.
- Antimicrobial substances such as immunoglobulin and lysozymes: Protect against bacteria that enter the mouth.
- Buffers prevent tooth decay by neutralizing acid

Tongue: composed of skeletal muscles. Helps to mix the food with saliva and make bolus of food that makes easier for swallowing. Then helps to push the bolus into the posterior part of the oral cavity and into the pharynx.

Pharynx: a common passage of the respiratory tract and the digestive tract. The pharynx leads to the esophagus.

Esophagus:

It is a long tube which connects the pharynx and the stomach. It is found in the thoracic cavity. The wall of the esophagus consists of both skeletal and smooth muscles. The skeletal muscles are located towards the uppermost part of the esophagus and these muscles function during swallowing. The rest of the esophagus consists of smooth muscles which are involved in the process called peristalsis. During this process the food bolus is pushed along the esophagus which is a alternative wave of rhythmic contractions and relaxations of the smooth muscles lining the esophagus.

Stomach- The stomach is a J- shaped dilated sac in the abdominal cavity. The inner surface of the stomach is highly folded and contains large number of pits that leads to gastric glands. Gastric glands contain three types of cells: mucus cells, chief cells and parietal cells. The stomach wall is very elastic. Distal part of the stomach connects with the small intestine. Sphincters are found at the junctions between esophagus and stomach (cardiac sphincter) and stomach and the small intestine (pyloric sphincter). They are made up of circular smooth muscles. These sphincters help to regulate the passage of materials between these organs.

Chemical digestion in the stomach

The gastric glands of the stomach secrete gastric juice. The gastric juice mainly consists of mucus, pepsinogen and HCl. Mucus and pepsinogen (inactive form of pepsin) are secreted by mucous cells and chief cells respectively. The parietal cells release hydrogen ions and chloride ions separately into the stomach lumen where HCl is formed. Pepsinogen is initially converted into pepsin by HCl. These activated pepsin help to activate remaining pepsinogen molecules. This activated pepsin initiates the chemical digestion of proteins in the stomach. The churning action of the stomach facilitates the chemical digestion. This is a series of muscle contraction and relaxation. This process mixes the swallowed food with gastric juice. Proteins are hydrolyzed to small polypeptides by pepsin. In the stomach food is mixed with gastric juice forming chyme (partially digested semisolid, acidic, food mass).

The stomach lining is protected from the digestion of HCl and pepsin in several ways: Enzymes are secreted in to the lumen as an inactive enzyme; Gastric glands secrete mucus that protect against self-digestion of the stomach lining; Every three days, cell division adds a new epithelial cell layer which replaces the destroyed/ damaged cells in the lining of the stomach.

Functions of the stomach

- Act as a temporary reservoir for food due to high convolution and very elastic wall.
- Mechanical digestion of food by churning action due to muscular contraction.
- Produce gastric juice which starts the chemical digestion of proteins to polypeptide by pepsin
- Absorption of some materials such as water, alcohol and some drugs
- Non specific defense-HCl kills microbes
- Small jets of gastric contents push out through pyloric sphincter as chyme
- Secretion of gastrin hormone which regulates digestion in the stomach.

Small intestine-

It is the longest organ in the alimentary canal. It is divided into three regions: duodenum, jejunum and ileum. The duodenum: C shaped curve, around the head of the pancreas. The jejunum is middle part of the small intestine. The ileum is the terminal part of the small intestine. The surface area of the small intestine is greatly increased by permanent circular folds and villi. The villi are tiny finger like projections of the intestinal wall. Most of the digestion is completed in the duodenum. The major sites for nutrient absorption are jejunum and ileum.

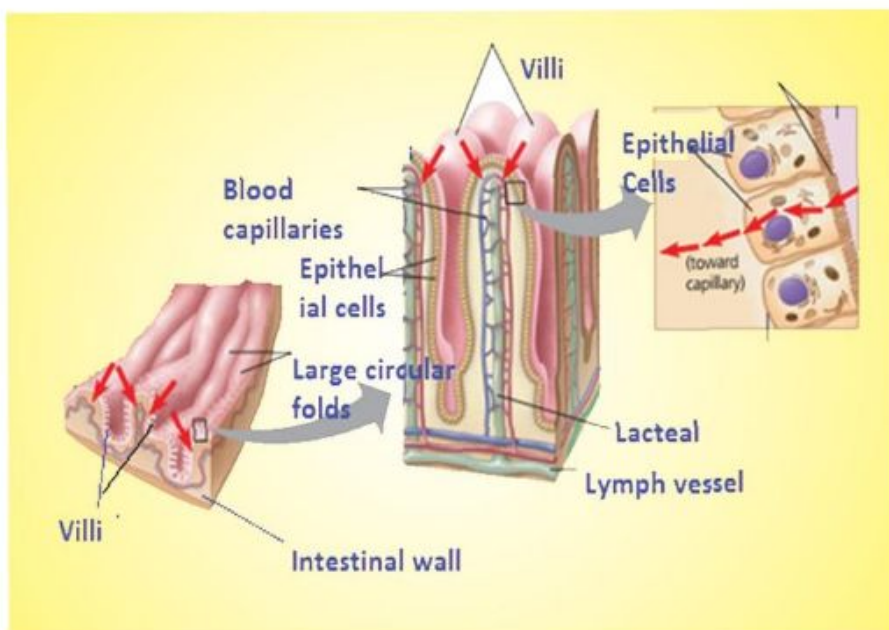


Fig 5.9 Structure of the villus

Chemical digestion in the small intestine

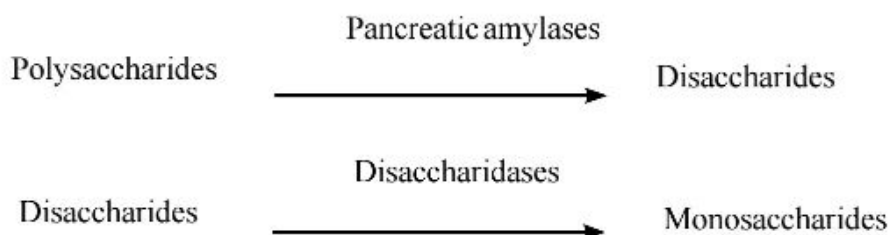
Small intestine receives chyme from the stomach. Peristaltic contractions aid the receiving of this chyme. Pyloric sphincter regulate the passing of chyme into the small intestine. The chyme is mixed with secretions of glands in intestinal wall and secretions of pancreas and liver. (refer pages no: 169,170). The epithelium of the duodenum secretes several digestive enzymes. Glands of the intestinal wall secrete enzymes such as Disaccharidases, Dipeptidases, Carboxypeptidases, Aminopeptidases, Nucleotidases, Nucleosidases and Phosphotases. Some of these enzymes are secreted to the lumen and others are bound to the surface of the epithelium.

Two hormones namely cholecystokonin and secretin secreted by duodenum stimulates the release of pancreatic juice and the bile. Pancreatic juice contains enzymes such as Trypsin, Chymotrypsin, Pancreatic amylase, Pancreatic Carboxypeptidases, Pancreatic Nucleases and Pancreatic Lipases. In addition it also contains bicarbonates. The liver secretes Bile which is stored in the gall bladder until released into the duodenum.

The Bile contains Bile salts which act as emulsifiers that help in fat digestion and absorption.

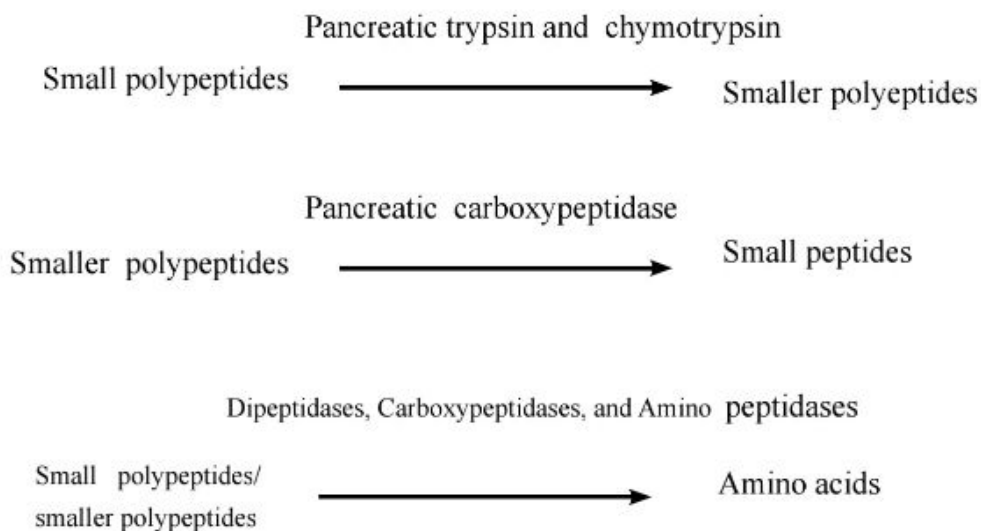
Carbohydrate digestion

Pancreatic amylase catalyze the conversion of polysaccharides (e.g. starch) into disaccharides. Intestinal disaccharidases catalyze the conversion of disaccharides into monosaccharides.



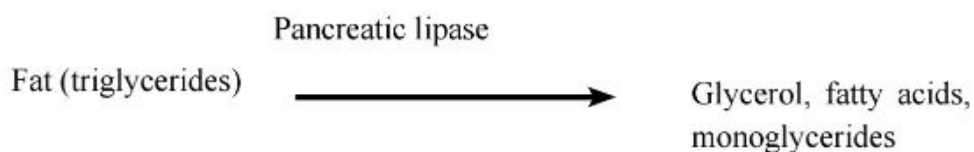
Protein digestion

Trypsin and Chymotrypsin catalyse the conversion of small polypeptides into smaller polypeptides. These smaller polypeptides are converted to small peptides and amino acids by the catalytic action of Pancreatic carboxypeptidases. Proteases secreted by the intestinal epithelium (Dipeptidases, Carboxypeptidases and Aminopeptidases) catalyse the conversion of small peptides into amino acids.

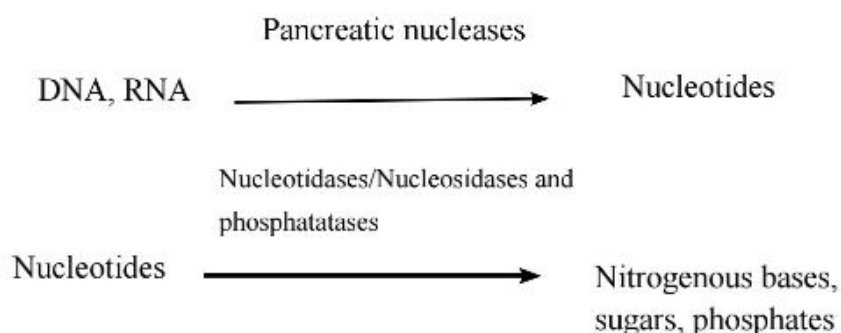


Fat digestion

Digestion of fats (triglycerides) starts in the small intestine. First bile salts emulsify fats. Next Pancreatic lipase catalyse the conversion of these fats into fatty acids, glycerol and monoglycerides.

**Nucleic acid digestion**

Digestion of nucleic acids start in the small intestine. Pancreatic nucleases catalyse the conversion of DNA and RNA into nucleotides. These nucleotides are eventually converted into nitrogenous bases, sugars and phosphates by the catalytic action of intestinal Nucleotidases, Nucleosidases and Phosphatases.

**Absorption in the small intestine**

- For effective absorption, the surface area of the intestinal wall has been increased with three structural modifications: heavy permanent foldings, finger like projections called villi in the intestinal wall and finger like microscopic projections called microvilli in the epithelial cells of the villi. These micro villi are exposed into the intestinal lumen, it gives the appearance of brush (brush border).
- Transport of the nutrients across the epithelium may be active or passive. For example Fructose is absorbed by facilitated diffusion. Amino acids, small peptides, vitamins, and most glucose molecules are actively transported into the epithelial cells.
- Then these nutrients from the epithelial cells are transported into the blood capillaries in the villi. Those blood capillaries are converged into the hepatic portal veins. These nutrients are carried in to the liver via the hepatic portal veins. From the liver, this nutrient filled blood is transported into the tissues.
- But absorption of some products of fat digestion takes place in a different pathway: Fatty acids and monoglycerides are absorbed into the cell through microvilli. Within the cells triglycerides are reformed and they are incorporated into water soluble globules called chylomicrons. These chylomicrons are transported into the lacteal and then into the blood vessels through lymph. Then they are transported throughout the body via the circulatory system.

- In addition to nutrient absorption, recovery of water and ions mostly occur in the small intestine. In addition to the water intake (about 2 L) digestive juices add more water (about 7 L) into the small intestine. Most of this water is reabsorbed via osmosis.

Large intestine – The large intestine is the terminal end of the alimentary canal. It is divided into three regions: colon (proximal part), cecum and rectum. The small intestine is connected to the large intestine at a 'T' shaped junction. One arm of the 'T' junction is colon and the other arm is a small pouch called cecum. A finger like projection in the cecum is called the appendix. The colon leads to the rectum and anus. Cecum is important for fermentation of indigested materials by microbes, especially in animals that eat large amount of plant matter.

Functions of the large intestine

- The colon: completes the reabsorption of water, synthesize some Vitamin B complexes, Vitamin K and folic acid with the help of microbes and move feces (consists of undigested matter such as fibres) along the colon by peristalsis.
- The rectum stores feces until they are eliminated. Presence of two sphincters between the rectum and anus can regulate feces movement. Strong contractions in the colon trigger the defecation.

Associated glands

Pancreas

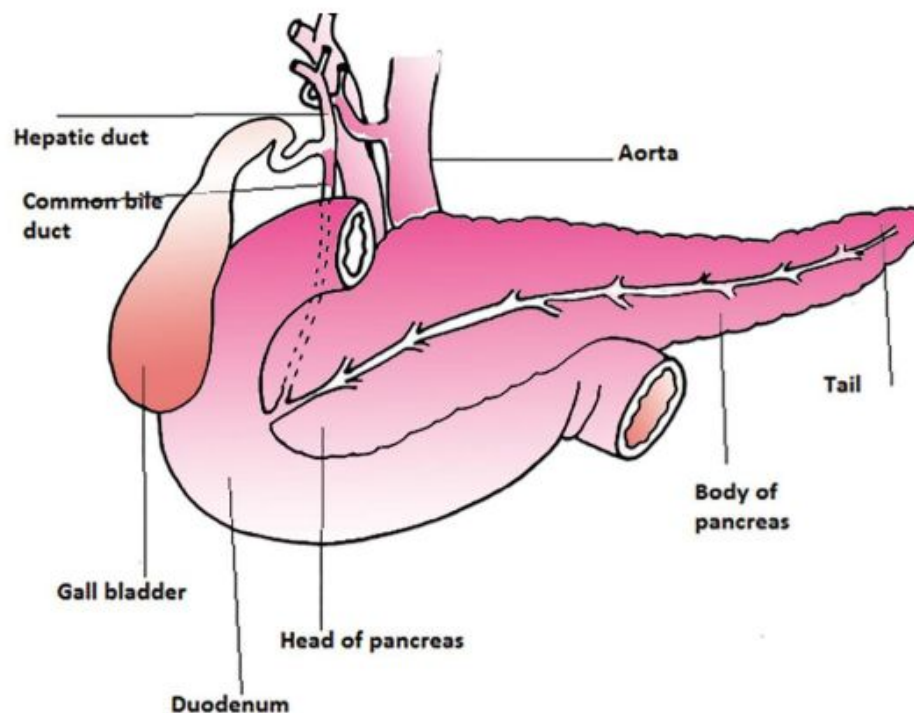


Fig 5.10: The pancreas in relation to the duodenum and biliary tract

Histological structure of pancreas

The pancreas is a pale grey gland which consists of a broad head, a body and a narrow tail. Head is in the curve of the duodenum. Pancreas is both an exocrine and endocrine gland.

The exocrine part consists of a large number of lobules made up of small acini, the walls of which consist of secretory cells. Each lobule is drained by a tiny duct and these unite eventually to form the pancreatic duct which joins with bile duct to form hepato pancreatic duct and opens into the duodenum at its midpoint. Exocrine part of the pancreas secretes pancreatic juice. The components of the pancreatic juice are bicarbonate, carbohydrate digesting enzymes (pancreatic amylase), pancreatic lipase, nucleases and inactive form of protein digesting enzymes (trypsinogen and chymotrypsinogen). These inactive enzymes are converted to active enzymes (trypsin and chymotrypsin) upon secretion into the lumen of the duodenum.

Endocrine part of the pancreas is the islets of Langerhans, which consist of group of specialized cells. They do not have ducts. Islets of Langerhans secrete hormones, glucagon and insulin which are involved in glucose homeostasis.

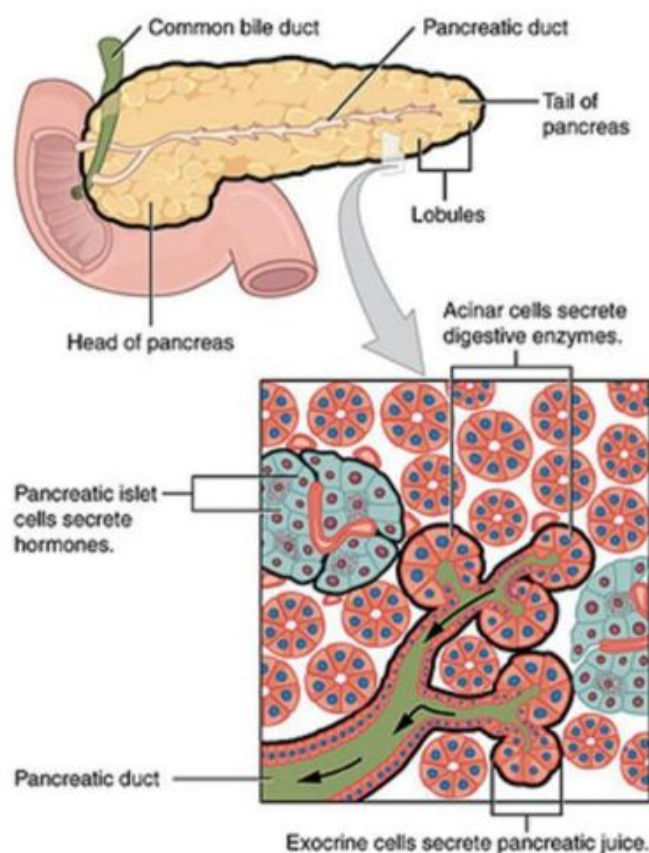


Fig 5.11: Histological structure of the pancreas

Liver

Liver is the largest gland in the body. Its upper and anterior surfaces are smooth and convex. Its posterior surface is irregular in outline. Liver contains four lobes. Each lobe is made up of tiny hexagonal shape lobules which are the functional unit. These lobules are made up of cuboidal cells called hepatocytes which are arranged in pairs of columns radiating from a central vein. Between two pairs of column of cells there are sinusoids (blood vessels with incomplete walls) containing mixture of blood from the tiny branches of the portal vein and hepatic artery. This arrangement allows venous blood (high concentration of nutritional materials) to mix with arterial blood and come into close contact with liver cells. Hepatic macrophages (Kupffer cells) are found in the lining of the sinusoids. Blood drains from the sinusoids into central veins which joins with veins from the other lobules, forming larger veins and eventually the hepatic vein. (fig 5.12). Bile canaliculi run between columns of liver cells. Canaliculi join up to form larger bile canals. In the corner of the hexagonal structure a branch of hepatic artery, a branch of the hepatic portal vein and intra lobular bile duct can be found.

Liver is a vital organ that performs many important functions. In addition to its role in food digestion it is also perform functions such as metabolism of carbohydrates, fats and proteins, detoxification of drugs and toxic substances, defense against microbes, some hormone inactivation and heat production.

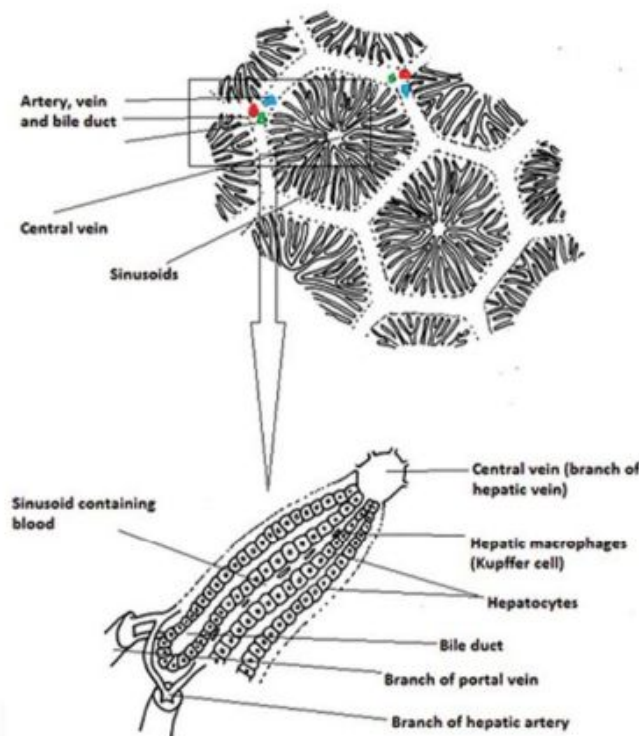


Fig 5.12: Histological structure of the liver

Function of liver related to digestion

The liver secretes bile which is stored in the gall bladder until released into the duodenum. The bile contains bile salts which act as emulsifiers that help in fat digestion and absorption.

Most of the absorbed nutrients reach the liver and it regulates the distribution of nutrients to the rest of the body. Excess glucose is stored as glycogen in the liver cells. Glycogen deposition and break down in the liver cells are regulated by insulin and glucagon hormones. Fat soluble Vitamins (A,D,E and K) and some water soluble vitamins (B12), iron and copper are also stored in liver.

Regulation of digestion in man

Digestion in man is regulated by two ways: nervous regulation and endocrine regulation. Nervous regulation is mainly by nervous reflexes. For example nervous reflex stimulates the release of saliva when food reach the mouth. Arrival of food in the stomach trigger churning and release of gastric juices. Endocrine system plays a critical role in digestion especially in the stomach and small intestine.

when food arrives the stomach, the stomach wall is stretched. This triggers to release the hormone gastrin. Gastrin circulates via the blood stream and arrives the stomach. Then gastrin stimulates the production of gastric juice at the stomach.

Fatty acids and amino acids in the chyme trigger the release of Cholecystokinin and Secretin from the duodenum. Cholecystokinin triggers release of bile from the gall bladder and digestive enzymes from the pancreas. Secretin stimulates the release of bicarbonate from the pancreas. Bicarbonate neutralize the chyme received from the stomach

When the chyme is rich in fat, food digestion in the stomach slows down due to high levels of Cholecystokinin and Secretin secreted by duodenum. These hormones act on the stomach and inhibit peristalsis and gastric juice secretion.

Balanced Diet

The balanced diet contains the all essential nutrients required for health in the appropriate proportions. Essential components of the balanced diet contain carbohydrates, proteins, lipids, fibers, minerals, vitamins and water. Carbohydrates and lipids supply energy. Energy requirements vary with age, sex, body size and activity. Twenty amino acids are needed to synthesize proteins in the body. Most of these amino acids are synthesized within the body. They are known as non essential amino acids (e.g. Alanine, cystine, etc). Other amino acids (e.g. lysine and histidine, etc.) must be obtained from the diet as they can't be synthesized within the body. They are called essential amino acids. Animal proteins contain all the essential amino acids in proper proportions. However most plant proteins lack one or more essential amino acids. Therefore vegetarian based diet requires several sources of plant proteins to obtain all the essential amino acids.

Components of foods and their functions

- Carbohydrates
- Proteins
- Lipids
- Vitamins
- Mineral elements
- water
- fibers

Carbohydrates

Carbohydrates are sugars and polysaccharides. They can be found in a variety of foods such as rice, bread, biscuits, cereals, hoppers, etc. during digestion most carbohydrates are broken down into monosaccharides which are absorbed into blood stream.

Functions of digestible carbohydrates

- Provide energy and heat: breakdown of carbohydrates provides ATP for body functions and generates heat.
- Act as an energy stores. e.g. excess carbohydrates are converted into glycogen and fat
- Facilitates protein sparing- proteins are not used to get energy when there is an adequate carbohydrates in the food

Proteins

Proteins are made up of amino acids during the digestion, proteins are broken down into amino acids and absorbed into the blood stream.

The amino acids are grouped into two groups i.e. essential amino acids and non essential amino acids. These essential amino acids cannot be synthesized in the body, therefore they should be obtained into the body through the diet. The non essential amino acids can be synthesized within the body. Therefore it is not necessary to obtain them through the diet.

Functions of proteins in the diet

- The amino acids which are supplied from proteins
 - are used for growth and repair of body cells and tissues
 - are used for synthesis of plasma proteins, enzymes, antibodies and some hormones
- Act as an energy source for body functions

Lipids

Lipids in the diet are mainly composed of fats and oils. Fatty acids are composed of fats and oils. Fatty acids can be grouped as essential and non essential fatty acids. Essential fatty acids cannot be synthesized within the body while the non essential fatty acids can be synthesized within the body. Therefore essential fatty acids should be obtained through the food.

Functions of lipids in the diet

- Provide energy and heat (on weight basis fats and oils provide more energy compared to carbohydrates and proteins)
- Help in transport and storage of fat soluble vitamins such as Vitamin A, D, E and K
- Store energy as fat in the adipose tissues
- Help to synthesize steroid hormones from cholesterol.
- Provide insulation: (e.g fat found in subcutaneous layer in the skin reduces heat loss , constituents of myelin sheath of neurons)

Vitamins

Vitamins are organic compounds required in small amounts for the maintenance of normal health and metabolism. Vitamins cannot be produced in the body and therefore should be provided in the diet. If the vitamins are insufficiently taken into the body, that may lead to the deficiency diseases. Vitamins are two types they are fat soluble vitamins (Vitamin A, D, E and K) and water soluble vitamins (Vitamin B and C).

Main Functions of Vitamins

- Vitamin A- form visual pigments in the eye, epithelial tissue maintenance, promotion of growth and immunity
- Vitamin B- components of coenzymes such as FAD and NAD, promote red blood cell production
- Vitamin C- act as an antioxidant, used in collagen synthesis
- Vitamin D- aids in absorption and use of Calcium and Phosphorous
- Vitamin E- act as an antioxidant
- Vitamin K- important in blood clotting

Minerals

Minerals are inorganic substances and they are also important for normal health and many body functions. Major mineral elements needed by humans are Ca, P, S, K, Cl, Na, Mg, Fe, F and I . In addition minerals needed in trace amounts include Co, Cu, Mn, Mo, Se and Zn.

Main functions of minerals include

- Ca- form bones and teeth, helps clotting blood and nerve and muscle function
- P- form bones and teeth, help maintain in acid base balance
- S- components of some amino acids
- K- help maintain in acid base balance and water balance, nerve function
- Cl- help maintain in acid base balance, maintain osmotic balance, nerve function
- Na- help maintain in acid base balance and water balance, nerve function
- Mg- act as enzyme cofactor
- Fe- components of hemoglobin and electron carriers, act as an enzyme cofactor
- F- maintenance of tooth structure
- I- component of thyroid hormone

Water

Water accounts for around 60% of the body mass in humans. Normally water is lost through urine, sweating and feces. Therefore amount of water in the body should be balanced within the body. This water can be taken in to the body by drinking and via foods.

Functions of water in human body

- Provides the moist internal environment for all living cells.
- Major component of blood and tissue fluid therefore helps to transport materials around the body and to exchange materials between blood and tissues and body cells
- Regulate body temperature mainly through evaporative cooling
- Dilute waste products and toxins and provide a medium for their excretion
- Moistens the food and that make easier to swallow

Fibres

Dietary fibres (non starch polysaccharides) are made up of indigestible polysaccharides in the diet. Fibres are rich in fruit, vegetable and cereals.

Functions of dietary fibres

- Provide bulk to the diet and satisfy the appetite.
- Prevent constipation by attracting water to increase faecal bulk and stimulating peristalsis leading to defecation.
- Adequate fibres in the diet protect against some gastro-intestinal disorders such as cancers in the colon and rectum.

Essential nutrients: Essential nutrients are the substances that cannot be synthesized in the body from simple precursors and must therefore be taken through the diet. These essential nutrients include essential amino acids, essential fatty acids, vitamins and minerals. Essential nutrients have key functions in bio synthetic reaction in the body cells. If these essential nutrients are not supplied in correct proportions in the diet that will lead to malnutrition. Therefore it is essential to obtain them in correct amounts.

Essential amino acids: Essential amino acids are the amino acids that must be obtained from the food since they cannot be synthesized within the body from organic precursor molecules. Of the 20 amino acids required to make proteins in the body 8 amino acids are essential amino acids. Examples for essential amino acids are leucine and methionine. The animal protein products (e.g. eggs, meat, cheese, etc.) will provide all essential amino acids in correct proportions required for body functions. Most plant proteins are “incomplete” as they are deficient in one or more amino acids. Therefore vegetarian diet should contain a variety of plant proteins in order to obtain all the essential amino acids required.

Essential fatty acids: Essential fatty acids are the fatty acids that should be obtained from the diet since they cannot be synthesized in the body from organic precursors. Seeds, grains and vegetables provide enough amounts of essential fatty acids.

Table : Dietary sources and deficiency symptoms of vitamins and minerals

Vitamin/ Mineral	Main dietary sources	Deficiency symptoms
Fat soluble vitamins		
Vitamin A (retinol)	Dark green vegetables, orange vegetables and fruits, dairy products	Blindness, skin disorders, immunity impairment
Vitamin D	Egg yolk, dairy products	Bone deformities(rickets) in children, bone softening in adults
Vitamin E	Vegetable oils, nuts, seeds	Nervous system degeneration
Vitamin K	Green vegetables, tea, produced by colon bacteria	Defective blood clotting
Water soluble vitamins		
Thiamine (Vitamin B ₁)	Legumes, peanuts, whole grains, pork	Beriberi(characterized by tingling, poor coordination, susceptibility to infection, reduced heart function)
Riboflavin (Vitamin B ₂)	Dairy products, meats, vegetables, enriched grains	Skin lesions (cracks at corners of mouth)
Niacin (Vitamin B ₃)	Grains, nuts, meats.	Pellagra(characterized by lesions in skin, mental confusion and diarrhea)
Pantothenic acid (Vitamin B ₅)	Dairy products, fruits, vegetables, grains	Fatigue, numbness, tingling of hands and feet

Vitamin/ Mineral	Main dietary sources	Deficiency symptoms
Pyridoxine (Vitamin B ₆)	Whole grains, Meats, vegetables	Irritability, anemia
Biotin (Vitamin B ₇)	Meats, legumes, vegetables	Neuro- muscular disorders, scaly skin inflammation
Folic acid (Vitamin B ₉)	Green vegetables, whole grains	Anemia, birth defects
Cobalamin(Vitamin B ₁₂)	Dairy products, eggs, meats	Loss of balance, numbness, anemia
Ascorbic acid (Vitamin C)	Citrus fruits, broccoli, tomatoes	Scurvy (characterized by degeneration of skin and teeth) , delayed wound healing
Minerals		
Calcium (Ca)	Dairy products, dark green vegetables, legumes	Loss of bone mass, impaired growth
Iron (Fe)	Whole grains, green leafy vegetables, legumes, meats, eggs	Anemia, weakness, impaired immunity
Phosphorus (P)	Rice, bread, milk, dairy products, fish, red meat	Decaying of teeth and bones, weakness
Potassium (K)	Fruits, vegetables, meat , dairy products, grains	Muscle weakness, nausea , paralysis, heart failure
Iodine(I)	Sea foods , vegetables, iodized salt	Goiter(enlarged thyroid glands)
Sulfur (S)	Foods containing proteins	Fatigue, Impaired growth, swelling
Chlorine (Cl) and Sodium (Na)	Table salt	Reduced appetite, muscle cramps
Magnesium (Mg)	Green leafy vegetables, grains	Disturbance in nervous system
Fluorine (F)	Tea, sea food, drinking water	Tooth decay

Basal metabolic rate (BMR)

- Basal metabolic rate is defined as the minimum metabolic rate at rest, when in a post absorptive stage (at least 12 hour fasting) and is not experiencing stress.
- BMR is measured under a “comfortable” temperature range.
- BMR of humans averages for adult males 1,600-1,800 kcal per day and 1,300-1,500 kcal for adult females.

Energy budget: An energy budget is a balance sheet of energy intake against energy expenditure in a particular animal. The basic model of energy budget can be shown as follows;

$$C=M+U+F+P$$

Where C=Energy content in the food sources taken in

M= Energy spent for metabolic activities

U= Energy associated with urinary loss

F= Energy associated with fecal loss

P= Production (Energy available for growth and reproduction)

In energy budgets, energy content in the food intake is compared with energy expenditure which includes energy spent for basal metabolism and extra activities (M), energy associated with excretory products namely urinary loss (U) and fecal loss (F). The energy differences between the energy intake and the energy expenditure for metabolism and excretion are available for production which includes growth and reproduction. Energy budget can be calculated for each animal based on energy measurements from field and laboratory. Energy budgets are useful for estimating energy available for growth and reproduction.

Food for healthy life: For a healthy life diet should contain correct proportions of carbohydrates, proteins, lipids, water, fiber, essential mineral elements and vitamins. Dietary deficiencies can have negative impact on health. When food intake exceeds daily energy requirements especially in inactive individuals can lead to ill health conditions specially diabetes mellitus and heart diseases. Some individuals develop allergic reactions to foods such as pineapple, peanuts and tomatoes. Such individuals should avoid these types of foods. Antioxidants present in the food material (e.g. vitamin C and vitamin E) are also important in avoiding disorders in the alimentary canal and maintaining a healthy life. As humans cannot synthesize all the required antioxidants some of them should be obtained from the diet.

Malnutrition: Malnutrition can arise due to failure of obtaining an adequate nutrition when the diet lacks one or more essential nutrients or consistently supplies less chemical energy than the energy required by the body. According to the WHO if, body mass index (BMI) is less than 18.5 is said to be malnutrition. BMI of a person is calculated as follows,

$$\text{BMI} = \text{Mass} / \text{height}^2 \text{ (kg/ m}^2\text{)}$$

Obesity: Obesity arises when energy expenditure of a person is much less than the energy intake. According to the WHO criteria, if the BMI is at 30.0 or over it is known as obesity. This condition is a growing issue worldwide. Obesity can lead to many diseases such as diabetes mellitus, cardiovascular diseases, some cancers etc.

Common disorders in the alimentary canal

Gastritis: gastritis is a condition resulting inflammation of the stomach which can be due to several reasons. In gastritis, glands of the stomach wall are stimulated and secrete excess HCl causing damage to the mucosa. Due to the damages of mucosa layer of the stomach, blisters can be formed. Prolonged starvation and mental stress are one of the reasons for the secretion of excess HCl. Some drugs like aspirin can also induce gastritis conditions. Longer lasting gastritis conditions is usually associated with the infection by the acid tolerance bacterium *Helicobacter pylori*. As prolonged starvation is one of the reasons for developing gastritis proper food habits should be practiced to control this condition.

Constipation: Constipation occurs due to the slow movement of feces that promotes the water reabsorption and as a result feces become more solid. Inhibition of the reflex action in defecation may also lead to constipation. This leads to pain in the anus and difficulty in defecating. Constipation can be controlled by developing behavioral adjustments to carry out defecation properly. Intake of adequate fiber in the diet can help prevent constipation.

Circulatory Systems in Animals

Need of a circulatory system

A circulatory system is required in animals for transportation of materials within the body and exchange of materials with the external environment. The simple animals (e.g. Cnidarians, Flat worms) lack specialized system for the transport and distribution of material because many or all cells are in direct contact with the external environment. In these animals exchange of materials over the body surface through direct diffusion is sufficient for their needs. In these animals those materials can be transported by diffusion through short distance within the body.

As organisms increase in size and complexity, the amount of materials moving in and out of the body also increases. The distance that materials have to be transported within the body also increases and many cells are not in direct contact with their external environment. Therefore diffusion is not sufficient to transport materials throughout the body. Therefore circulatory systems have evolved in such organisms to exchange materials between cells and their immediate surroundings.

Substances that are transported in the body

Substances that are transported in the body include respiratory gases (oxygen, carbon dioxide), nutrients (glucose, amino acids, fatty acids, vitamins, etc.), waste products of metabolism (urea, ammonia, etc), hormones and antibodies.

Blood circulatory systems in the animal kingdom

A circulatory system has three basic components: a muscular pumping device (heart), interconnected vessels and a circulatory fluid (blood/ hemolymph). Circulatory fluid flows through the vessels mainly due to the pressure generated by the heart. The circulatory system functionally connects the fluid environment of the body cells to the organs that exchange gases, absorb nutrients and dispose of wastes by transporting fluids throughout the body. Various degrees of complexity in the arrangement of circulatory systems can be seen in the animal kingdom.

Main circulatory systems in the animal kingdom

There are two types of circulatory systems among the animals: open circulatory system and closed circulatory system.

The open circulatory system: It is a circulatory system in which a fluid called hemolymph that bathes the tissues and organs directly. There is no distinction between the circulatory fluid and the interstitial fluid surrounding cells. The heart pumps hemolymph through the circulatory vessels into the spaces (interconnected sinuses) which surround body tissues. Chemical exchange occurs directly between the hemolymph and body cells. Back flow of the hemolymph takes place via the pores (ostia) with valves found in the heart during the relaxation. The open circulatory system has evolved in some invertebrate phyla such as Arthropoda and Mollusca (some mollusc groups).

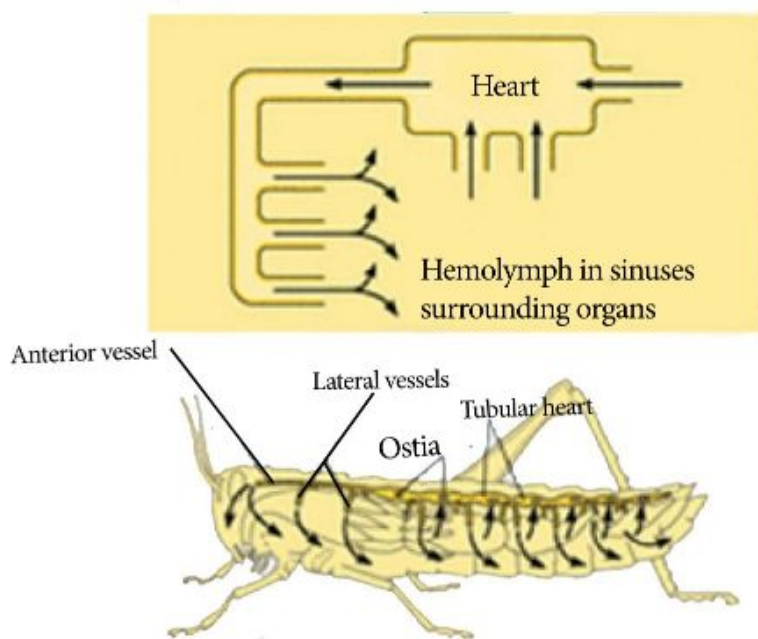


Fig 5.13: Circulatory system of a Grass hopper

The closed circulatory system: It is a circulatory system in which blood is restricted to vessels and kept apart from the interstitial fluid. Blood is pumped by the heart/s into large vessels. These large blood vessels branches into small vessels and they penetrate into the organs. Chemical exchange occurs between the blood and the interstitial fluid and body cells. It may contain one or more hearts. This type of circulatory systems can be seen in vertebrates and invertebrates such as Annelids. In comparison to open circulatory system enable effective delivery of oxygen and nutrients to the cells of larger and more active animals due to relatively high blood pressure.

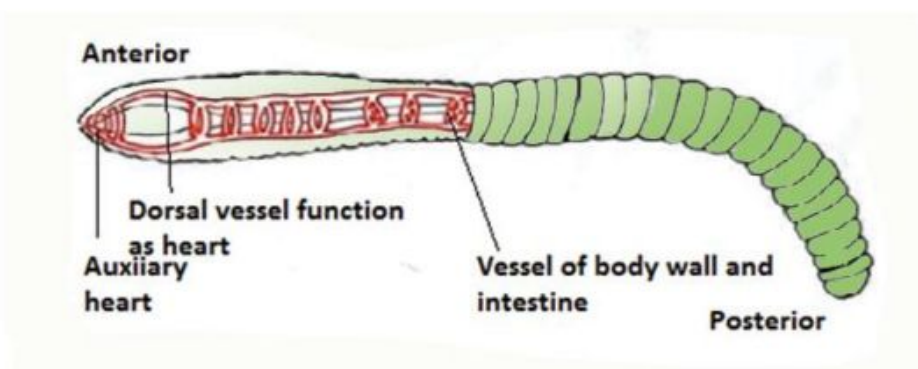


Fig 5.14: Closed blood Circulatory system of an Annelid

Organization of vertebrate circulatory systems: Single circulation and double circulation

Vertebrates have a closed circulatory system where there are three main types of blood vessels: arteries, veins and capillaries. Within each type blood flows in only one direction. The blood vessels which carry blood from the heart to organs are called arteries. When these arteries branch into smaller vessels within organs they are called arterioles. They pass blood to capillaries which are microscopic vessels with thin and porous walls. These are the places where materials exchange occurs between blood and interstitial fluid surrounding body cells through diffusion. Capillaries converge into venules and they converge into veins which carry blood back to the heart.

Single circulation

During single circulation, in a complete circulation through the entire body, blood passes through the heart only once. In animals that demonstrate single circulation, possess two chambers in the heart. They are atrium and ventricle.

During a single circulation, the oxygen poor blood returning from the body enters atrium and pass into the ventricle. Then the ventricle is contracted, blood is pumped into the capillary bed in the gills. There gas exchange occurs between the capillaries and the external environment. The O_2 is diffused into the blood while CO_2 is removed from the blood. Next the oxygen enriched blood circulates throughout the body and reaches the body cells through body capillaries. e.g.: Bony fishes, Cartilagenous fishes such as rays and sharks.

Double circulation

During double circulation, in a complete circulation through the entire body, blood passes through the heart twice. Such circulatory system consists of separate pulmonary and systemic circuits in which blood passes through the heart after completing each cycle. e.g. Amphibians, Reptiles, Aves, Mammals. Amphibians and most reptiles have a three chambered heart: two atria and one ventricle. Birds and mammals have a four chambered heart where heart is completely divided into left and right sides. This arrangement allows the complete separation of oxygen enriched and oxygen poor blood. The oxygen poor blood from systemic circulation flows to the right atrium of the heart and then to the right ventricle. Right ventricle pumps blood into the lungs. Oxygen enriched blood from the lungs reaches the left atrium and pass to the left ventricle. The left ventricle pumps oxygen enriched blood into the systemic circulation.

Double circulation is more effective in supplying blood to all body organs and tissues especially brain and muscles due to the higher pressure exerted by the heart in the systemic circulation. This in contrast to single circulation where blood flows under reduced pressure from the gas exchange organs to other organs.

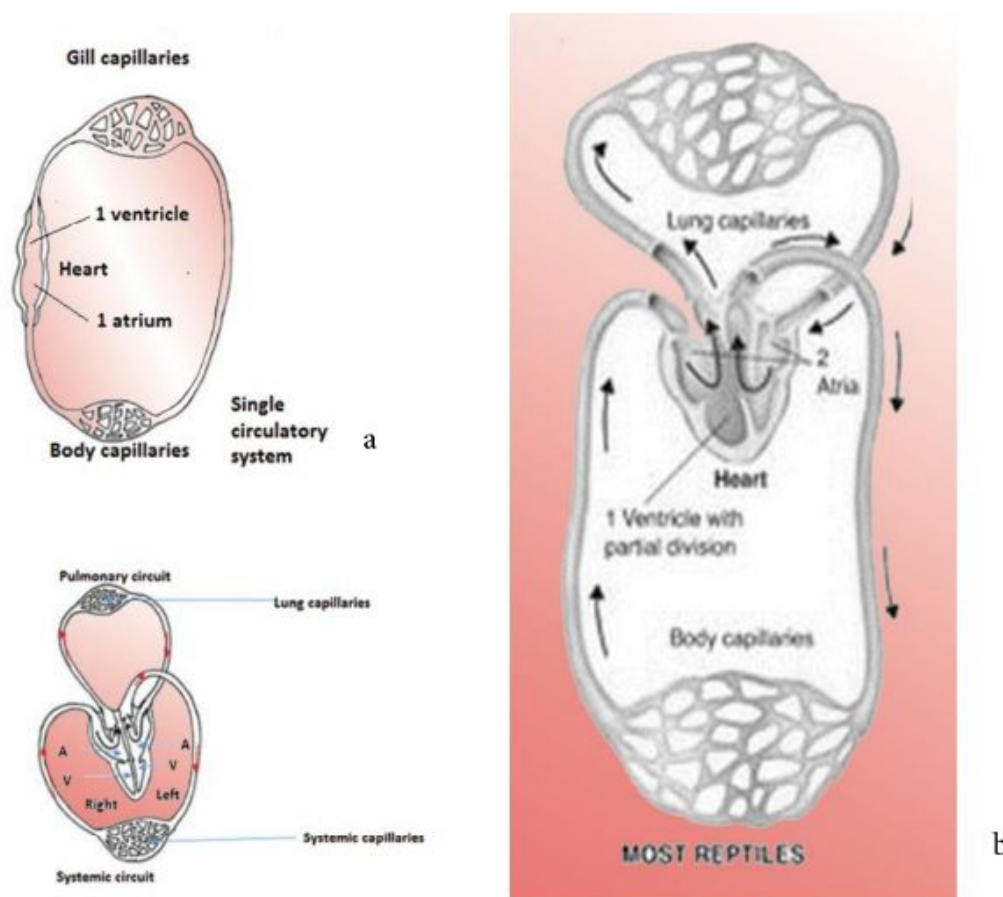


Fig 5.15: Single and double circulatory systems in animals: a. Single circulation (fish), b. double circulation (amphibian) c. double circulation (mammal)

Basic plan of human blood circulatory system and lymphatic system

Basic plan of human blood circulatory system

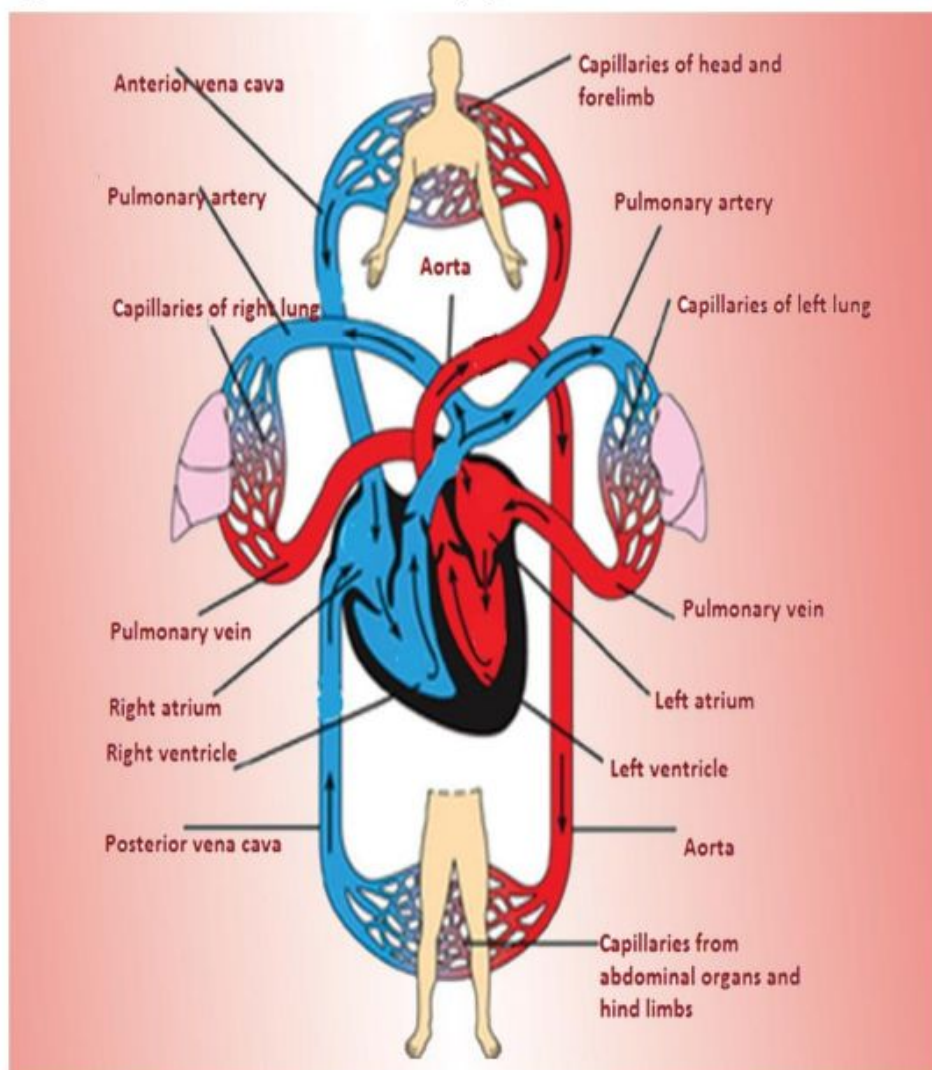


Fig 5.16: Basic plan of the human blood circulatory system

Figure (5.16) depicts the basic plan of the human blood circulatory system. The human heart consists of four chambers; they are two ventricles and two atria. There is a dual circuit which operates simultaneously. The pulmonary circuit takes oxygen poor blood to the respiratory surface, the lungs and returns the oxygen enriched blood back to the heart while the systemic circuit supplies oxygen enriched blood to all organs and tissues in the body and returns oxygen poor blood from organ and tissues back to the heart. Each circuit consists of major arteries/arteries, arterioles, capillary beds, venules and veins/major veins.

During ventricular contraction, the right ventricle pumps the oxygen poor blood into the two lungs via the pulmonary arteries. Then in the lungs O_2 is loaded into the blood through diffusion while CO_2 is unloaded from blood into the external environment.

This process occurs in the capillary beds in the left and right lungs. Then the oxygen rich blood is transported into the left atrium via the two pulmonary veins. During atrial contraction, this oxygen rich blood is transported into the left ventricle. During ventricular contraction oxygen rich blood is pumped into the aorta. Through arteries the aorta conveys this oxygen rich blood throughout the body. First the aorta branches into the coronary arteries which supplies blood into the heart muscles. Then the aorta branches into arteries, arterioles leading to capillary beds in the head and arms and the capillary beds in the abdominal organs and legs. The exchange of gases occurs in the capillary beds where O_2 rich blood is diffused into the tissues while the CO_2 rich blood diffused into the blood capillaries. These blood capillaries rejoined to form venules which direct oxygen poor blood into veins. Oxygen poor blood from trunk and hind limbs is drained into the inferior vena cava and oxygen poor blood from the head, neck and fore limbs are directed into the superior vena cava. The blood from both inferior and superior vena cava is pumped into the right atrium where it is passed into the right ventricle. This blood is directed to the pulmonary circuit as explained above.

Basic plan of human lymphatic system

The lymphatic system is closely connected with the blood circulatory system both structurally and functionally. It consists of lymph vessels through which lymph travels. Other structure in the lymphatic system includes lymph nodes, lymphoid tissues (tonsils) and lymphoid organs (e.g. spleen and thymus). Lymph vessels consist of tiny vessels and larger vessels. Tiny lymph vessels are in close contact with the capillaries of the blood circulatory system. Lymph nodes are composed of connective tissues and white blood cells.

The lymphatic system returns lost fluid and proteins from the blood capillaries back into the blood. The lost fluid from the blood capillaries is called lymph when they are inside the lymphatic system. The composition of the lymph is same as interstitial fluid. Lymph vessels have valves. That prevents the backflow of the lymph. The lymph is drained into veins at the base of the neck via two large ducts. The rhythmic contraction of the lymph vessel walls and skeletal muscle contraction help to move the lymph.

The functions of human lymphatic system include tissue drainage to maintain the blood volume in the blood circulatory system, absorption of fat and fat soluble vitamins from the small intestine and for immune responses.

Structure and function of the human heart

The human heart is roughly a cone shaped hollow muscular organ. The heart wall is composed of three layers of tissues: Pericardium, Myocardium, Endocardium.

Pericardium: The pericardium is the outer most layers. It is made up of two sacs: The outer fibrous pericardium and inner serous pericardium.

Myocardium: Myocardium is the middle layer of the heart wall. It is composed of specialized cardiac muscle found only in the heart. Running through the myocardium is also a network of specialized conducting fibres responsible for transmitting the heart's electrical signals.

Endocardium: Endocardium is the inner layer of the heart wall. It lines the chambers and valves of the heart. It is a smooth membrane and consists of flattened epithelial cells. It is continuous with the endothelium lining of the blood vessels.

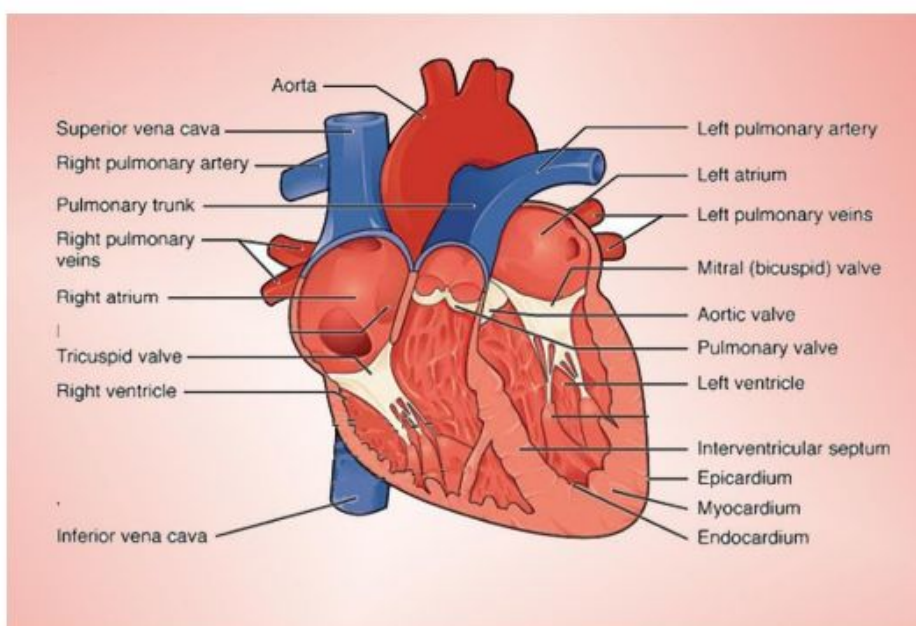


Fig 5.17: Interior of the human heart

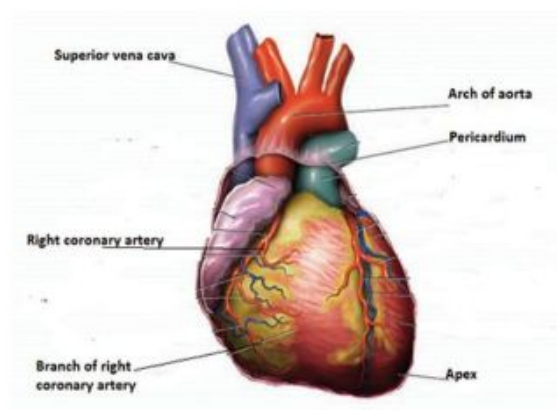


Fig 5.18: External appearance of the human heart

There are four chambers in the heart two upper atria and two lower ventricles. Ventricles have to pump blood to the whole body where as atria pump blood to the ventricles only. Therefore walls of the ventricles are thicker than walls of the atria. Wall of the left ventricle is thicker than walls of the right ventricle because the right ventricle pumps blood to the lungs which are closer to the heart whereas the left ventricle has to pump blood throughout the body.

Therefore the blood entering the aorta from the left ventricle is at much higher blood pressure than the blood entering the pulmonary artery from the right ventricle.

The heart is completely divided into a right and left side by a septum. The atria and ventricles on each side are divided by an atrio-ventricular valve (AV). The right atrioventricular valve has three flaps hence known as tricuspid valve and the left atrioventricular valve has two flaps hence known as bicuspid valve. Conical shaped papillary muscles are extensions of the inner wall of the ventricles. Atrio-ventricular valves attached to the papillary muscles by fibrous cords which are called chordae tendineae. Atrio-ventricular valves are anchored by strong fibres. This prevents the valves from being turned inside out. Semilunar valves are found at the points where the pulmonary artery and aorta leave the right and left ventricles respectively. These valves prevent the backflow of blood into the ventricles.

Two pulmonary arteries with oxygen poor blood leave the heart from the upper part of the right ventricle. Two pulmonary veins from each lung carry oxygen rich blood back to the left atrium. The aorta with oxygen rich blood leaves from the upper part of the left ventricles. The superior vena cava and inferior vena cava open into the right atrium and empty their contents into the right atrium. The heart is supplied with arterial blood by the right and left coronary arteries which branch from the aorta immediately after the aortic valve.

The conducting system of the heart

Heart generates its own electrical impulses and beats independently of nervous or hormonal control. However it is supplied with both sympathetic and parasympathetic nerve fibers which increase and decrease respectively the intrinsic heart rate. In addition to that heart responds to a number of circulating hormones including adrenaline and thyroxine.

Small group of specialized neuromuscular cells in the myocardium initiate and conduct impulses. The conducting system of the heart consists of following specialized system.

- SA node (Sinoatrial node)
- AV node (Atrioventricular node)
- Atrioventricular bundle (bundle of His), bundle branches and Purkinje fibres

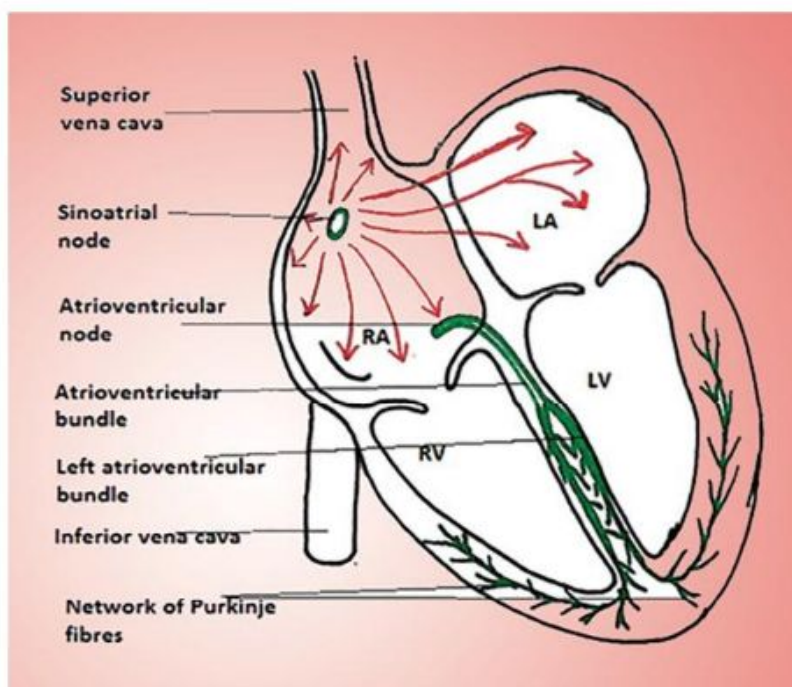


Fig5.19: The conducting system of the human heart

SA node / Sinoatrial node

SA node is a small mass of specialized cells. It lies in the myocardium of the right atrium near the opening of the superior vena cava. The stimulus for contraction of the heart originates in the 'SA node'. The SA node initiates the heart beat and sets the rhythm of the heart beat so it is called the pace maker. But the heart rate can be varied by the stimulation from the autonomic nervous system, hormones such as adrenaline, thyroxine and temperature.

AV node

AV node is also a small mass of specialized cells. It is situated between wall of the left and right atria. The AV node transmits the electrical signals from the atria into the ventricles.

Atrioventricular bundle (bundle of His), bundle branches and Purkinje fibres

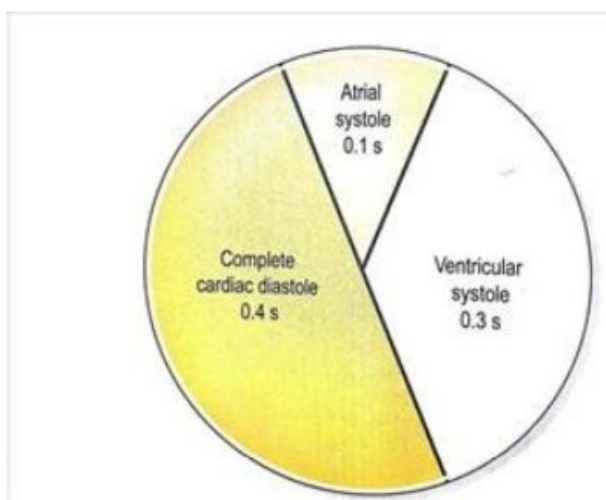
AV bundle is a mass of fibers. It originates from the AV node. The AV bundle crosses the fibrous rings that separate atria and ventricle at the upper end of the ventricular septum it divides into right and left bundle branches. Within the ventricular myocardium the branches break up into fine fibres. These fine fibers are Purkinje fibers. The AV bundle branches and the Purkinje fibers transmit electrical impulse from the AV node to the apex of the myocardium. As a result of this impulse, wave of ventricular contractions begin. Then the contraction sweeps upwards and outwards pumping blood simultaneously into the pulmonary artery and the aorta.

The cardiac cycle

The cardiac cycle refers to the sequences of events that take place in a complete heart beat. During this process one complete cycle of pumping and filling of blood into the heart occurs. Complete cardiac cycle lasts for 0.8 second. It occurs as follows:

1. Atrial systole – Contraction of the atria
2. Ventricular systole - Contraction of the ventricles
3. Complete cardiac diastole – Relaxation of the atria and ventricles

At rest the healthy adult heart is likely to beat at a rate of 60- 80 beats per minute. During a single heart beat, the heart contracts (systole) and then relaxes (diastole). During a single contraction the amount of blood pumped by a ventricle is called the stroke volume.



Total period of 1 cycle = 0.8 second

Fig 5.20: The stages of Cardiac cycle

Complete cardiac diastole

This lasts for 0.4 second. Both atria and ventricles are relaxed and blood return to the heart. The superior vena cava and the inferior vena cava transport oxygen poor blood into the right atrium. At the same time as the four pulmonary veins bring oxygen rich blood into the left atrium. The pressure of the atria is more than the pressure of the ventricles. Therefore atrioventricular valves are open and some blood flows passively through to the ventricles.

Atrial systole

When blood flows into the atrium SA node is stimulated. Then SA node triggers a wave of contractions that spreads over the myocardium of both atria. Hence the remaining blood in the atria flows into the ventricles thereby emptying the atria. This lasts for 0.1 second.

Ventricular systole

Through the atrial muscles the electrical impulses reaches the AV node. Then AV node triggers its own electrical impulses which quickly spread to the ventricular muscles via the AV bundle, the bundle branches, and Purkinje fibers. This results in a wave of contractions which sweep upwards from the apex of the heart across the wall of the ventricles. As a result both ventricles contract.

The pressure in the right ventricle is more than the pressure in the pulmonary artery and the pressure in the left ventricle is more than pressure in the aorta. Therefore pulmonary valve and aortic valves open and blood flows into pulmonary artery and aorta respectively.

The high pressure generated during ventricular contractions force the atrioventricular valves to close preventing backflow of blood into the atria. Ventricular systole lasts for 0.3 seconds. When ventricles relax, the pressure within them falls. The pulmonary and aortic valves close. Pressure within the pulmonary artery and aorta is more than pressure within the ventricles. The valves of the heart and great vessels open and close according to the pressure within the chambers of the heart. The sequence of opening and closing of valves ensure that blood flows only in one direction.

Electrocardiogram (ECG)

Electrical activity in the heart can be detected on the surface of the skin by placing electrodes on the chest or limbs as the body tissues and fluids conduct electricity well. Such a recording is called an electrocardiogram (ECG). The ECG indicates the spread of the electrical signal generated by the SA node as it travels throughout the heart. The normal ECG tracing of a healthy individual shows five waves which by convention have been named P, Q, R, S and T.

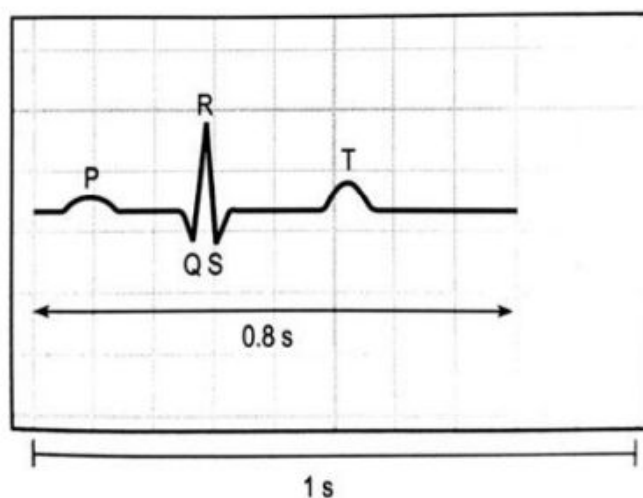


Fig 5.21: Electrocardiogram of one cardiac cycle

P wave - It represents the impulse from the SA node as it sweeps over the atria (atrial depolarization).

QRS wave complex – Represents rapid spread of impulse from the AV node throughout the ventricles and electrical activity of the ventricular muscles.(ventricular depolarization)

T wave – Represents ventricular repolarization and relaxation of the ventricular muscles. Due to the larger QRS complex, atrial repolarization which occurs during ventricular contraction is not seen.

Information about the heart function of a person (state of the myocardium and the cardiac conduction system) can be obtained by examining the pattern of waves and the time interval between cycles and parts of cycles.

Blood Pressure

The force that the blood exerts on the walls of blood vessels as it travels is referred to as blood pressure. Blood pressure in the arteries of systemic circulation maintains the essential flow of blood into and out of the organs of the body.

It is very important to keep blood pressure within normal limits. High blood pressure could lead to damage blood vessels resulting in formation of clots or bleeding from damaged sites. If the blood pressure falls too low, there will be inadequate blood flow through tissue capillary beds. This will adversely affects the normal functioning of vital organs such as the brain, heart and kidneys.

Blood pressure varies according to the time of day, the posture, gender, age, activity, exercise and stress (Emotional states) of an individual. Blood pressure falls at rest and during sleep. Blood pressure increases during excitement, fear or anxiety.

Systolic and diastolic pressure

Systolic pressure

Systolic pressure is the pressure produced within the arterial system when the left ventricle contracts and pushes blood into the aorta. At rest , systolic pressure in a normal healthy adult systolic pressure is about 120 mmHg.

Diastolic pressure

Diastolic blood pressure is the blood pressure within the arteries following ejection of blood at complete cardiac diastole(when the heart is at rest. In a normal healthy adult diastolic pressure is about 80 mmHg.

Arterial blood pressure is measured by a sphygmomanometer. It is expressed as

Systolic pressure (mm Hg)

Diastolic pressure (mm Hg)

120/80 mmHg

Hypertension and Hypotension

Hypertension

Sustained elevated blood pressure above normal limits is called hypertension.

Consequences of hypertension are kidney damage, adrenal gland disorders, heart attack (because of the increased heart rate and cardiac contraction), stroke (caused by cerebral haemorrhage), damaged blood vessels which can lead to death

Risk Factors for Hypertension

- Obesity
- Diabetes mellitus
- Family history
- Smoking
- A sedentary life style
- High intake of salts
- High intake of alcohol
- Stress
- Deposition of low density lipoprotein (LDL) on artery walls.

Hypotension

Sustained reduction of blood pressure below normal limits is called hypotension. Hypotension usually occurs as a complication of other condition such as shock, Dengue hemorrhage fever, standing up suddenly from sitting or lying position, over bleeding/ hemorrhage condition, fasting, low nutrition etc. Low blood pressure leads to inadequate blood supply to the brain. Depending on the cause unconsciousness may be brief (fainting) or prolonged possibly causing death.

Coronary circulation

The heart is supplied with arterial blood by the right and left coronary arteries which branch from the aorta immediately distal to the aortic valve.

The coronary arteries travel the heart wall eventually forming a vast network of capillaries. Most of the venous blood is collected into a number of cardiac veins that joins to form the coronary sinus which opens into the right atrium. The remainder passes directly into the heart chambers through little venous channels.

Consequences of blockage of coronary arteries

The inner lining of the arteries can be thickened and harden leading to the condition called atherosclerosis which occurs as a result of fatty deposits especially cholesterol particles. This can affect the normal blood supply to the organs and tissues.

One or more branches of coronary arteries can be blocked due to atherosclerosis which can be complicated by thrombosis (blood clot). Depending on the place (s) of the block in the coronary arteries and the degree of blockage related parts of the heart muscle will be deprived of oxygen and nutrients. Hence, narrowing of the arteries leads to chest pain (Angina). The complete occlusion due to the blockage of one or more coronary arteries leads to heart attacks (Myocardial infarction) which refers to the damage or death of cardiac muscle tissue due to lack of adequate oxygen and nutrients. Due to this, heart beat rhythm may be abnormal and the heart may cease to be an effective pump. The other vital organs such as brain may be deprived of inadequate supply of oxygen rich blood and heart attack may be fatal if not treated on time.

Stroke – Similarly blockage due to atherosclerosis or rupture of arteries supplying blood to the brain may cause the death of nervous tissue due to lack of oxygen and nutrients. This is referred to as stroke.

Respiratory pigments

Respiratory pigments are organic compounds which can combine with oxygen where the partial pressure of oxygen is high and release oxygen where partial pressure of oxygen is low. Since oxygen is less soluble in watery medium including blood, transportation of oxygen from respiratory surface to the tissues/ organs is a problem for complex animals. To overcome this problem animals have evolved the respiratory pigments.

Different respiratory pigments can be seen in the animal kingdom:

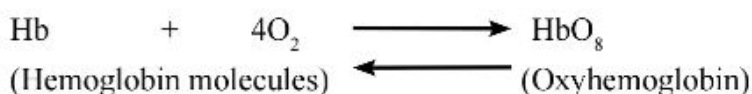
- Haemoglobin- present in blood of human, other vertebrate and annelids
- Haemocyanin- present in hemolymph of arthropods and molluscs.
- Chlorocruorin- present in the blood of many annelids
- Haemoerythrin- present in the blood of marine invertebrates (some annelids)
- Myoglobin- present in vertebrate muscles

All these respiratory pigments except myoglobin transport oxygen from respiratory surfaces to the tissues and organs and while transporting carbon dioxide from tissue/ organs to the respiratory surface for elimination. Myoglobin present in the muscle tissue has an oxygen storage function.

Transport of respiratory gases in human blood

Transport of oxygen

It is the hemoglobin molecule found in the erythrocytes which is responsible for the transport of oxygen around the body. Hemoglobin is composed of four subunits. Each subunit is composed of a globin protein and the haem group. Haem groups are responsible for the characteristic red colour of the blood. A ferrous (iron) atom is located within each haem group and each of these can combine reversibly with one molecule of oxygen. Therefore each hemoglobin molecule can carry up to four oxygen molecules.



Combination of oxygen with hemoglobin to form oxyhemoglobin

Transport of Carbon dioxide

Carbon dioxide is carried by the blood in different ways.

- As HCO_3^- ions in the plasma (about 70%): When CO_2 diffuses into the red blood cells the enzyme carbonic anhydrase catalyzes the combination of CO_2 with water to form bicarbonate (HCO_3^-) and H^+ ions. The HCO_3^- moves out of the erythrocytes into the plasma.
- As carbaminohemoglobin (about 23%): CO_2 combined with protein group of hemoglobin and forms carbaminohemoglobin. Therefore CO_2 does not compete with oxygen binding sites in hemoglobin.
- Dissolved in plasma (about 7%): as free gas.

Composition and major functions of human blood

Blood which is a connective tissue is composed of cells and plasma. Cellular components of the blood are three types namely red blood cells, white blood cells and platelets. ((fig. 5.22) Red blood cells, leukocytes and platelets are developed from the bone marrow in the bones such as ribs, vertebrae, sternum and pelvis. Erythropoietin hormone (from kidneys) stimulates the generation of red blood cells.

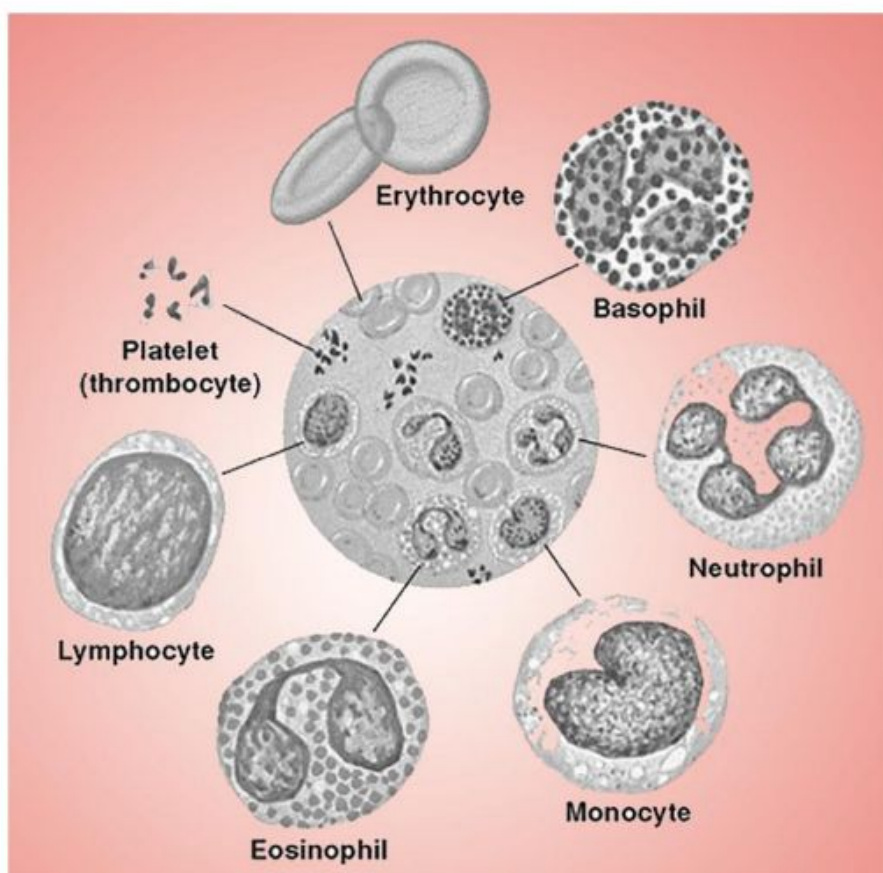


Fig 5.22: The composition of blood

Red blood cells (erythrocytes)

They are small biconcave disk-like cells. Mature erythrocytes lack nuclei. This character helps to carry more hemoglobin molecules within the cell. They also lack mitochondria thus they produce ATP via anaerobic respiration. If they produce ATP by aerobic respiration that will reduce the O_2 transport efficiency. They have about 120 days of life span.

Generally a micro liter of blood contains 4- 6 million red blood cells. This figure can be varied depending on the gender and health status.

Main function of red blood cells is the transportation of O_2 molecules. They also transport CO_2 molecules.

White blood cells (Leukocytes)

There are five types of leukocytes. They are Basophils, Lymphocytes, Eosinophils, Neutrophils and monocytes. Main functions of leukocytes are body defense, phagocytic engulfing and digesting microorganisms. Lymphocytes develop into T cells and B cells. These cells increase immune response against foreign substances.

Platelets

Platelets are derived from bone marrow cells. They also do not have nuclei and they play a major role in blood clotting.

Blood plasma

Blood plasma consists of inorganic ions in dissolved forms, plasma proteins such as albumin, antibodies and fibrinogen, nutrients, metabolic wastes, respiratory gases and hormones. pH of human blood is around 7.4. Protein concentration in plasma is higher than in interstitial fluid.

The dissolved ions in the plasma buffer and maintain the osmotic balance in the blood. Albumin in the plasma also buffers the blood and antibodies are involved in defense. Fibrinogen in the plasma aids in blood clotting. When the clotting factors are removed from the plasma it is called as serum.

Major Functions of blood

- Transport of oxygen to organs and removal of carbon dioxide from the organs and tissues
- Transport of soluble excretory materials to organs of excretion
- Transport of nutrients
- Transport of hormones from the glands where they are produced to target organs
- Defence against foreign invasions
- Aids in osmoregulation

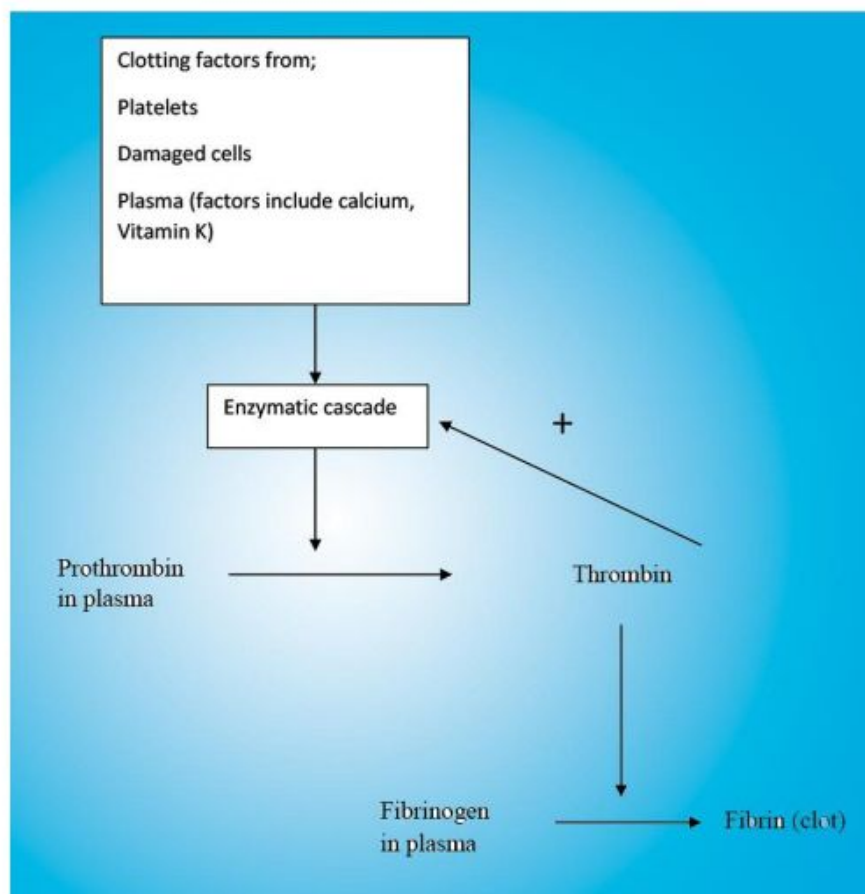
Blood clotting

When a tissue is damaged, blood flows from it and coagulates to form a blood clot. This prevents further blood loss and entry of pathogenic micro organisms which is of clear survival value. In general the blood in undamaged vessels does not clot.

A highly complex series of reactions takes place in order for coagulation to occur as well as prevent unwanted clotting. When the blood vessel is damaged the connective tissues of the vessel wall is exposed. Therefore platelets in the blood adhere to the collagen fibers in the connective tissue and release substance that makes close by platelets sticky. This platelet plug provides instant protection against blood loss.

Then platelets release clotting factors. They trigger the formation of thrombin. Then thrombin converts fibrinogen into fibrin. Next this fibrin aggregates into threads that form a network of the clot. The activated thrombin is also involved in formation of more thrombin which completes the formation of blood clot.

The cascade reaction during blood clotting is given below;



Clotting does not occur in undamaged blood vessels because the lining of the vessels is very smooth and does not promote platelet aggregation or cell rupture. Also some substances such as Heparin prevent clotting. Heparin prevent the conversion of prothrombin into thrombin and fibrinogen to fibrin and is widely used clinically as an anticoagulant.

Grouping of blood

The surface of the red blood cells carries antigens called agglutinogen (antigen A and antigen B). In addition individuals have antibodies in plasma (anti-A and anti-B). According to ABO blood grouping system there are four blood groups namely A, B, AB and O. A person with a specific antigen in red cells does not possess the corresponding antibody in the plasma. e.g. Anyone with antigen A on the red blood cell membrane has no anti-A antibody in the plasma.

If red blood cells have antigen A and plasma has antibodies b (anti-B) that person's blood group is A

If red blood cells have antigen B and plasma with antibodies a (anti-A) that person's blood group is B

If red blood cells have both antigen 'A' and 'B' and plasma has no anti-A or anti-B antibodies that person's blood group is 'AB'

If red blood cells have no antigen A or B but plasma has both antibodies (anti-A and anti-B) that person's blood group is 'O'

When a patient receives a blood transfusion it is vital that they receive blood that is compatible with their own. If it is incompatible a type of immune response occurs. This is because the donor's red cell membranes possess glycoprotein which act as antigens and react with antibodies (agglutinin) in the recipient's plasma. The result is that the donor's cells are agglutinated.

Therefore when transfusion occurs it is important to know blood group of donor and recipient. People with blood group AB make neither anti-A nor Anti-B antibodies. Transfusion of type A, B or AB blood into these individuals is likely to be safe since there are no antibodies to react with them. Person with AB blood group is known as a universal recipient.

Individual with blood group O has neither antigen A nor antigen B on their plasma membrane of red blood cells. but they do have antibodies (anti-A and anti-B) in their plasma. So these individuals having blood group O can donate blood to the persons with any blood group. A person with the blood group O is known as a universal donor. Therefore prior to transfusion cross-matching is still required to ensure that there is no reaction between donor and recipient blood.

The Rhesus system

Some individuals have antigen called Rhesus factor on the plasma membrane of red blood cells. Individuals having this factor on the red blood cells are called Rh⁺ and those who do not have this factor are called Rh⁻.

Rh⁺ individuals do not have anti Rhesus antibodies in the plasma while individuals who are Rh⁻ have anti-Rhesus antibodies in their plasma. However if Rh⁺ blood enters a Rh⁻ negative individual the recipient responds by manufacturing Rh antibodies in the blood plasma.

When a Rh⁻ mother bears a Rhesus positive (Rh⁺) child during delivery few Rh⁺ red blood cells of the fetus may enter the mother's circulation and cause the mother to produce Rh antibodies in her plasma. If the mother is pregnant for the second time with a Rhesus positive fetus, the Rh antibodies developed in her plasma in response to the first child's red blood cells can pass across the placenta to the fetus and destroy fetal red cells. Normally Rh antibodies are not formed in large enough quantities in the mother's plasma to affect the first born child. However subsequent Rh⁺ children can suffer destruction of their red blood cells.

Gas exchange in animals

Need of respiratory structures in animals and evolution of complexity of respiratory structures in different animal groups

Respiratory gas exchange (uptake of oxygen into the body and release of carbon dioxide into the external environment) occurs by diffusion. In simple animals e.g. cnidarians and flat worms every cell in the body is close enough to the external environment so that gas exchange can occur directly between all cells and the environment. Diffusion through body surface is adequate as these animals have a simple body form and low energy requirement.

In large animals, body complexity and energy requirement is high and the bulk of the cells in the body lack immediate access to the external environment. Hence, gas exchange through the body surface is not adequate to full fill their energy requirements. As a result, specialized surfaces referred to as respiratory surfaces have evolved where gaseous exchange occurs.

With the increase of the body size and complexity the surface area to volume ratio (A/V) of animals decreases. However, a large surface area is required for efficient gas exchange and thus diverse respiratory structures with large surface area with folding and branching has evolved for efficient gas exchange. Examples for such respiratory structure are Gills, Trachea, and lungs. External projections of the body such as gills were evolved in aquatic animals for efficient extraction of dissolved oxygen from water. On the other hand, surface invaginations like trachea and lungs were evolved in terrestrial animals for efficient extraction of oxygen from the atmosphere.

Characteristics of respiratory surfaces

An effective respiratory surface must have the following properties.

- It must be permeable, and wet so that gases can pass through by dissolving.
- It must be thin because diffusion is only efficient over short distances.
- It should possess a large surface area to allow a sufficient volume of gases to be exchanged according to the organism's need.
- It should possess a good blood supply (maintain a steep diffusion gradient)

Respiratory structures in animals

- Body surface: Cnidarians, Flatworms, Earthworms
- Gills

- External Gills: marine annelids
- Internal Gills: Fish, shrimps, prawns
- Tracheal systems: Insects
- Lungs: Mammals (Human), Reptiles, Birds.
- Skin: Amphibians
- Book lungs: Spiders, Scorpions

Human Respiratory System

Gross structure and function of the human respiratory system

Human respiratory system consists of the following major parts: nostrils, nasal cavity, pharynx, larynx, a series of branching ducts starting from the trachea, two bronchi one leading to each lung and smaller bronchioles, which finally end in air sacs called alveoli. The bronchioles and the alveoli are contained within the paired, cone-shaped lungs located in the thoracic cavity. The two lungs differ slightly in shape and size. The left lung is slightly smaller than the right because the apex of the heart is slightly to the left of the median plane and it has 2 lobes while the right lung has 3 lobes. Each lung is surrounded by two membranes. The inner membrane, called the visceral pleura adheres to the outer surface of the lungs while the outer membrane called the parietal pleura adheres to the wall of the thoracic cavity. Between these two membranes there is a thin, fluid filled space.

During respiration, air enters the respiratory system through the nostrils. In the nasal cavity air is filtered by hairs and is warmed and humidified as it travels through spaces in the nasal cavity. The nasal cavity leads to the pharynx which is a common passage for both air and food. That means air passage and food passage cross each other. During swallowing of food the larynx moves upwards which allows the epiglottis to close the opening of the larynx called the glottis. This allows food to go down the esophagus to the stomach. The rest of the time the glottis is open so that air can move from the pharynx through the larynx to the trachea. In the larynx are vocal cords which are made up of largely elastic fibers. These vocal cords help produce sound when expired air rushes across the stretched or tensed vocal cords, causing them to vibrate. Both the walls of the larynx and trachea are strengthened by cartilage that help these airways to keep open. The air passes from the trachea into the two bronchi that lead into each lung. Within the lungs the air passes through smaller and smaller branches of the bronchi called bronchioles.

The epithelium found in the major branches of this respiratory tract has cilia and a thin film of mucus. The mucus helps trap the dust and other particulate contaminants in the inhaled air. Then the beating of cilia moves this mucus upwards towards the pharynx where it is swallowed into the esophagus. This process is referred to as the “mucus escalator”. It helps clean the respiratory system.

At the tips of tiniest bronchioles are large number of small air sacs clustered together. The air passes into these air sacs called alveoli where gas exchange occurs. The walls of the alveoli are made up of a single layer of flattened epithelial cells that lack cilia. This inner lining of the alveoli is coated by a thin film of fluid. The lungs contain millions of alveoli. This allows a large surface area for gas exchange. Each alveolus is also surrounded by a network of capillaries. Oxygen in the air that enters the alveoli dissolves in the moist film and rapidly diffuse across the thin epithelium into the capillaries. Meanwhile a net diffusion of carbon dioxide occurs from the capillaries into the alveoli. Since there are no cilia in the alveoli, there are white blood cells in the alveoli to engulf foreign particles. Alveoli are also coated with a surfactant that reduces the surface tension thereby preventing the collapse of alveoli due to high surface tension.

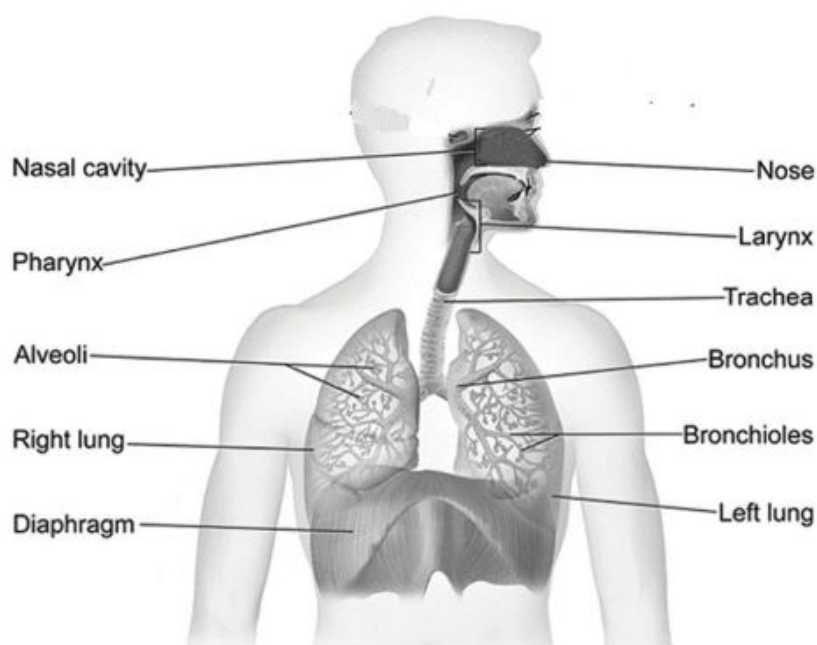


Fig 5.23: Gross structure of human respiratory system

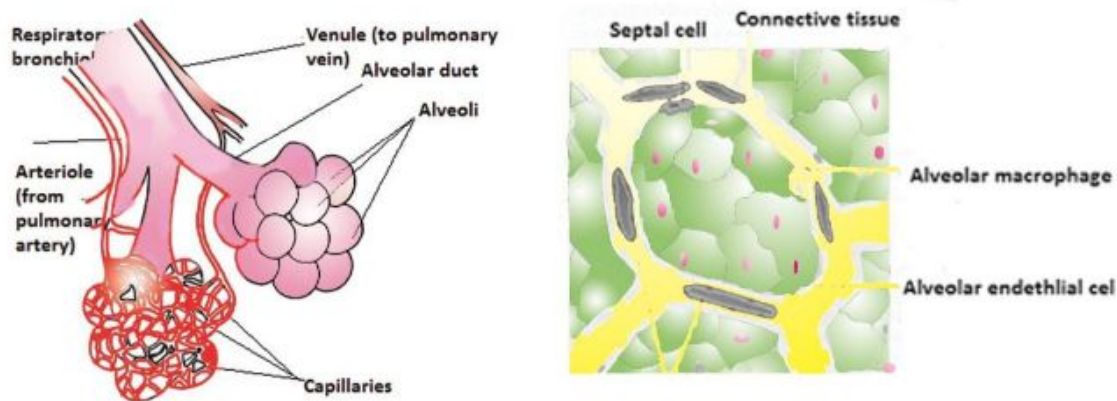


Fig 5.24: The alveoli and their capillary network

Mechanism of ventilation of the lungs

- Ventilation of the lungs is necessary to maintain high oxygen and low carbon dioxide concentrations in the alveoli or the gas exchange surface.
- Ventilation is accomplished by breathing, which is the alternating movement of air into (inhalation) and out of (exhalation) the lungs.
- Humans employ what is referred to as negative pressure breathing where air is pulled rather than pushed into lungs.
- Inhalation is an active process. Contraction of rib muscles or intercostal muscles and the diaphragm which is a sheet of skeletal muscle that forms the bottom of the thoracic cavity leads to the expansion of the thoracic cavity.
- The visceral and parietal pleurae surrounding the lung stick together due to the surface tension of the fluid between these two membranes. This allows the two membranes to slide smoothly past each other. Hence, as the volume of the thoracic cavity increases, the lung volume increases as well.
- As a result, the pressure within the lungs decrease relative to the outside air.
- This creates a pressure gradient between the atmosphere and the lungs.
- Thus, air flows from a high pressure gradient in the atmosphere to a lower pressure gradient in the lungs.
- During exhalations which is usually a passive process, the rib muscles and the diaphragm relax. This cause the volume of the thoracic cavity to reduce.
- As a result, the pressure inside the lungs increase in relation to the air outside. This pressure forces air to move out of the lungs through the respiratory tubes into the atmosphere.
- When a man is at rest contraction of rib muscles and contraction of diaphragm are enough for breathing.
- However, depending on the activity level, additional muscles may be used to aid breathing such as muscles of the neck, back and chest. These muscles further help to increase the volume of the thoracic cavity by raising the rib cage. e.g. during exercise

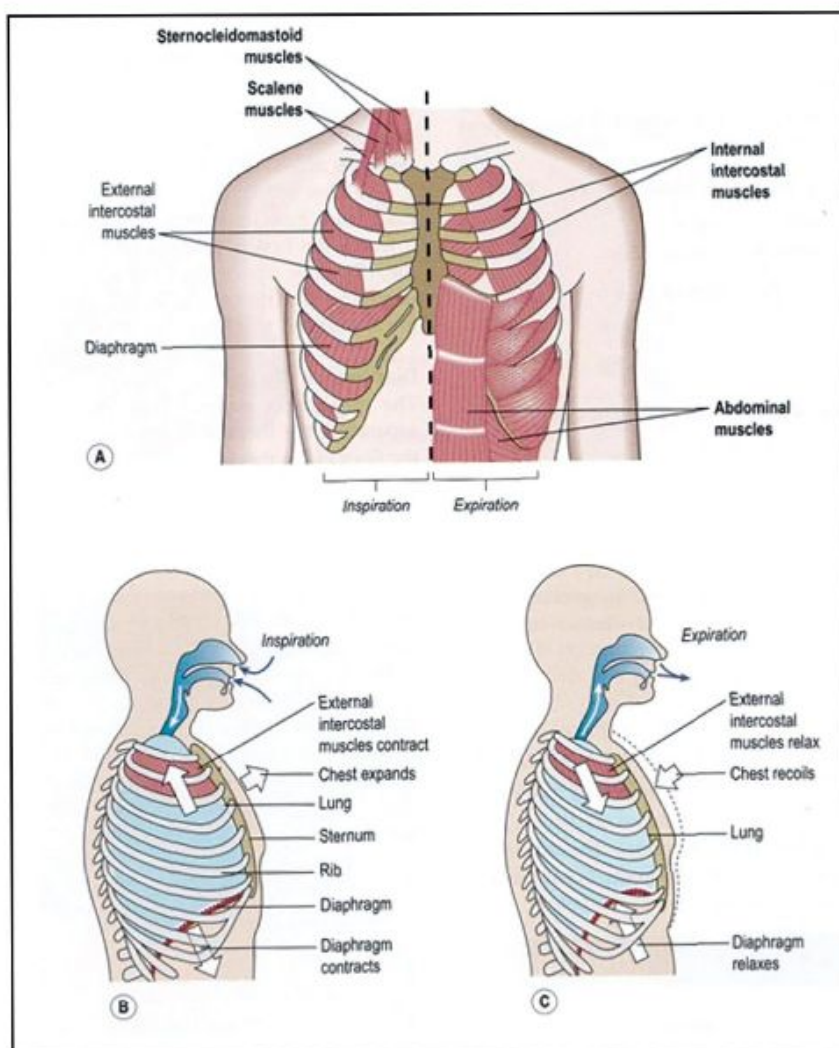


Fig 5.25: (A) Muscles involved in respiration; (B) and (C) Changes in chest volume during inspiration and expiration

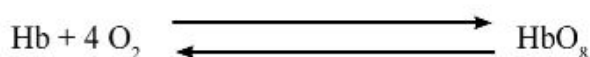
- The lungs serve as an efficient respiratory surface because:
- Alveoli create a large surface area for gas exchange.
- Alveoli and capillary walls are both lined by simple squamous epithelia which reduce the distance the gasses need to travel by diffusion.
- The alveoli surface is moist to dissolve respiratory gasses for diffusion.
- Alveoli are highly vascularized which enables the maintenance of a steep diffusion gradient of respiratory gasses

Gas exchange at the alveoli and in the tissues is a continuous process. It requires transport of O_2 from the lungs to the blood and movement of CO_2 from the blood (referred to as external respiration) and movement of O_2 from blood to the tissues and CO_2 from tissues to the blood (referred to as internal respiration).

Diffusion of O_2 and CO_2 requires partial pressure gradients between the alveolar air in the lungs and blood (during external respiration) and blood and tissues (during internal respiration).

During inhalation, fresh air mixes with the stale air in the lungs. This mixture in the lungs has a higher partial pressure of oxygen (PO_2) and a lower partial pressure of carbon dioxide (PCO_2) than the blood in the alveolar capillaries. There is thus a concentration gradient favoring the diffusion of these two gases in opposite directions. Net diffusion of O_2 takes place from the air in the alveoli to the blood and net diffusion of CO_2 takes place from the blood into the alveoli.

When O_2 molecules diffuse into blood capillaries they bind to haemoglobin in the red blood cells. Four molecules of O_2 bind reversibly with one molecule of haemoglobin and form oxyhaemoglobin.



When blood leaves the alveolar capillaries the oxygen and carbon dioxide partial pressures are in equilibrium with those of alveoli air. Once this blood returns to the heart, it is pumped through the systemic circuit.

Blood reaching the tissues in the systemic capillaries have a higher PO_2 and a lower PCO_2 than in the tissues. These partial pressure gradients result in the net diffusion of O_2 from the blood stream into the tissue and CO_2 diffusion from the cells into the blood stream across the extracellular fluid/interstitial fluid. This is called unloading of O_2 and loading of CO_2 . Then the blood returns to heart and pumped to lungs again.

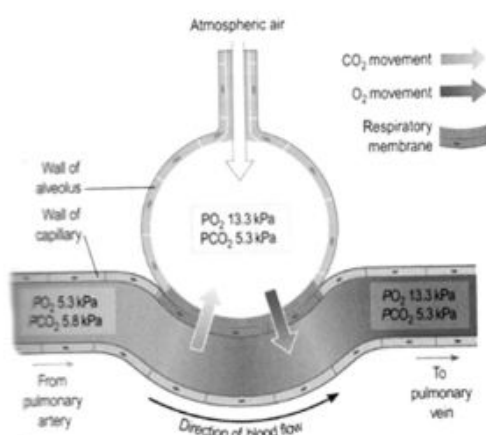


Fig 5.26: External respiration

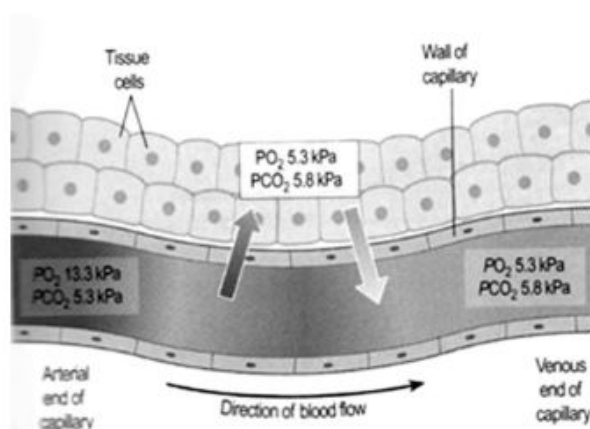


Fig 5.27: Internal respiration

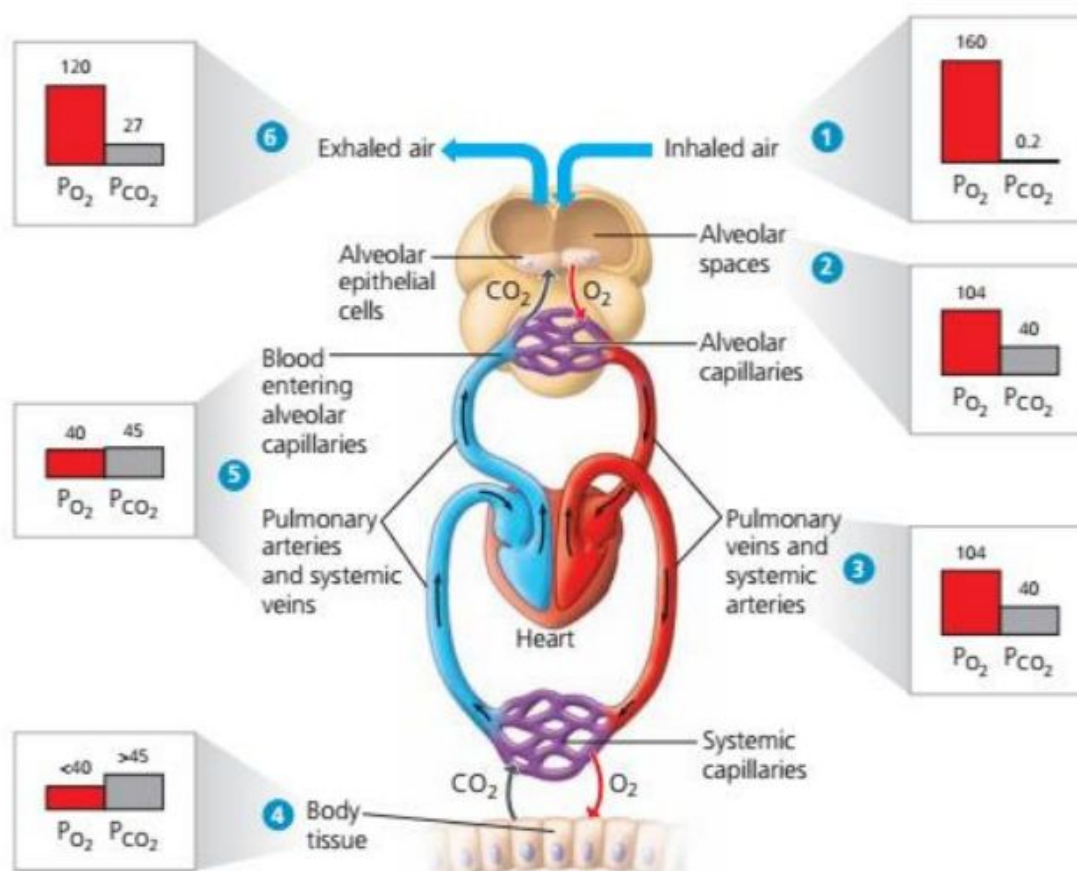


Fig 5.28: Loading and unloading of respiratory gases

Homeostatic control of Breathing

- Typically breathing is regulated by involuntary mechanisms. These involuntary mechanisms help coordinate gas exchange with blood circulation and metabolic demands
- Medulla oblongata is the main breathing regulating center found at the base brain. There are a pair of breathing control centers found in medulla and they are responsible for regulating the breathing rhythm.
- A negative-feedback mechanism is involved in regulating this process. Sensors which detect stretching of the lung tissues are found in the lungs. During inhalation, these sensors send nerve impulses to the neurons that act as control circuits in the medulla and further inhalation is inhibited and this prevents the lungs from over expanding.
- To regulate breathing, the medulla depends on pH changes in tissue fluids. The pH of tissue fluid is an indicator of blood carbon dioxide concentration. For

example, when metabolic activities increase, the concentration of CO_2 in the blood increases. Because CO_2 diffuses into the cerebrospinal fluid, this results in an increase of CO_2 concentration in the cerebrospinal fluid as well. There CO_2 reacts with water and forms carbonic acid (H_2CO_3). H_2CO_3 dissociates into HCO_3^- and H^+



- Hence, a high CO_2 concentration results in an increase in H^+ concentration, thereby a lower pH.
- This pH change is detected by the sensors in the medulla and in major blood vessels called arteries and aorta.
- Sensors in the medulla and major blood vessels detect this decrease in pH. In response, the control circuits in medulla increase the depth and rate of breathing until the excess CO_2 is removed in exhaled air and the pH of blood comes to its normal value which is 7.4
- The O_2 level has little influence on the breathing control centers. But, when O_2 concentration becomes very low, O_2 sensors found in the aorta and the carotid arteries send impulses to the medulla to increase the breathing rate.
- The regulation of breathing is also modulated by additional neural circuits in the pons, a part of the brain stem found above the medulla.

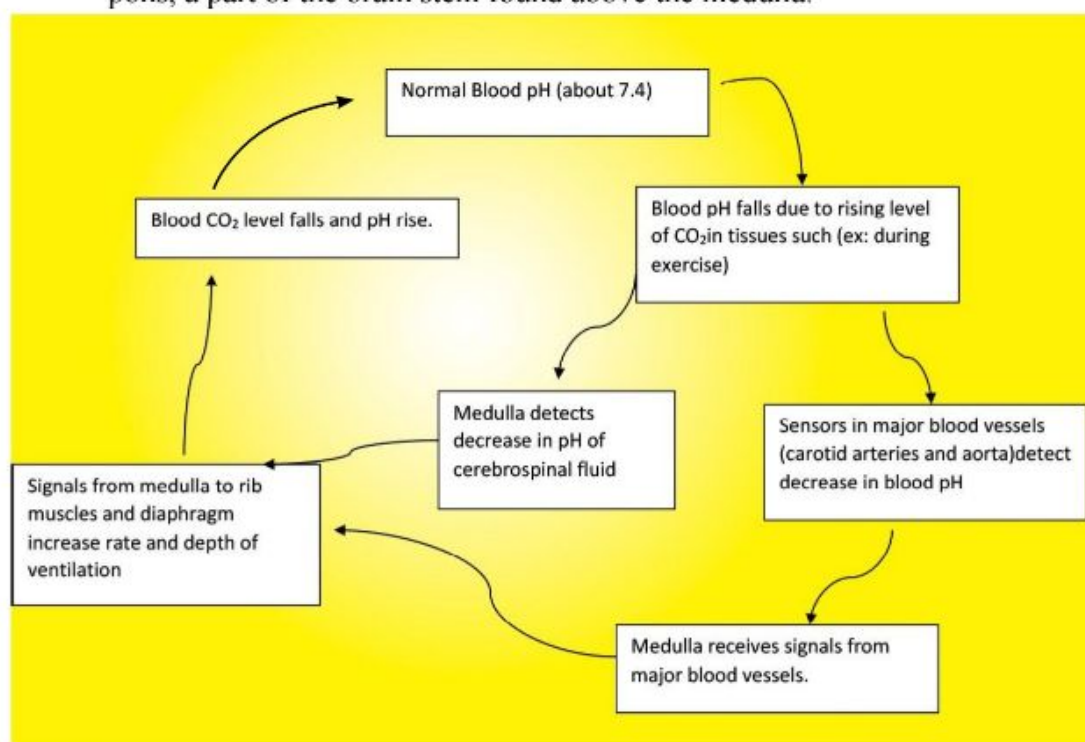


Fig5.29: Homeostatic control of breathing

Disorders of the respiratory system**The effect of smoking on the smooth functioning of the respiratory system**

- Cigarette smoke harms nearly every organ in the body including the organs of the respiratory system and increase the risk of illness, disability and death. Smokers inhale large number of chemicals which mainly come from burning tobacco. Some of these inhaled compounds are chemically active and can trigger damaging changes in the body.
- Nicotine is among the compounds inhaled in tobacco smoke which is the addictive drug in the smoke. It temporarily increases the rate of heart beat and constriction of peripheral blood vessels causing a temporary increase in blood pressure.
- Cigarette smoke stimulates the secretion of mucus by the goblet cells and inhibits the action of cilia in the respiratory tract causing accumulation of mucus in bronchioles and blocking them, leading to bronchial inflammation or bronchitis. As a result, breathing may become difficult.
- Some chemicals such as hydrogen cyanide in cigarette smoke stops the cilia from working properly. Due to loss of action of cilia, dust and other particulate matter get collected in the lung, resulting in an increase in phagocytic cells in the lung tissue. Due to release of large amounts of lytic enzymes by these cells, the alveolar tissue is destroyed thus reducing the effective area available for gas exchange.
- Carbon monoxide (CO) present in tobacco smoke is absorbed into the blood and is able to bind to hemoglobin better than oxygen and combines irreversibly with hemoglobin. Thus it decreases the amount of oxyhaemoglobin produced. Therefore, oxygen transport through blood is decreased.
- Tobacco smoke also contains a large number of cancer-causing substances (carcinogens). Nearly 90% of lung cancers are due to smoking. Long term exposure to such chemicals in cigarette smoke results in the proliferation of cells in the bronchial epithelium, forming a mass of abnormal cells. A cancer may develop among these cells. If these cells break free, the cancer may spread to other parts of the lungs and or to other organs.
- Passive or second hand smoking will also result in the above mentioned ill effects.

Silicosis

This may be caused by long-term exposure to dust containing silica compounds. High risk industries are,

- Quarrying granite, slate, sandstone

- Mining hard coal, gold, tin, copper
- Stone masonry and sand blasting
- Glass and pottery work

When silica particles are inhaled they accumulate in the alveoli. These particles are ingested by macrophages, some of which remain in the alveoli and come out in to the connective tissue around bronchioles and blood vessels close to the pleura. Progressive fibrosis is stimulated which eventually obliterates the blood vessels and respiratory bronchioles. Gradual destruction of lung tissue eventually leads to pulmonary hypertension and heart failure.

Asbestos related diseases - Asbestosis

Those who are involved in making or using products containing asbestos are at risk. This occurs when asbestos fibers are inhaled with dust. In spite of their large size the particles penetrate the level of respiratory bronchioles and alveoli. Macrophages accumulate in the alveoli and the shorter asbestos fibers are ingested. The larger fibers are surrounded by macrophages, protein materials and iron deposits. The macrophages that have engulfed fibers move out of the alveoli and accumulate around respiratory bronchioles and blood vessels, stimulating the formation of fibrous tissue. These cause progressive destruction of lung tissue and pulmonary hypertension.

Lung cancer

Nearly 90% of lung cancer is due to smoking. When one smokes, the nasal hairs, mucus and cilia in the respiratory tract that otherwise is sufficient to protect the lung from chemical and biological irritants, are overwhelmed and eventually stop functioning. As a result, irritants, free radicals, carcinogens and pathogens accumulate in the lungs. Eventually these cause lung cancer.

Tuberculosis (TB)

Tuberculosis is an infectious disease caused by the bacterium *Mycobacterium tuberculosis*. The bacterium spreads when an infected person coughs and the bacterium enters the body of an uninfected person through inhaled air. The most common form is Pulmonary TB which affects the lungs. Other organs may also be affected. Transmission of pulmonary TB is by inhaling the bacterium into the lungs. This bacterium can survive in the air and in the house dust for long periods. Malnutrition and other infectious can reduce resistance to the disease.

Symptoms

Loss of appetite, loss of weight, excessive sweating, fever, a racking cough and spitting up blood.

Asthma

Asthma is characterized by wheezing and chest tightness causing breathing difficulty. This is caused by the sudden contractions of smooth muscles in the walls of the bronchioles which causes the bronchioles to narrow or even close. During this time breathing causes whistling or wheezing sound. The cause of asthma is an over reaction of an immune response to stimuli like pollen, dust, mites, spores, particular food, cold air, exercise, smoking gases. Anti-inflammatory drugs help control.

Respiratory cycle and lung volumes and capacities

Inhalation and exhalation during a single breath is referred to as a respiratory cycle. The amount of air that flows in and out of the lungs depends on the conditions of inspiration and expiration. Thus, four respiratory volumes are described.

- **Tidal volume (TV):** This is the volume of air inhaled and exhaled with each breath during normal breathing. On average it is about 500 ml in a resting adult human.
- **Inspiratory reserve volume (IRV):** This is the extra volume of air that can be forcibly inhaled beyond the tidal volume.
- **Expiratory reserve volume (ERV):** The extra volume of air which can be expelled from the lungs after a tidal expiration.
- **Residual volume (RV):** The volume of air that remains in the lungs even after forceful expiration. This is on average is about 1,200 ml.

Specific combinations of respiratory volumes are called respiratory capacities. Thus, respiratory capacities always consist of two or more lung volumes. The respiratory capacities are important to determine the respiratory status of a person.

- **Inspiratory capacity (IC):** The total volume of air that can be inspired after a tidal expiration.

Thus, $IC = TV + IRV$

- **Functional residual capacity (FRC):** The volume of air remaining in the lungs at the end of a tidal expiration.

Thus, $FRC = RV + ERV$

- The functional residual capacity is important for continuous exchange of gas in the alveoli and to prevent the collapse of the alveoli during expiration.
- **Vital capacity (VC):** The maximum volume of air which can be inhaled and exhaled. It is normally around 3100 mL in women and 4800 mL in men.

$VC = TV + IRV + ERV$

- **Total lung capacity (TLC):** The maximum volume of air the lungs can hold or the sum of all lung volumes. This is normally around 6000 mL.

In addition, some of the inspired air fills the system of branching conducting tubes (trachea, bronchi and bronchioles) and never contributes to the gas exchange in the alveoli. This volume is referred to as the anatomical dead space and it is typically about 150 mL.

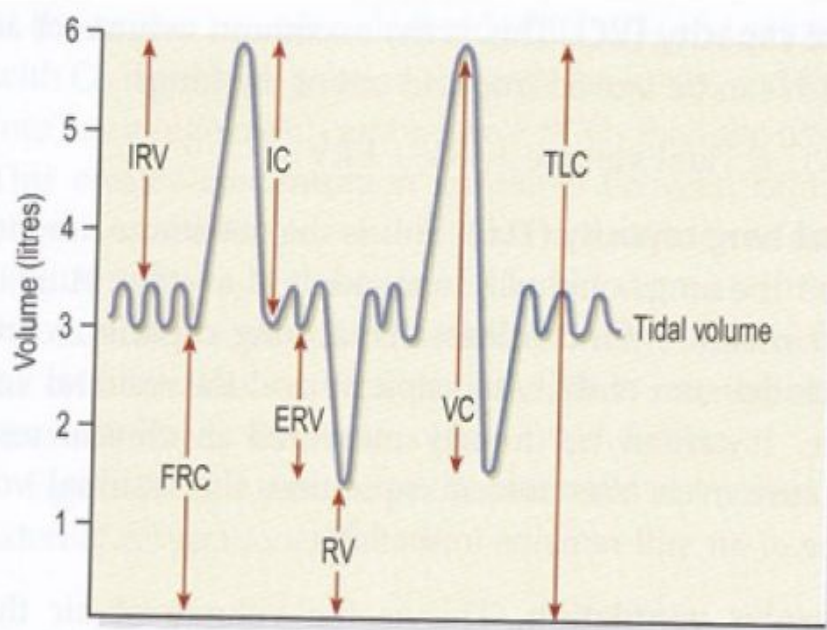


Fig 5.30: Lung volumes and capacities

- IRV: Inspiratory reserve volume
IC: Inspiratory capacity
FRC: Functional residual capacity
ERV: Expiratory reserve volume
RV: residual volume
VC: Vital capacity
TLC: Total lung capacity

Immunity

The state of being resistance to injury, invading pathogens and foreign substances through defensive mechanisms in the body is known as immunity. Pathogens which are the agents that can cause infectious diseases include some bacteria, virus, and fungi. The substances that can be recognized as foreign to the body include chemical components of pollen grains, incompatible blood cells and transplanted tissues. Defenses in the animal body against these foreign invasions make up the immune system. Immune system of animals should be able to distinguish own body cells (self) from foreign cells/particles within the body (non-self) for initiating defensive immune responses for destruction of the foreign agents such as pathogens. Special cell types in the body fluid and tissues of most animals can interact with these foreign invasions and destroy them. Immune cells produce receptor molecules that bind specifically to molecules from foreign cells and agents and activate defense responses.

Immune responses in animals can be divided into two types:

- Innate immunity
- Acquired immunity (Adaptive immunity)

Innate immunity

Innate immunity is the ability to resist damage or diseases in the body through inherent body defenses which offer rapid responses against a broad range of pathogens and foreign substances. In innate immunity, recognition and defense responses will depend on characters common to groups of pathogens. Innate immunity lacks specific responses to specific invaders and its protective mechanisms functions the same way regardless of the type of the invader. Hence innate immunity is also known as non-specific defense. Innate immune responses include defense mechanisms that provide immediate but general protection against foreign invasion. Innate immunity is found in both invertebrates and vertebrates. Innate defense mechanisms can be broadly divided into two types: External barriers (External defenses/ barrier defense) and Internal nonspecific defenses (Internal defenses).

External defenses/ barrier defense in innate immunity

External barriers discourage pathogens and foreign substances from penetrating the body. So they are considered as the first line of defense. For innate immunity in the human body, external defenses/barriers are found in the skin, mucus membranes and secretions of various organs. They act as physical and chemical barriers.

- Human **skin** with its many layers of closely packed, keratinized cell layers in the epidermis provides a significant physical barrier to entrance of microbes. In addition periodic shedding of epidermal cells helps remove microbes from the skin surface.
- The **mucous membranes** which line the body cavities provide a physical barrier to entrance of many microbes (e.g. the linings of the respiratory tract, digestive tract, urinary tract and reproductive tract). The mucous membranes produce mucus which traps microbes and other particles. In the respiratory tract, ciliated epithelial cells sweep mucus and any entrapped material upward. Coughing and sneezing speed up the mucus movement and its entrapped pathogens out of the body preventing their entry to the lungs.
- **Secretions** by various organs (e.g. tears, saliva, mucus) help as physical and chemical barriers to protect epithelial surface of the skin and mucous membranes. Tears in the eyes provide protection against irritants and microbes. Tears in the eyes provide continuous washing action that helps to dilute microbes and prevent settling on the surface of eyes. Saliva washes microbes from the mouth surface and the flow of saliva reduces the colonization of microbes in the mouth. Mucus secretions which bathe various exposed epithelia provide a continual washing action to dilute and inhibit colonization microbes such as bacteria and fungi. Lysozyme (an enzyme) present in tears, saliva, perspiration and mucous secretions can destroy cell walls of some bacteria. Gastric juice which provides an acidic environment in the stomach can destroy many bacteria and bacterial toxins ingested with food. Secretions of the sweat and sebaceous glands of the skin give acidity of the skin which helps to prevent growth of bacteria.

Internal defenses in Innate immunity

When the pathogens penetrate the external defensive barriers in the skin and mucus membranes in the human body, they encounter a second line of innate immunity responses called internal defenses. Within the body, detection of non-self is accomplished by molecular recognition in which receptor molecules on specific cells in the immune system will bind specifically to molecules of foreign agents such as pathogens.

In innate immunity, internal defenses consist of Phagocytic cells, Natural killer cells, Antimicrobial proteins and Inflammatory responses.

- **Phagocytic cells:** These are specialized cells that can ingest microbes, foreign particles and cell debris for intra cellular digestion and destruction. Phagocytes use the receptor molecules to detect components of foreign agents and particles. Neutrophils and Macrophages are the two main types of phagocytic cells in man. While circulating in the blood, neutrophils are attracted first to the infected site

by signals from affected tissues. Then neutrophils can ingest and destroy infected pathogens. Macrophages are larger and more potent phagocytic cells.

- **Natural killer cells:** These are a type of lymphocytes present in the blood and some tissue/organs such as spleen and lymph nodes which function in nonspecific defense. They can detect the cells with abnormal surface molecules (e.g. virus-infected body cells and some cancerous cells) and kill them. Natural killer cells do not engulf these abnormal cells but upon binding they can release chemicals to kill the virus-infected cells and cancerous cells which could inhibit further spread of the virus or cancer.
- **Antimicrobial proteins:** They are proteins present in the blood and interstitial fluids which function in innate defense by attacking microbes directly or impeding their reproduction. Interferons and Complement proteins are two such antimicrobial proteins that discourage microbial growth. **Interferons** are proteins secreted by virus-infected body cells that protect uninfected host cells from viral infections by interfering with the viral replication. Once released by virus-infected cells, interferons diffuse to uninfected neighboring cells where they are stimulated to produce “anti-viral proteins” which inhibit viral replication. Some interferons activate macrophages which enhance the phagocytic activity. Complement proteins are a group of normally inactive proteins in the blood plasma and plasma membranes. When they are activated by different substances present on the surfaces of microbes, a cascade of biochemical reaction occurs which lead to lysis of invaded cells. They also promote phagocytosis and inflammatory response.
- **Inflammatory response:** This is an innate immune defense response in the body to tissue damage triggered by microbial infections or injury of the tissues. This involves the release of substances that promote increased permeability and dilation of blood vessels, enhance migration of phagocytes, destruction of invading pathogens and aid in tissue repair (Figure 5.31). Inflammation attempts to destroy the microbes at the site of the injury preventing the spread to other tissues and promote tissue repair.

Inflammatory response is brought about by various signaling molecules upon infection or injury. Histamine is one of the important inflammatory signaling molecules released mainly by mast cells in the connective tissues at the site of damage. Histamine causes increased permeability and dilation of nearby blood vessels (blood capillaries). Increased permeability of the blood vessels enhance the infiltration of white blood cells, antimicrobial proteins and clotting elements to enter the injured area from the blood that aid in destruction of invading pathogens and tissue repair. Dilation of blood vessels allows more blood to flow through the damage area which helps to remove dead cells. Activated phagocytes (macrophages and neutrophils) moved from the

blood to the damaged tissue area can also discharge signaling molecules (cytokines) which also promote blood flow to the injured or infected site. During inflammation, activated complement proteins can cause further histamine release which attracts more phagocyte cells to enter injured tissue and carry out additional phagocytosis. This process can digest the microbes and cell debris at the site of injury.

Signs and symptoms of inflammation are redness, heat, swelling and pain. Dilation of blood vessels causes redness and heat production due to high metabolism in the area. Increased permeability of blood vessels triggers localized swelling due to leaking of tissue fluid into neighboring tissues. Pain results from injury to neurons and microbial toxins. As a result of most inflammatory responses, pus may be accumulated. It is a fluid rich in dead phagocytes, dead pathogens and cell debris from the damaged tissue. Minor injury or infection causes a localized inflammatory response. If the injury or infection is severe it may lead to a systemic response (throughout the body) leading to fever. Elevated body temperature within limits may enhance the phagocytosis and accelerate tissue repair by speeding up the chemical reactions.

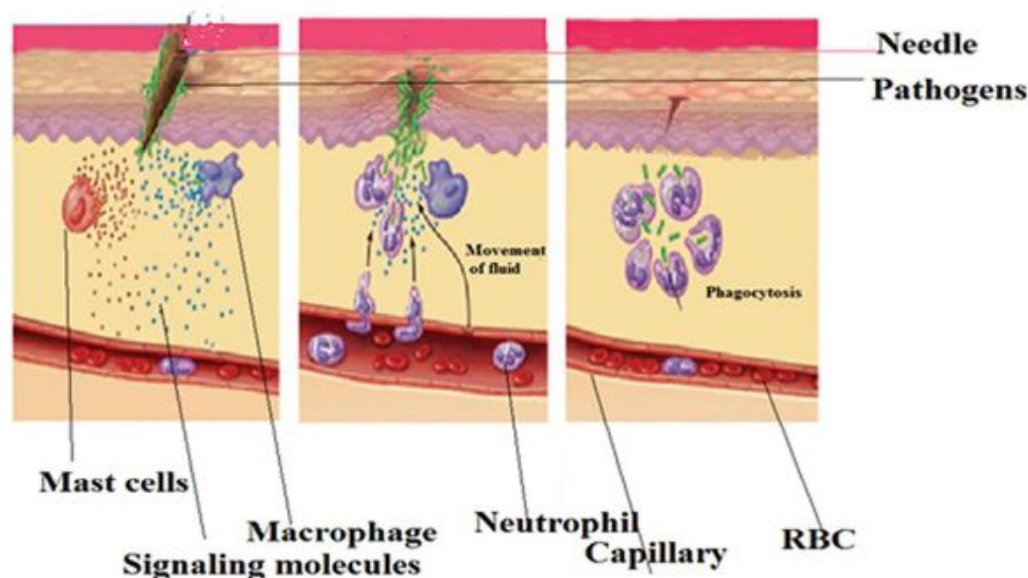


Fig 5.31: Major events in inflammatory response

Acquired Immunity (Adaptive Immunity)

Acquired immunity is the ability of the body to defend itself against invading foreign agents (e.g. pathogens) through specific defense responses mediated by diverse **T lymphocytes and B lymphocytes**. Acquired immunity shows (i) specificity for particular foreign molecules (ii) recognition of animals own molecules (self-molecules) from non-self-molecules and (iii) memory for most previously encountered pathogens such that the subsequent encounter causes a stronger and more rapid response (immunological memory). In the animal kingdom, acquired immunity is found only in the vertebrates.

The cells that have developed the ability to carry out acquired immune responses if they are activated against foreign agents are called **T lymphocytes** and **B lymphocytes**. In man, both types of lymphocytes are originated from stem cells in the bone marrow. Some of the lymphocytes that migrate to thymus for maturation are called T lymphocytes (T cells). The lymphocytes that remain in the bone marrow for completion of development are called **B lymphocytes** (B cells). Before leaving these lymphocytes to the secondary lymphatic tissues, their plasma membranes acquire diverse specific protein receptors (antigen receptors) which have the ability to recognize specific foreign invasions (There can be over 100,000 antigen receptors on the surface of a single B lymphocyte or T lymphocyte)

An **antigen** is a substance that has the ability to stimulate an immune response through T lymphocytes and B lymphocytes and to react with the specific cells or antibodies that resulted from the stimulated immune response. Viral proteins, bacterial toxins and chemical components of bacterial structures such as flagella and cell walls can be antigenic. Structural components of incompatible blood cells, transplanted tissues can also be antigenic. Antigens are usually large foreign molecules such as proteins and polysaccharides. In general not the entire antigen, but certain parts of a large antigen molecule act as the triggers for the acquired immune responses. The small accessible portion of the antigen that binds to a specific antigen receptor of a T lymphocyte or B lymphocyte is called an epitope (for exp a group of amino acids in a large protein). Can serve as an epitope. Usually a single antigen has several epitopes (Figure 5.32) each can bind with a specific antigenic receptor of the single T or B lymphocyte.

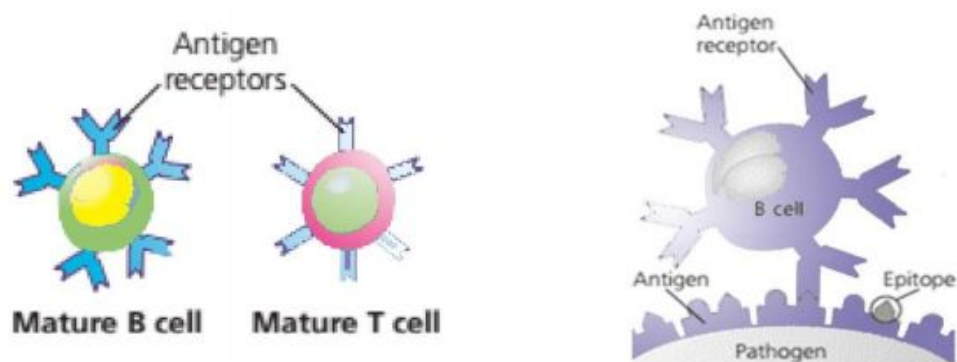


Figure 5.32: (a). Mature T lymphocyte and mature B lymphocyte with antigen receptors on the plasma membrane, (b). B cell receptor binds with an Epitope on antigen

In acquired immunity, two types of immune responses are mediated by T lymphocytes and B lymphocytes. They are Cell mediated immune responses and Humoral immune responses. Humoral immune response is also called as Antibody mediated immune response. Both immune responses are triggered by antigens. A given pathogen may provoke both types of immune responses.

Cell mediated immune response

Cell mediated immune response is a type of acquired immunity in which specifically sensitized T lymphocytes attach to the antigen undergo proliferation and eventually differentiate into “Cytotoxic T cells” that can directly kill the cells with the invading antigen. In addition “Memory T cells” are formed that can cause stronger and more rapid response at the subsequent encounter of the same antigen to the body. This is particularly effective against infected cells (fungi, parasites and virus that are present within host cells), some cancer cells and foreign transplanted cells. Cell mediated immunity always involves cells attacking cells.

Humoral immune response

Humoral immune response is a type of acquired immunity in which specifically sensitized B lymphocytes attach to a particular antigen undergo proliferation and eventually differentiate into “Plasma cells” that secrete circulating antibodies that can neutralize and inactivate the specific toxins and pathogens in the blood and lymph. In addition “Memory B cells” are formed that can cause stronger and more rapid response at subsequent encounter of the same antigen. Humoral immune response works mainly against antigens present in body fluids and extracellular pathogens (mainly bacteria) that multiply in the body fluids.

Antibodies

Antibodies are proteins secreted by plasma cells (differentiated B lymphocytes) in response to specific antigens; the antibody binds with that antigen to neutralize, inhibit or destroy it. Antibodies can neutralize and inactivate the specific toxins and pathogens in the body fluids. The antibodies do not directly kill the pathogens but can interfere with activity of the pathogen or mark the pathogen for inactivation and destruction. Antibody-antigen complexes can activate complement system and phagocytosis to destroy the pathogen. Antibodies are also called as immunoglobulins. Immunoglobulin has the same Y shaped structure as B lymphocyte antigen receptors but are secreted than membrane bound.

Role of T lymphocytes and B lymphocytes in acquired immunity**Recognition of the antigen, binding to the antigen and sensitization:**

For an acquired immune response to occur, some T lymphocytes or B lymphocytes must first recognize that a foreign antigen is present in the body. Even though there are vast variety of antigen receptors present on different B lymphocytes and T lymphocytes, only a very small fraction are specific for a particular epitope. Hence, antigen should be presented to the B lymphocytes and T lymphocytes until a match is made. Recognition of the antigen occurs through successful match between an epitope of the antigen and an antigen receptor on small number of B lymphocytes or T lymphocytes. As specific antigen receptors produced by a single T cell or B cell can be identical they can bind to the same epitope. Hence, both T and B cells can respond to any pathogen that produces molecules containing that same epitope. But B cells and T cells encounter antigens in different ways. T lymphocytes only recognize the fragments of antigenic proteins that are presented to the cells by a special cells called “antigen presenting cells” (macrophages, dendritic cells and B cells). However, B lymphocytes can recognize and bind to the antigens present in blood plasma, lymph and interstitial fluid. The binding of an antigen to the specific antigen receptor results in sensitization (activation) of a specific T lymphocyte or B lymphocyte which initiates cell mediated and antibody mediated immune response as described below.

Proliferation and differentiation into Effector cells: Once activated the T lymphocyte or B lymphocyte undergoes multiple cell divisions (proliferations) resulting a clone, a population of cells that are identical to the original lymphocyte. Some cells of clones become Effectors cells which are short lived cells that take effect immediately against antigen to provide primary immune responses.

Elimination of invaders: The effector forms of T lymphocyte are “Cytotoxic T cells” and “Helper T cells”. Cytotoxic T cells use toxic proteins to kill the cells infected with the pathogen. Signals from Helper T cells activate cytotoxic T cells to kill the infected cells. Signals from Helper T cells can also activate B lymphocytes to initiate antibody production. Effector forms of B lymphocytes are “Plasma cells”. A single activated B lymphocyte can form thousands of identical Plasma cells. The plasma cells begin producing and secreting a soluble form of the B lymphocyte antigen receptor (antibodies) in large quantities which are released to the blood and lymph. Hence, circulating antibodies can neutralize and inactivate the specific toxins and pathogens in the body fluids.

Provide immunological memory: Following differentiation into Effector T cells (Cytotoxic T cells and Helper T cells), other T lymphocytes in the clones remain as “Memory T cells” which are long lived that can give rise to Effector T cells if the same

antigen is encountered later in the life. Similarly the remaining B lymphocytes in the clones are “Memory B cells” which are long lived that can give rise to Plasma cells if the same antigen is encountered later in the life. These Memory T cells and Memory B cells can cause stronger and more rapid response at subsequent encounter of the same antigen to the body. This immunological memory is called secondary immune responses.

Active immunity

Active immunity is a long lasting immunity mediated by the action of B lymphocytes and T lymphocytes in the body and the resulting B and T memory cells specific for a pathogen. Active immunity can be developed as a result of natural infection of a pathogen or artificial immunization.

Naturally acquired active immunity

Long lasting immunity developed in the body against various infectious diseases in response to natural infections of pathogens is called naturally acquired active immunity. In response to a disease causing agent entering the body naturally for the first time (e.g. Virus of Chickenpox), some T lymphocytes and B lymphocytes in the body become activated and eventually produce specific cytotoxic T cells and antibodies to destroy the pathogen. Memory B cells and T cells produced in this process are long lived that will provide a stronger and rapid immune responses to destroy the particular antigen if the same antigen (e.g. Virus of Chickenpox) is encountered later in the life. In this way the body can resist to subsequent infections of the same antigen.

Artificially acquired active immunity

Long lasting immunity induced artificially in the body against various infectious diseases through vaccination (immunization) of attenuated (virulence-reduced) pathogens is called artificially acquired active immunity. Immunization can be carried out with preparations of antigens (vaccines) from many sources such as killed or weakened pathogens, inactivated bacterial cells or genes encoding microbial proteins. These vaccines act as the antigens and stimulate cell mediated and antibody mediated immune responses leading to production of long lived memory B and T cells to destroy the antigen. If the pathogen from which the antigen was derived, is encountered naturally later in the life, long lived memory cells can provide a stronger and rapid immune responses to destroy the particular pathogen. In general, the antigens used in the vaccines are pretreated to be immunogenic but not pathogenic. For example, BCG vaccine which is used against tuberculosis disease in man, has been prepared from a strain of the attenuated live tuberculosis bacteria. Polio vaccine consists of live attenuated poliovirus strains. Polio vaccine produces antibodies in the blood against polio virus, and in the event of infection, this protects the individual by preventing the spread of poliovirus to the nervous system.

Passive Immunity

Passive immunity is the short term immunity developed within the body due to the transfer of antibodies produced by another individual. Passive immunity provides immediate protection, but the body does not develop memory as passive immunity does not involve recipients' T cells and B cells. Passive immunity persists only until the transferred antibodies last (few weeks to few months). Therefore the recipient is at risk of being infected by the same pathogen later unless they acquire active immunity or vaccination. Passive immunity can be developed as a result of transferring antibodies to the recipient naturally or artificially.

Naturally acquired passive immunity

Short term antibody mediated immunity for some infectious diseases can be developed within the body of the fetus or nursing infant due to the natural transfer of antibodies produced by the mother. The immunity occurs due to the transfer of antibodies to the fetus blood from mother's blood across the placenta. Antibodies also can pass from mother to the nursing infant through the colostrum and the milk during breast feeding. The baby develops the resistance against some infectious diseases for a short time. In this way the infant may be protected from these diseases until its own immunity system is fully functional. This is known as naturally acquired passive immunity.

Artificially acquired passive immunity

Artificially acquired passive immunity is a temporarily induced defensive protection achieved by the transfer of antibodies artificially to the blood of the recipient from another source. These readymade antibodies can be administered as blood plasma or serum (human or animal), or as injections of pooled human immunoglobulin from immunized donors or as monoclonal antibodies. Passive transfer of antibodies is used to prevent some infectious diseases when infectious agents are suspected to have accidentally entered the body (e.g. readymade human serum antibodies for hepatitis A virus). It is also used in the treatment of several types of acute infections (e.g. readymade human anti-tetanus immunoglobulin for acute conditions of tetanus). Passive immunization is also used to treat poisoning from venomous snake bite (e.g. antivenin, serum prepared from horses that have been immunized against snake venom). Immunity derived from artificially acquired passive immunization lasts for few weeks to four months.

Allergies

Some persons are overly reactive to substances that are tolerated by most other people. Antigens that induce hypersensitive reactions in some persons are called allergens. Exaggerated responses of the body to certain antigens (allergens) are called allergies. Common allergens include pollens, dust, some food (e.g. shellfish), some antibiotics

(e.g. penicillin), venom from honey bees and wasps. Whenever an allergic reaction takes place the tissue injury occurs. The most allergens stimulate production of plasma cells which secrete antibodies specific for the antigen. When the same allergen enter the body later, it become attach to the antibodies specific to the allergen which induce the mast cells to release histamine and other inflammatory chemicals. Acting on a variety of cell types these signals bring about typical allergy symptoms such as sneezing, runny nose, teary eyes and smooth muscle contractions in the airways of the lungs that can result in breathing difficulties. An acute allergic conditions sometimes lead to death of the person due to breathing difficulties and low blood pressure with a few seconds of exposure to an allergen.

Autoimmune diseases

In some persons, the immune system becomes active against particular self-molecules of the body and begins to attack the person's own tissues leading to an autoimmune disease. Possible causes for autoimmune diseases may be genetic factors, gender and unknown environmental triggers. Many autoimmune diseases affect females than males. A variety of mechanisms produce different autoimmune diseases. Some involve the production of autoantibodies that can affect normal functioning of certain body molecules. Some involve activation of Cytotoxic T cells that destroy certain body cells. Examples for autoimmune diseases include Type 1 Diabetes mellitus, Multiple sclerosis and Rheumatoid arthritis. In Type 1 Diabetes mellitus, T cells attack the insulin producing pancreatic beta cells. In Multiple sclerosis, T cells attack myelin sheaths around neurons. In Rheumatoid arthritis, painful inflammations of the cartilage and bones occur as the immune system mistakenly sends antibodies to the lining of the joints, where they attack the tissue surrounding the joints.

Immunodeficiency diseases

Immunodeficiency disease is a disorder in which responses of the immune system to antigens are defective or absent. An immunodeficiency can lead to frequent and recurrent infections and increased susceptibility to certain cancers. An inborn immunodeficiency results from a genetic or developmental defects in the production of immune system cells or specific proteins such as antibodies or proteins of the complement system. Acquired immunodeficiency can be developed later in life due to the exposure to chemicals or biological agents. Drugs used to fight autoimmune diseases or prevent transplant rejections suppress the immune system leading to an immunodeficiency state. The human immunodeficiency virus (HIV), the pathogen that cause Acquired Immunodeficiency Syndrome (AIDS) escapes and attacks the immune system of man. The HIV causes progressive destruction of immune responses in the person leading to frequent infections and increased susceptibility to certain cancers which can cause death.

Osmoregulation and excretion

Osmoregulation is processes by which organisms control solute concentrations and water balance within the body. Simple unicellular organisms such as *Amoeba*, *Paramecium* etc. use contractile vacuoles for osmoregulation. But animals have developed different structures for osmoregulation. The chemical reactions that occur in organisms result in the formation of waste products, often toxic, which must be disposed in some way. The removal of the nitrogenous metabolite and other metabolic waste products from the body is called excretion. Defecation is not considered under excretion as it involves the removal of undigested food from the gut. In many animals excretory and osmoregulatory systems are linked structurally and functionally.

Importance and need of osmoregulation and excretion

For effective body functioning and survival animals have to maintain a constant internal environment specially the relative concentrations of water and solutes within favorable limits. Therefore animals need to regulate the chemical composition of body fluids by balancing uptake and loss of water and solutes. Animal cells will swell and burst if water uptake is excessive. On the other hand, animal cells will shrink and die if water loss is high. The driving force of loss of water in animals as in plants is the concentration gradient of solutes across the cell membrane. Animals have evolved different osmoregulatory strategies depending on the environment in which they live for their survival.

Animals have to get rid of toxic products produced during metabolism in order to safeguard the composition of their internal environment. Otherwise these excretory end products become toxic to the body cells. For example protein and nucleic acids are broken down within the body cell during metabolism and the amine group is converted to ammonia which is highly toxic. Ammonia also acts as a weak base. Oxidation of glucose during metabolism will release CO_2 which is a weak acid. Accumulation of such weak acids and bases will alter the acid base balance in the internal environment. Changes in acid base balance will lead to adverse effects such as denaturation of proteins. Therefore removal of excretory products from the body is essential to maintain the internal environment within favorable limits for effective body functioning and survival.

Relationship between metabolic substrates and excretory products

Metabolic substrates in the cells are carbohydrates, fats, proteins and nucleic acids. The excretory products of these substrates will vary depending on several factors such as the chemical structure and the composition, availability of enzymes, oxygen availability and the habitat in which they live.

When carbohydrates are metabolized within the body cells when oxygen is available final excretory end products are CO_2 and water. If they are subjected to anaerobic respiration in general lactic acid is produced.

When fats are subjected to aerobic metabolism final excretory products are CO_2 and water. Since proteins contain amine groups in their structure, during metabolism of excess amino acids ammonia is produced. Since nucleic acids contain nitrogenous bases ammonia is produced as an excretory product during their metabolism. Depending on the habitat and the availability of enzymes ammonia will be further converted to other nitrogenous waste products such as urea and uric acid.

Relationship between the nitrogenous excretory products and living environment

Nitrogenous excretory products of animals are ammonia, uric acid and urea. These different forms vary significantly in their toxicity and the energy costs of producing them.

Since ammonia is highly toxic, a large volume of water is needed to excrete ammonia. Therefore typically the organisms that live in water such as bony fishes, many aquatic invertebrates and aquatic amphibians specially tadpoles excrete ammonia since they have ready access to water. Energy cost for producing ammonia for excretion is comparatively low.

Terrestrial animals do not have access to sufficient water to excrete ammonia as the main excretory product. Instead most terrestrial animals such as mammals and adult amphibians mainly excrete urea as the main nitrogenous excretory product. Urea is less toxic. However animals must expend more energy to produce urea from ammonia. Some marine fishes such as sharks also excrete urea (which they use for osmoregulation) as the main nitrogenous waste.

Some terrestrial animals such as birds, many reptiles, land snails and insects excrete uric acid as the main excretory product. Uric acid is relatively non-toxic and generally insoluble in water. Therefore it is excreted as a semisolid with trace amount of water. However uric acid production from ammonia requires more energy than urea production.

The diversity of excretory structures of animals (Fine structures are not necessary)

Body Surface - The cells of some animals which are in direct contact with the environment and eliminate excretory products by diffusion. e.g. cnidarians

Flame cells- These are specialized excretory cells connected to a network of tubule which opens to the outside of the animal. E.g. flatworms.

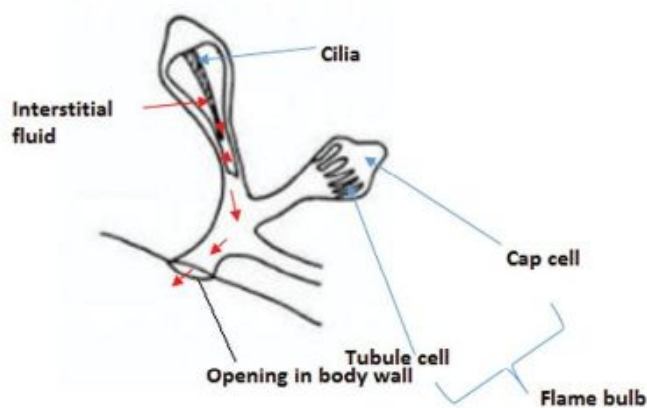


Fig 5.33: Structure of the flame cell

Nephridia – They are multi cellular, tubular structures. One end of the tubule is open to the coelom while the other end opens to the outside. e.g. Annelids

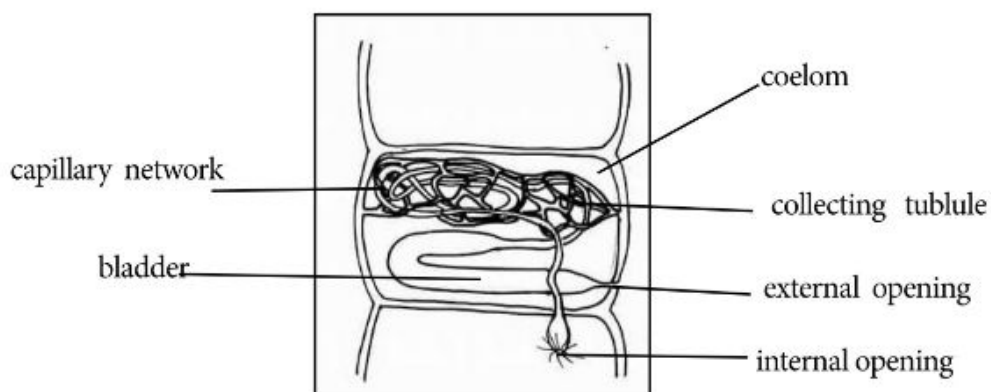


Fig 5.34: Structure of the nephridia

Malpighian tubules – These are extensive blind end tubules immersed in hemolymph and opens in to the digestive tract. e.g.: Insects and other terrestrial arthropods

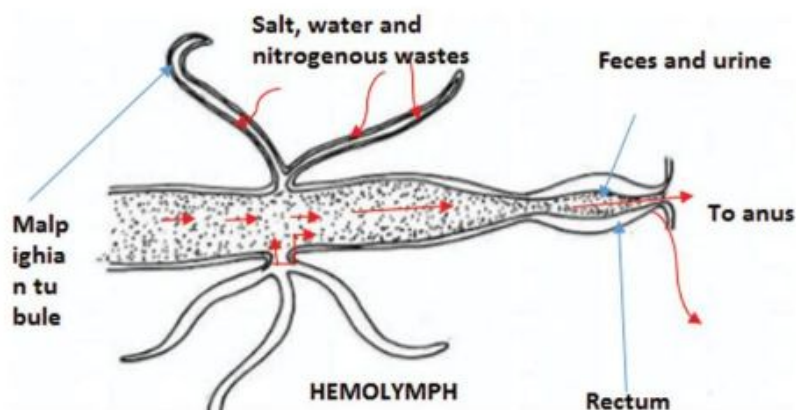


Fig 5.35: Malpighian tubules

Green glands / Antennal glands –Two large glands found ventrally in the head and anterior to the oesophagus. e.g. Crustaceans

Sweat glands –There are coiled tubular glands situated in the dermis and connected to a sweat duct which open as a pore on the surface of the skin. E.g. human skin.

Salt glands –They are paired glands found near the eyes to excrete excess salts. e.g. Marine birds and marine reptiles.

Kidney – These are the major excretory and osmoregulatory organs of all vertebrates.

Human Urinary System

Human urinary system consists of two kidneys, two ureters, urinary bladder and urethra. Their main functions are given in the following table;

Part	Main Function
Kidney	Produce urine to excrete waste products while maintaining osmotic balance and acid base balance.
Ureter	Receives urine from kidney and send it to bladder
Urinary bladder	Temporary storage of the urine
Urethra	Provide the passage through which urine stored in the bladder leaves the body

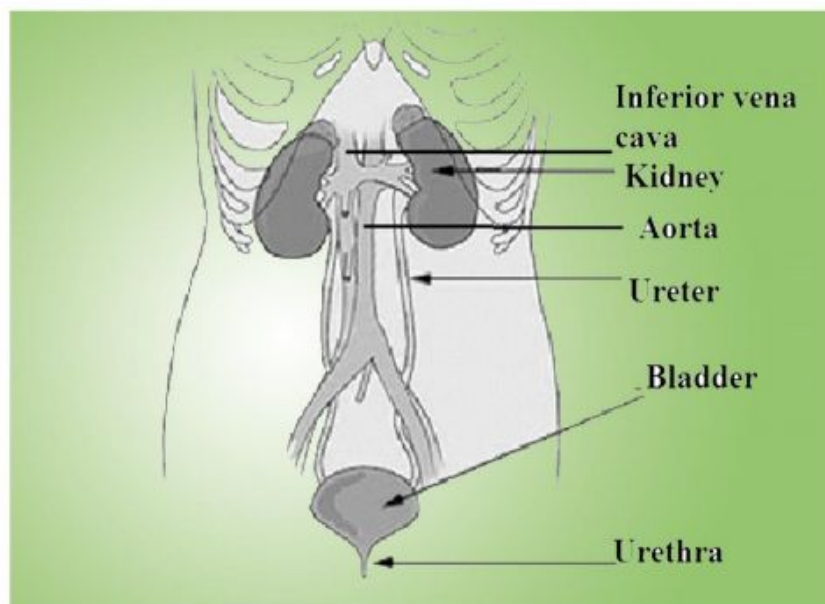


Fig 5.36: The parts of the human urinary system

Location of kidneys

Two kidneys are located on the posterior abdominal wall one on either side of the vertebral column, behind the peritoneum and below the diaphragm. Right kidney is slightly lower than the left.

Blood supply

The kidneys receive blood from aorta via the renal arteries and renal veins return blood to the inferior vena cava.

Gross structure of the kidney

Kidney is a bean shaped organ which is held in position by a mass of fat and both are surrounded by a fibrous connective tissue. In the longitudinal section of the kidney three areas of tissues can be seen to the naked eye. They are outer fibrous capsule, renal cortex and inner renal medulla. Cortex and medulla are supplied with blood vessels and tightly packed with excretory tubules. Renal Cortex is granulated due to the presence of glomeruli. Medulla is composed of renal pyramids, which have striated appearance. Apices of pyramids project in to the renal pelvis through renal papillae. Renal pelvis leads into the ureter. Renal artery and renal vein pass through the pelvis.

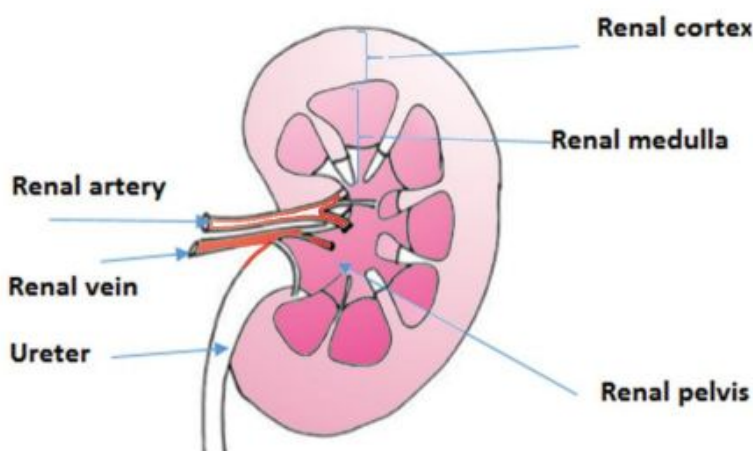


Fig 5.37: Longitudinal section of human Kidney

Structure of Nephron

Nephron is the structural and functional unit of the kidney. There are over millions of nephrons in each kidney. There are two types of nephrons; they are cortical nephrons (reach short distance to the medulla) and juxta medullary nephrons (extend deep into the medulla).

Majority of the nephrons are cortical nephrons.

A nephron consists of a single long tubule and a ball of capillaries called the glomerulus. The tubule is closed at one end forming Bowman's capsule which surrounds the glomerulus. The other end of the tubule joins with the collecting duct.

Tubule consists of;

- Bowman's capsule
- Proximal convoluted tubule
- Loop of Henle
- Distal convoluted tubule

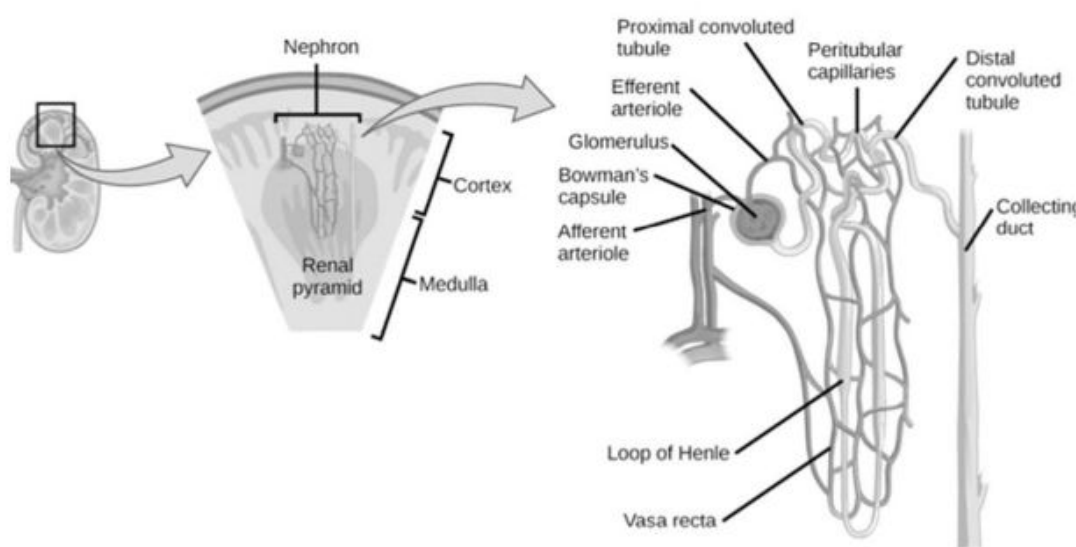


Fig 5.38: A nephron and associated blood vessels

Bowman's capsule (Glomerular capsule)

This is the expanded and closed end of the tubular structure of the nephron. It is a cup-shaped and double-walled structure. The inner layer of Bowman's capsule consists of a single layer of flattened epithelial cells specialized for filtration. The outer layer of the Bowman's capsule is composed of simple squamous epithelium. The space between the inner and outer layers is known as the capsular space, which is responsible for receiving the glomerular filtrate. The glomerular filtrate passes through three major tubular regions of the nephron: the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule.

Glomerulus

The glomerulus is a ball of capillaries which is surrounded by Bowman's capsule. The nephron is supplied with blood from the afferent arteriole. The blood vessel leaving away from the glomerulus is the efferent arteriole. The efferent arteriole has a smaller diameter than the afferent arteriole. This modification is important for increasing blood pressure in the glomerulus for ultrafiltration.

The efferent arteriole forms two capillary networks, one forms the peritubular capillaries which surrounds the proximal and distal convoluted tubules and the other network forms the vasa recta which extend towards the medulla surrounding the loop of Henle.

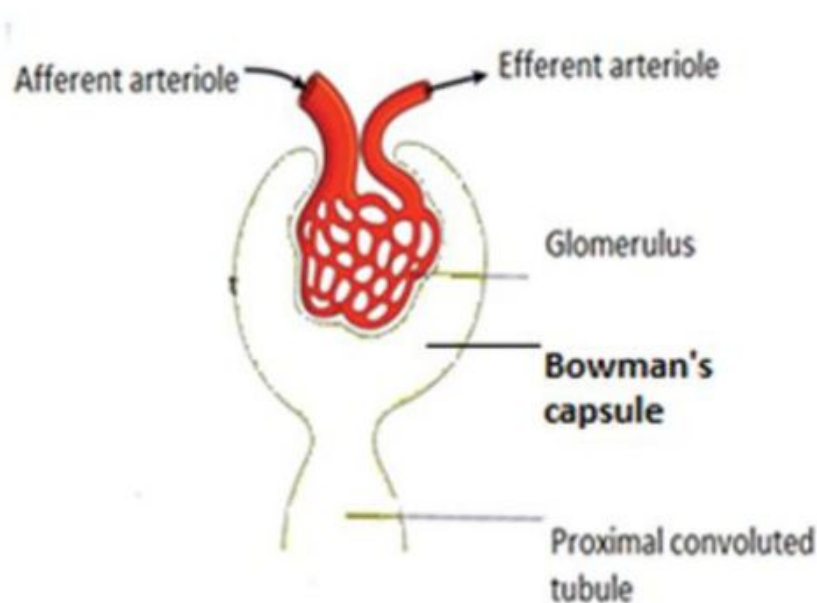


Fig 5.39 The Glomerulus and the Bowman's capsule

Proximal convoluted tubule

It is comparatively longer and wider than the distal convoluted tubule. This is lined by simple epithelium which has been specialized for selective reabsorption of substances (nutrients, ions and water) from the glomerular filtrate.

Loop of Henle

It is a 'U' shaped part of the nephron with descending limb and ascending limb which are lined by simple epithelium.

Lining of the descending limb of loop of Henle is specialized for water reabsorption as it allows free movement of water. But lining of the ascending limb of loop of Henle is impermeable to water.

Distal convoluted tubule

It is lined by simple epithelium which has been specialized for selective reabsorption of specific ions and water. It leads into collecting duct.

Main steps in urine formation

There are 3 processes involved in urine formation. They are;

- ultrafiltration
- selective reabsorption
- secretion

Ultra filtration

- Filtration of the blood under high pressure into the cavity of the Bowmans' capsule is called ultrafiltration.
- Filtration occurs through the capillary walls of glomerulus and inner wall of Bowman's capsule.
- Blood capillaries of glomerulus are porous and cells lining the Bowmans' capsule are specialized for filtration of small size molecules and ions. These specializations allow passage of water and small solutes through the blood capillary walls into the Bowman's capsule. But due to their large size, blood cells, platelets and large molecules such as plasma proteins do not pass into the Bowmans' capsule.
- The filtrate in the Bowmans' capsule contains salts, amino acids, glucose, vitamins, nitrogenous wastes and other small molecules. The composition of the glomerular filtrate is similar in composition to plasma with exceptions of blood cells, platelets and plasma proteins.

Selective reabsorption

- The process through which useful molecules, ions and water from the glomerular filtrate are recovered and returned to the interstitial fluid and then into capillary network of the tubules is called selective reabsorption.
- Most of the reabsorption from the glomerular filtrate back into the blood takes place in the convoluted tubule. Ions, water and valuable nutrients are reabsorbed either active or passive transport from initial filtrate.

Secretion

- The process by which foreign materials and substances not required to the body including waste are cleared from the peritubular capillaries and interstitial fluid into the filtrate is called secretion

- Secretion is required because such substances may not be entirely filtered due to the short time they remain in the glomerulus.
- Substances that are secreted in to the filtrate include H^+ , NH_3 , creatinine, drugs (e.g. penicillin, aspirin) and excess K^+ . Tubular secretion of H^+ and NH_3 are important to maintain the normal pH in the blood by formation of NH_4^+ in the urine. NH_3 can combine with H^+ to form NH_4^+ .
- Secretion occurs in the proximal and distal convoluted tubules. Secretion may be either active or passive depending on the location and / or the substance.

Process of urine formation

Glomerular filtrate in the Bowman's capsule which contains all the substances in the blood except blood cells, platelets and large molecules pass to the proximal convoluted tubule. At this region selective reabsorption of ions, water and valuable nutrients from the initial filtrate occurs. Nutrients especially glucose and amino acids are actively transported to the interstitial fluid. Cells lining the tubule actively transport Na^+ into the interstitial fluid and this transfer a positive charge out of the tubule drives the passive transport of Cl^- . Proximal tubule also reabsorbs K^+ and most of the HCO_3^- by passive transport. Reabsorption of HCO_3^- in the filtrate contributes to the pH balance in body fluids. As solutes move from the filtrate to interstitial fluid water is reabsorbed passively by osmosis. A major portion of water reabsorption from the filtrate occurs at this site. As the filtrate pass through the proximal convoluted tubule, secretion of specific substances into the filtrate takes place. Cells lining the tubule secrete H^+ (by active transport) and ammonia (by passive transport) into the lumen of the tubule. Secreted ammonia act as a buffer to trap H^+ forming NH_4^+ . In addition some materials such as drugs and toxins that have been metabolized in the liver are actively secreted into the lumen of the proximal convoluted tubule. As a result of water reabsorption and secretion of different substances, the filtrate becomes more concentrated as it passes through the proximal convoluted tubule.

As the filtrate moves into the descending limb of loop of Henle passive reabsorption of water through osmosis continues and filtrate becomes more concentrated. The filtrate reaches the ascending limb of the loop of Henle via the tip of the loop. Ascending limb is impermeable to water so that no water absorption takes place but a considerable amount of NaCl reabsorption occurs at this site. Most of the Na^+ is transported into the interstitial fluid by active transport. As a result of losing NaCl but not water the filtrate become more diluted as it moves towards the distal convoluted tubule.

The distal convoluted tubule plays an important role in regulating K^+ and NaCl concentration of body fluids. The amount of K^+ secreted (by active transport) into the filtrate and the amount of NaCl (by active transport) reabsorbed from the filtrate can be varied at this site according to the needs of the body. Distal tubule also contributes

to pH regulation by controlled secretion of H^+ and reabsorption of HCO_3^- . At the distal convoluted tubule passive water reabsorption can be increased under the influence of Antidiuretic hormone (ADH) to form concentrated urine. Aldosterone secreted by the adrenal gland stimulates increase reabsorption of Na^+ and water and excretion of K^+ . This filtrate of the distal convoluted tubule finally leads to the collecting duct.

As the filtrate pass along the collecting duct filtrate become concentrated and urine is formed. At this site water reabsorption can also be increased under the influence of ADH and urine become more concentrated. Aldosterone hormone stimulates active reabsorption of Na^+ and passive reabsorption of water at the collecting duct. Because of the high urea concentration in the filtrate at this region some urea diffuses into the interstitial fluid. Final processing of the filtrate at the collecting duct forms the urine.

When producing dilute urine the kidney actively reabsorb salts without allowing water to be reabsorbed by osmosis.

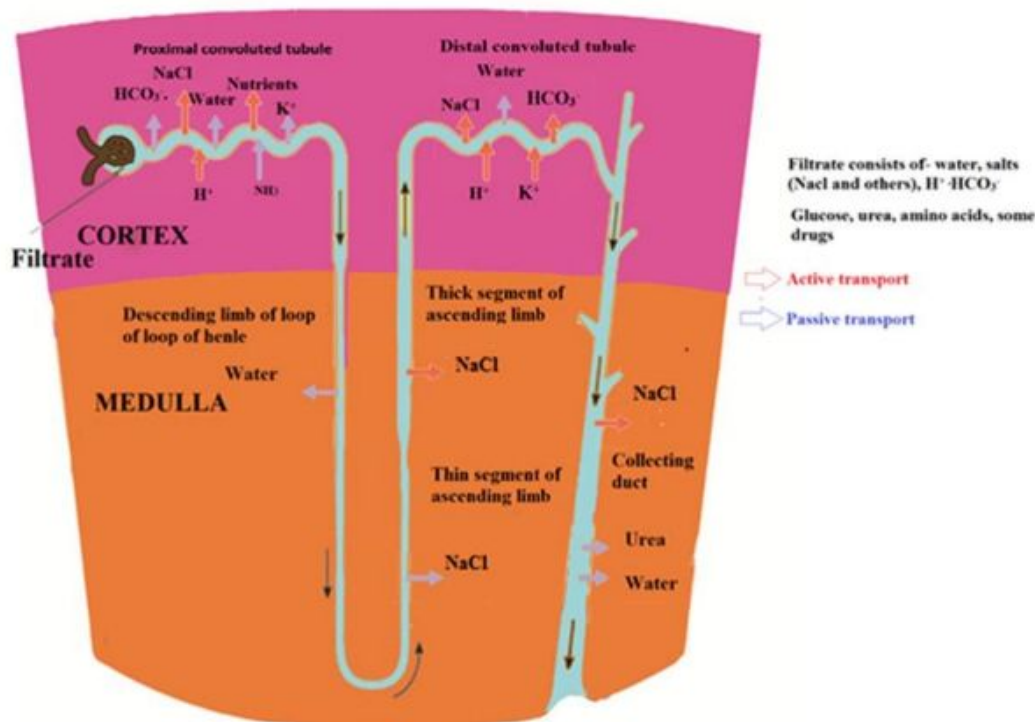


Fig 5.40 Reabsorption and secretion of different molecules and ions in the nephron and formation of urine in the collecting duct

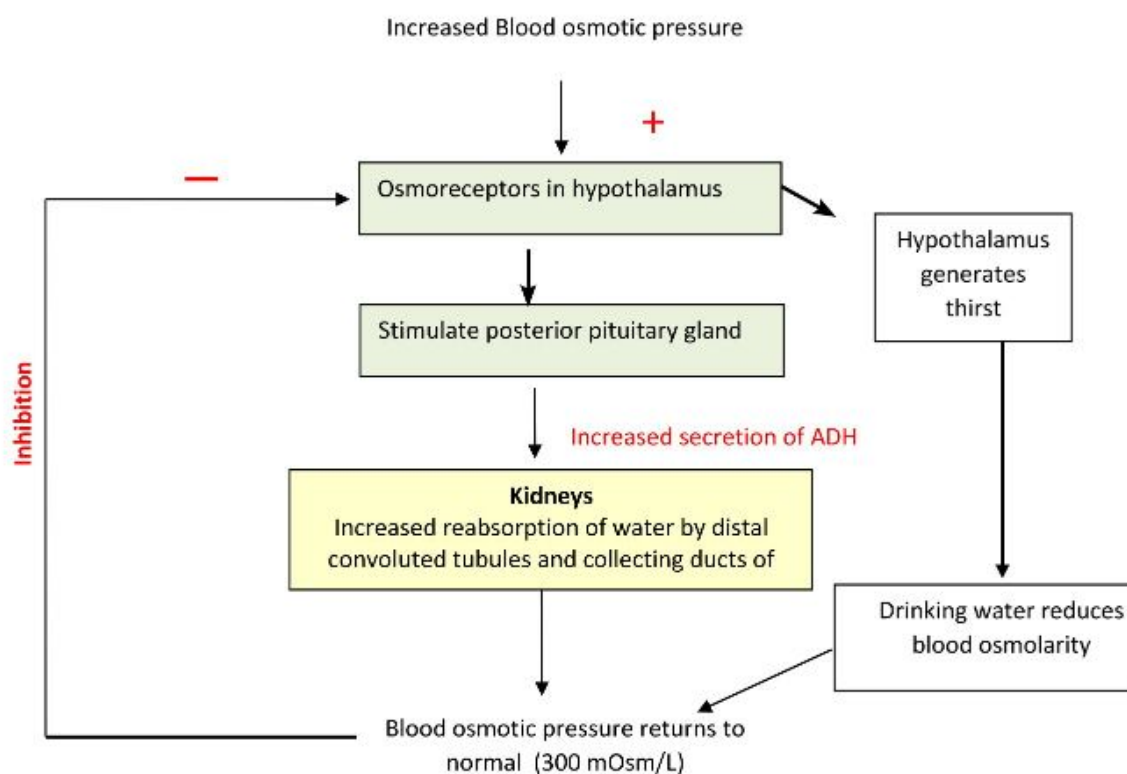
Role of hormones on the functions of the kidney

Fig5.41 Regulation of blood osmotic pressure and fluid retention in the kidney by ADH

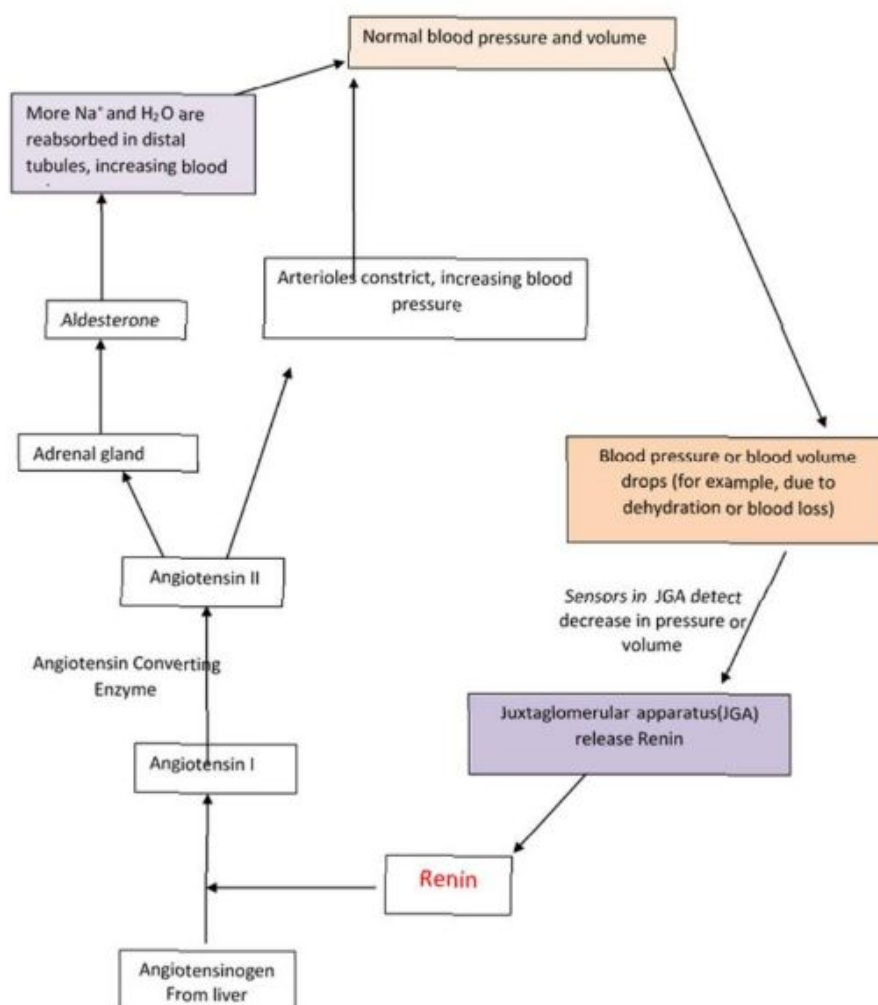


Fig5.42: Regulation of blood osmotic pressure and fluid retention in the kidney by ADH

Role of kidney in homeostasis

- Maintaining electrolyte and water balance in the body fluids (osmoregulation).
- Excretion of toxic waste products from the body.
- Regulating blood pH through acid base balance.
- Controlling blood volume and blood pressure.
- Secretion of erythropoietin hormone that stimulates red blood cell production.
- Production and Secretion of renin an enzyme important in control of blood pressure.

Disorders related to human urinary system**Bladder and kidney stones**

These are formed due to precipitation of urinary constituents (usually oxalates and phosphates) normally in urine. They are also called renal calculi.

Causes include

- Dehydration due to not drinking sufficient amount of fluids.
- Alkaline nature of urine.
- Infections that can alter pH of urine
- Metabolic condition.
- Family history.

Measures for prevention

- Drinking plenty of water

Kidney failure

This is due to the inability of the kidneys to function properly. Therefore waste products and excess fluid will be accumulated in the blood.

Reasons for kidney failure

- Diabetes
- High blood pressure
- Having family history
- Getting older

Chronic kidney disease (CKD)

It is a condition of gradual loss of kidney function over time. There are many reasons for Kidney failure:

- Diabetes
- High blood pressure

- Having family history
- Getting older

Prevent CKD

- Follow a low salt, low fat diet
- Doing proper exercise
- Having regular check ups
- Prevent smoking

Dialysis

Dialysis is done for the patients with kidney failure. It is a process of removing excretory products, excess solutes and toxins from the blood by an artificial method.

Chronic kidney disease of unknown/uncertain etiology (CKDu) in Sri Lanka

- It is a condition of gradual loss of kidney function over time. The root cause of CKDu has not been definitively established yet – hence it is referred to as ‘Chronic kidney disease of unknown/uncertain etiology’. However it is a different form of chronic kidney disease (CKD), which is associated with conventional risk factors such as diabetes and high blood pressure, genetic disorders and urinary tract problems
-
- The onset of the disease appears to be asymptomatic, and by the time the patient seeks treatment the kidneys have reached a stage of irreversible damage -end stage renal disease (ESRD).
- In Sri Lanka, initially CKDu was prevalent among rural communities in North Central province (Medawachchiya, Kabithigollawa, Padaviya, Medirigiriya, regions), Uva (Girandurukotte), Eastern Provinces (Dehiattakandiya). CKDu is also reported in North Western, Southern and Central provinces, and parts of the Northern Province of the island.

Hypothesized reasons for CKDu

Cause of CKDu seems to be multifactorial.

- Exposure to Heavy metal/ metalloid such as Arsenic (As) and Cadmium (Cd) through food and water.
- Usage of low quality utensils for preparation of foods.
- High Flouride (F) levels in water.
- Exposure to pesticides.
- Genetic factors.
- Malnutrition and dehydration.

Notes:

This is to acknowledge that some of the diagrams used in this book have been taken from various electronic sources using internet . This book is not published to make profit and sold only to cover cost.

The resource book is prepared according to the subject content and learning outcomes of the G.C.E. (A.L) Biology new syllabus which is implemented from 2017.

The content of this Resource book declares the limitation of the G.C.E. (A.L) Biology new syllabus which is implemented from 2017.

References

1. Biology ,A Global Approach, 10th edition (by Campbell Reece, Urry, Cain, Wasserman. Minorsky, Jackson)
2. Ross and Wilson Anatomy and physiology in Health and Illness (12th edition by Anne Waugh and Allison Grant)